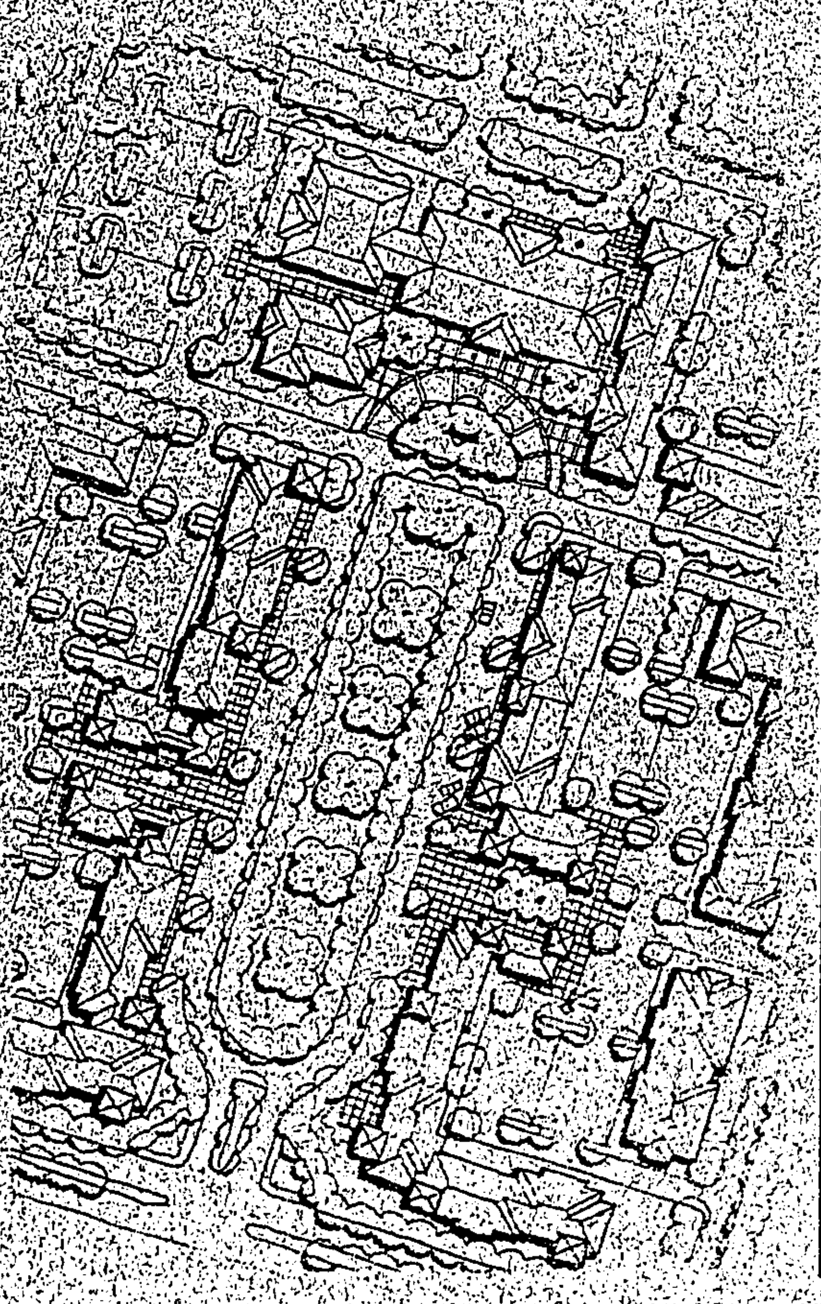
1993 - Oahu - FEIS - Wahiawa

GALBRAITH TRUST ESTATE

WAHIAWA LANDS DEVELOPMENT

Wahiawa District, Oahu, Hawaii



Final Environmental Impact Statement

Volume 2
Appendices

April 1993

Prepared for: Hawaiian Trust Company, Ltd.

Prepared by: Helber Hastert & Fee, Planners

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For submittal to: Planning Department
City and County of Honolulu

Pursuant to: Chapter 343, Hawaii Revised Statues

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APPENDIX A

Golf Course Impact Assessment

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January 22, 1993

ENVIRONMENTAL IMPACT ASSESSMENT FOR THE PROPOSED GOLF COURSE AT WAHIAWA LANDS/GALBRAITH TRUST DRAFT DEVELOPMENT PLAN

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EXECUTIVE SUMMARY

Introduction

This report is prepared in preparation for, and in support of, an overall Environmental Impact Statement (EIS) for the Hawaiian Trust Company's application for a Development Plan Amendment. This portion of the study focuses on the potential impacts of a proposed golf course that is included in the proposed development plan.

The purpose of this phase of the EIS is to accurately assess the potential impacts of a golf course in the proposed development plan. The report presents the assessment of numerous impacts (deleterious as well as innocuous or beneficial impacts) anticipated at the site. Some of the major issues addressed in the report, on a site specific basis include:

1. Leaching and runoff losses of nutrients and pesticides from the golf course during construction and after turfgrass establishment,
2. Soil erosion and runoff losses of sediment and nutrient during construction and losses from disturbed riparian zones,
3. Exposure of beneficial nontarget soil organisms, wildlife, and aquatic systems to pesticides (where possible),
4. Development and resurgence of insect and disease populations resistant to current chemical management schemes,
5. Excessive use of water resources for irrigation, use of effluent water for irrigation, and water re-use issues, and
6. Degradation of stream and lake quality resulting from sediment, chemical, and thermal pollution.

The site under consideration is located in the central part of Oahu, Hawaii, approximately 15 miles from Honolulu in a north by northwesterly direction. The site is at an elevation of about 873 feet and increases to almost 1000 feet in a northeasterly direction. The site consists of approximately 2000 acres of land. The development plan includes residential areas, commercial areas, schools, parks, waterways and a golf course all of which amounts to about 900 acres of developed land. The proposed golf course covers approximately 200 acres. Most of the proposed development occurs in the southern half of the property which is partially bordered by the H-2 Freeway to the south and west. The property is currently leased to the Del Monte Corporation and is planted in pineapple.

Important Findings: Site Conditions

Most of the site is occupied by WaA soils and WaB soils which are the Wahiawa soils with little to moderate slope (generally less than 6% as determined by on-site measurements). On the perimeter of the site there exist several soils of other series that are primarily differentiated with respect to slope. For example, the southern border of the property runs along the Wahiawa Reservoir and associated drainage areas. Here the soils slope steeply to the top of the reservoir from 25 to 90 percent in slope. The characteristics of the main soils occurring at the site are outlined in Appendix A, Table A-1 which note chemical, physical and land use characteristics and classifications. In general, analysis has shown the soils to be:

- Very productive, of near neutral pH, are well-drained with excellent permeability.
- Suitability for grass land areas and turf appears to be excellent, this is reflected in the fact that bermudagrass is native to the area.
- There is one area that recent field sampling showed to have characteristics not previously mentioned. The KuB soil in the upper half of the property (noted in the map) was found to have a moderately well formed hard pan at about 18 inches in depth. The pan is several inches thick and likely has a quite different permeability and hydraulic conductivity compared to the soil above it. This will act as a barrier to downward water movement and could alter the hydrologic flow path in this particular area. Based on its location and the extent of the soil it is not expected to significantly alter the flow path on a site wide basis (especially given the layout of the proposed course).

Topographic maps of the site (see Appendix A, Figure A-2) indicate that the area has only moderate slope characteristics except for the exceptions noted above. In addition, there is a gully that has formed in the lower southwesterly section of the property that appears to act as a drainage way for excess rainfall.

- The drainage gully likely seeps or empties into the Wahiawa reservoir. Based on the noted permeability of the majority of soils at the site (2-6"/hour), only rainfall in excess of this amount would contribute to significant drainage through the gully area.
- This area should be graded and leveled in the development to prevent runoff from reaching the reservoir.

Climate at the site is generally described as having:

- A mean annual temperature of 72°F,
- Mean rainfall between 40 and 60 inches per year with most of the rain occurring between November and April.

Important hydrologic features include:

- Depth to groundwater is always greater than 6 feet.
- The terrain slopes gently in a generally southerly direction with major drainage occurring in this direction ultimately emptying into the Wahiawa Reservoir and associated drainage areas.
- The soils are deep, very well drained with moderate to moderately high hydraulic conductivities.
- Runoff potential at the site is low (and slow) except in the southern boundary areas where slopes increase to almost 90 percent.

Vegetation at the site consists almost exclusively of pineapple. The only areas not in pineapple are those areas with slopes too severely to support production agriculture. These areas are confined to the immediate vicinity of the reservoir. These areas support an apparently diverse population of plant species.

- The current construction designs should have no effect on the area in terms of cutting/clearing or grading.
- The trees and shrubs in these areas may be affected by offsite transport of chemicals in the event that wind-drift becomes a significant problem. Use of the Integrated Turf Management Systen (TMS), outlined in this report, will minimize or eliminate this possibility.

Pesticide Use/Impact

We have compiled a list of pesticides that may be used at the proposed golf course. The list was selected based on information regarding use at other golf courses under similar climatic regimes:

TABLE 1 PESTICIDE SELECTION

Name	Trade Name	CAS Number	Category*	Family
Bendiocarb	Dycarb	22781-23-3	I	Carbamate
Chlorpyrifos	Dursban	2921-88-2	I	Organo-phosphate
Fenamiphos	Nemacur	22224-92-6	N	Organo-phosphate
Trichlorfon	Proxol	52-68-6	I	Organo-phosphate
Benomyl	Tersan 1991DF	17804-35-2	F	Carbamate
Chlorothalonil	Daconil 2787	1897-45-6	F	Halo-benzene
Metalaxyl	Apron 25W	57837-19-1	F	Dithio-carbamate
Bensulide	Betasan	741-58-2	H	Organo-phosphate
2,4-D	Many	94-75-7	H	Organo-phosphate
DCPA	Dacthal	1861-32-1 1918-00-9 62610393	H	Aryl aliph acid
Dicamba	Banvel	2300-66-5	H	Aryl aliph acid

* I = Insecticide H = Herbicide
F = Fungicide N = Nematocide

Assessment of pesticide behavior at the site is described fully in the report under a number of different scenarios. Below is a table that describes the different factors affecting runoff and pesticide losses (one of the main concerns at the site). We have added a column describing how specific site conditions at Wahiawa may affect runoff.

TABLE 2 PESTICIDE BEHAVIOR EXPECTED AT SITE

Factors	General Effect	Site Specific Effect
Rainfall/Pesticide and nutrient application.	Highest pesticide runoff occurs during first major runoff event.	Same. TMS will seek to minimize through proper application technique and timing.
Rainfall intensity.	Runoff occurs when rainfall rate exceeds soil infiltration rate.	Soils at the site have excellent permeability (2-6"/hour). If pesticide and nutrients are applied properly, then runoff potential decreases.
Rainfall amount and duration.	Affects runoff volume and leaching potential. Foliar pesticide washoff related to amount of rain.	Pesticide timing and placement are again factors that the TMS will address to minimize this effect.
Soil texture and organic matter content.	Infiltration rates are affected. Texture affects erodibility and particle transport potential. Organic matter usually increases pesticide adsorption.	Infiltration at site is good due to silty clay texture. Runoff expected to be low under most conditions. However, the soils are high in Al and Fe oxides and could erode if saturated. Presence of turf will minimize this. Organic matter content is 1-3% in most cases, which will aid in adsorption processes.
Soil water content.	High water content will decrease time to runoff.	Not a factor. Soils are very well drained and deep.
Slope.	Increasing slope will increase runoff potential.	Most of the acreage has only 1-6% slopes. Small pockets of the area increase to 10-25%. These can be graded or used as areas with less intensive management (e.g. fairways).

Factors	General Effect	Site Specific Effect
Pesticide solubility.	Soluble pesticides tend to be more readily leached into soil and not removed via runoff. Low solubility pesticides more likely to wash off (if rain duration is significant).	A few of the compounds suggested for use are soluble (e.g. 2,4-D, Dicamba, and Trichlorfon). TMS will carefully monitor use and application timing. If timing is not followed by rainfall, then leaching and runoff potential reduced.
Pesticide sorption.	Pesticides strongly adsorbed near soil or plant surface more likely to wash off. Runoff off amounts will then depend on particle or sediment transport.	Sorption properties of the soils are moderate to high due to amphoteric surfaces and organic matter. However, soil is well aggregated and tends not to erode easily unless saturated.
Persistence of chemicals	High probability of runoff with use of persistent compounds.	Minimize use of these compounds.
Irrigation practices	Sprinkler irrigation may move soluble pesticides into soil and thatch reducing runoff potential.	Addressed in TMS. This will likely be a reasonable approach for reducing runoff. Timing will still be a factor.

Below, we have again constructed a Table that relates different factors related to subsurface pesticide losses to conditions at the site. Quantitative assessment of the movement of pesticides is presented in the modeling section of this report.

TABLE 3 PESTICIDE BEHAVIOR EXPECTED AT THE SITE

Factor	Impact on Subsurface Transport	Site Specific Effect
Soil Water Content	Soil water ultimately transports pesticides not absorbed to soil surfaces. Increased soil water levels will increase both water and chemical flux beyond the root zone.	Due to the fact that the soils are very well drained at the site, high rainfall influx can be counter balanced with a rational approach to application and timing.
Hydraulic conductivity	Measure of soil's ability to transmit water and entrained solutes. Soils with high conductivity in relation to initial infiltration (sands) have a greater potential for mass transport of solutes.	Soils are silty clays with many fine pores in the upper soil profile. Conductivity is expected to be moderate and present as manageable in relation to leaching.
Organic Matter and Clay Content	Effect pesticide adsorption, which attenuate leaching potential.	Soils have relatively high adsorption capacity with 1-3% organic matter. Both will aid in reducing subsurface leaching. Adsorption surfaces capable of adsorbing most pesticides chosen.
Thatch Layer	The thatch layer is a continuous organic medium which may form between the turf canopy and the soil. It can act as an effective barrier to pesticide entering soil.	Magnitude of effect in many cases is unknown. In general thatch will decrease amount of pesticide available for subsurface leaching.
Depth to Groundwater	Shallow aquifers more likely to be contaminated.	Data not fully evaluated. (assume >6ft)
Pesticide Sorption Properties	High Kd values suggests that pesticide strongly adsorbed and the potential for leaching is thereby reduced.	Pesticides suggested for use have fairly high Kd values. Should be strongly adsorbed. Most pesticides found in groundwater have Kd values less than 1. Pesticides chosen, easily exceed this value.
Application Rate	Amount of pesticide applied is directly proportional to amount transported.	Reduce application rates and repeated use. Use only on areas requiring treatment. Both will reduce this potential.

There is a wide range of field and chemical conditions that influence potential transport of pesticides to groundwater. When persistent compounds that have high or intermediate mobility are applied to soils with minimal adsorptive capacity and shallow water tables, the leaching process may result in groundwater contamination. On the opposite end of the risk spectrum is the use of pesticides that are rapidly decomposed and/or strongly adsorbed. When these chemical are applied to soils with high adsorptive capacity, deep water tables, and appropriate water management, the probability of pesticide leaching is significantly reduced. However, under certain conditions, even very persistent and immobile compounds, such as chlordane, can be leached to groundwater (Cohen et al., 1990). Therefore the complex suite of conditions controlling the movement of chemicals must be evaluated on a site specific basis. These conditions and how they interact at the site are more fully described in the Modeling Section of the report.

Comparison of Anticipated Pesticide Behavior in Turfgrass to Present Land Use Management

Based on the review of the processes governing the offsite transport of pesticides from the site, it is possible to compare the effect of constructing and managing a golf course to the current agricultural practices at the site.

- **Surface Water Transport:** Surface water transport potential (runoff) will be reduced due to the presence of turfgrass over much of the southern part of the site (see map) compared to runoff under the present pineapple cultivation practices. This will occur through several likely mechanisms. The site at present has significant gully erosion occurring in the southwesterly section of the acreage (see Figure 3.1-1). Since the topographic features of the area suggest that this represents a significant drainage pathway for the site, the gully acts as a conduit for removal of runoff water from the site. This is further substantiated by the large amount of sediment observed leaving the site with runoff water. Sediment from the site covers the faces of roadcuts and parts of the highway around the reservoir. Development of the site with a turf cover should provide an additional absorptive surface for water, will increase soil stability and infiltration. Re-grading the gullied area will minimize or possibly recapture runoff for storage and possible reuse.

- **Pesticide Transport via Runoff:** This should also be reduced due to golf course development for similar reasons affecting the quantity of water leaving the site as noted above. However, it is also true that pesticide application site wide will be reduced due to the implementation of the TMS program which will seek to reduce the quantity of pesticide applied, will allow application only when needed, and will be timed to avoid predictable climatic situations that could lead to runoff. Present pesticide application at the site appears to be by schedule rather than by need.

- **Pesticide Transport via Erosion (Sediment):** The establishment of turfgrass at the site will definitely decrease the extent of erosion and particle bound pesticide at the site. Turf will cover large areas of now bare soil and overall will provide a "soil cover" for much of the site. Establishment of turf for erosion control is a common and recommended practice of the USDA and SCS.

- **Pesticide Leaching:** Leaching of pesticide at the site should also be reduced compared to the present cultivation practices. Establishment of turf will provide a buffer zone for capture of leachable pesticide presumably due to the high adsorptive capacity of the turf thatch layer. Presently, soluble pesticide that reaches the bare soil is free to leach to the extent determined solely by soil physical parameters and water movement.

Nutrient Use/Loss

The use of fertilizers is an important turfgrass management practice required to maintain the aesthetic quality and turfgrass growth rate to accommodate wear. Public concern is growing regarding the use of fertilizers for turfgrass management and the potential contamination of water supplies associated with golf courses.

On the basis of the review and site specific information, nitrogen, and in particular, nitrate, is the nutrient that would pose the most serious threat from an environmental impact and water quality perspectives. Several conclusions can be inferred:

1. Nitrogen is a relatively easily managed component at the site. It is expected that N fertilization at the site will entail use of relatively insoluble (slow-release) materials for fertilization of turf. Application will be based on initial soil test results, turf requirement, and turf condition throughout the year. TMS strategies will reduce both luxury consumption of N and subsurface leaching. If industrial or municipal effluent are available, these could be used as both a source of water at the site and as an additional source of nitrogen. Application of soluble N compounds for "quick" green up is not recommended.

2. If nitrogen residues are present in a soluble form above a concentration that can be used by the turfgrass and if water moves through thatch or soil, leaching of nitrogen past the root zone can occur. If the nitrogen is not in a soluble form, such as IBDU, leaching losses of nitrogen are significantly reduced.

3. Increasing the rate of nitrogen application to highly sandy greens will lead to a deterioration in drainage water quality. On sandy loam greens, increased nitrogen fertilization commensurate with uptake capacity of specific turfgrass species should not further reduce water quality.

4. Late fall is a common time for nitrogen fertilization. However, the agronomic benefits derived from this practice may be lost by the adverse environmental impacts in areas with vulnerable groundwater characteristics. Heavy fall fertilization is to be avoided.

5. Establishment of turfgrass at the site will result in soils with a high infiltration capacity thereby reducing the potential for nutrient loss and subsequent water quality deterioration by runoff. Numerous studies demonstrate that runoff of water from turfgrass is limited. Even on sites with 9 to 12 percent slopes with silt loam soil, runoff loss of N is rarely observed. It should be noted that high rates of infiltration will reduce surface runoff, but in exchange the rates of subsurface movement of water is increased. Timing of fertilizer application against the needs of the grass will reduce or eliminate subsurface leaching.

6. The leaching of fertilizer nitrogen applied to turfgrass at the site will be related to: soil texture and degree of conductivity of soil water; the amount of subsurface movement of water; nitrogen source, formulation, rate, and timing; and irrigation and rainfall. Significant leaching of nitrate will occur when soluble nitrogen is applied at a rate higher than normal on turfgrass grown on sandy soil. The potential for subsurface loss of nitrogen is further increased when the turfgrass is irrigated at a rate in excess of plant use, evapotranspiration, and soil storage.

7. If fertilization of turfgrass at the site does pose a threat to surface water and groundwater quality, several management options are available to minimize or eliminate the problem. Limiting irrigation to replacement of soil moisture used by the cover, use of slow release sources of nitrogen, and less sandy soils would significantly reduce or eliminate nitrate leaching from turfgrass. Timing of fertilizer application in relation to active uptake and potential runoff events as well as the use of realistic nitrogen application rates are primary methods to reduce nonpoint source losses of nitrogen from turfgrass systems. These recommendations are clarified in the Turf Management System.

8. Phosphorus fertilization will not pose a groundwater quality threat at the site. The soils of the area have an extremely high P adsorption capacity which will prevent subsurface leaching. Fertilization will be based on soil test results and turf requirement. Phosphorus enrichment of catchments and waterways in the vicinity of the proposed course could occur during construction phase where bare soil could be exposed to erosion. This will be minimized or eliminated by using barriers (fences) or other trap devices for preventing offsite movement of soil lost during excavation or grading activities.

Turfgrass Selection

Of the different potential warm season grasses, it is likely that the best candidates for the proposed golf course at the site would be bermudagrass or Zoysiagrass. Bermudagrass appears to be the most likely candidate since the it is native to the area and hence expresses adaptability to the climatic/soil/environmental conditions of central Oahu. A comparison of the two types of turfgrasses is presented below.

TABLE 4 COMPARISON OF BERMUDAGRASSES AND ZOYSIAGRASSES

Characteristic	Bermudagrasses	Zoysiagrasses
Plant description:		
leaf texture	Fine	Medium to fine
shoot density	High	Medium to high
Growth Habit	Rhizomes and stolons	Rhizomes and stolons
Seed Head	Short, few to numerous	Short and minimal
Adaptation:		
heat hardiness	Excellent	Excellent
low temperature hardiness	Poor	Poor to intermediate
drought resistance	Excellent	Excellent
shade tolerance	Very poor	Good
soil adaptation	Wide range	Wide range
salt tolerance	Good	Good
wear tolerance	Very good	Excellent
Establishment		
method	Vegetative	Vegetative
rate	Excellent	Poor
recuperative potential	Excellent	Excellent, but slow
Culture:		
intensity	High to medium	Medium
cutting height (in)	0.25-1.0	0.5-1.0
mower type	Reel	Reel
nitrogen needed (lb/1000sqft/month)	0.8-1.8	0.5-1.0
thatching tendency	High	Medium to high
Pest:		
diseases	Brown patch, dollar spot, spring dead spot, Helminthosporium	Brown patch, dollar spot, rust, Helminthosporium
insects	Sod bedworms, armyworms, mole crickets, bermudagrass mite, fruit fly	Hunting billbugs, army worms, mole crickets, sod bedworms
other	Nematodes	Nematodes

Bermudagrass is best adapted to moderately well drained, fertile soils of relatively fine texture but will tolerate a wide range of soil types. Bermudagrass growth is usually better on fine textured than coarse textured soils because of the higher fertility level and soil moisture retention associated with fine textured soils. Bermudagrass tolerates a wide range in soil pH (usually 5.5 to 7.5.) Salt tolerance is also quite good.

The improved bermudagrasses form a very dense, uniform turf of high quality when grown under proper conditions (climatic and cultural). It is utilized in the warm humid regions on lawns, parks, golf courses (fairways, greens, tees, roughs), roadsides, airfields, athletic fields, general lawn areas. It is especially suited for golf courses due to its excellent wear tolerance and recuperative potential.

Bermudagrass does require a medium to high intensity level of cultivation. Tolerance to close mowing is good because of its prostrate growth habit. Since bermudagrass is responsive to fertilization and irrigation, a high intensity of culture is generally needed to obtain optimum turfgrass quality. Bermudagrass is quite prone to thatching because of the vigorous growth rate. Common disease problems of bermudagrass include Helminthosporium, brown patch, dollar spot, Fusarium patch, Pythium blight, and spring dead spot. Common pests include sod bedworms, armyworms, mole crickets, mites, fruit flies, and nematodes. It is also intolerant of the triazine herbicides.

Several possible cultivars could be used at the site. For example, fairways and tees could be composed of Tifway bermudagrass, while greens could be composed of Tidwarf or Tifgreen cultivars. Some of the characteristics of these cultivars are noted below.

TABLE 5 CHARACTERISTICS AND USE OF CULTIVARS

Cultivar	Characteristics	Use
Tidwarf	Dark green color, fine texture, high shoot density, slow growth rate. Medium culture intensity.	Improved shade tolerance, superior tolerance to low mowing, used on greens.
Tifgreen	Dark green color, very fine texture, high shoot density, high intensity culture.	Excellent drought and wear tolerance, good recuperative potential, prone to 2,4-D injury, used on greens.
Tifway	Dark green, medium texture, high shoot density, vigorous growth, prone to thatching.	Used widely on fairways and tees.

Based on this initial assessment, we would probably recommend Tidwarf for use on greens, since selection of a cultivar that can be maintained with lower inputs of fertilizer and pesticide is a desirable quality from an environmental perspective. If the course were in a more arid region, we would have selected the more drought tolerant Tifgreen cultivar.

Zoysiagrass forms a uniform, dense, high quality turf with excellent drought and heat hardiness. It grows well on soils similar to those of the site (moderately acid to neutral with fine texture and moderate to excellent drainage characteristics). It also exhibits excellent salt tolerance. Its most desirable feature for this site would be the moderate level of cultivation required to maintain high quality. Its N requirement is much lower than bermudagrass (roughly one-half to two-thirds) and as such may be used in buffer strips, in areas around sandtraps, and even around the aprons of bermudagrass greens. Zoysiagrass is also free of major disease problems relative to the other turfgrasses. As such it could be used in many areas on the course to decrease the overall input of water, fertilizer and pesticide at the proposed golf course site.

Wind-Drift

After reviewing the literature and examining other studies aimed at assessing the potential for determining offsite wind-drift, we have concluded that no reasonable modeling approach can be used to yield estimates with any certainly. Rather, we suggest that a monitoring system be employed at the site that is capable of determining pesticide drift from the site.

We also note that if the TMS plan is implemented within the guidelines suggested here, that wind-drift can be minimized in most cases and eliminated in others. Implementation of the TMS will reduce the potential for pesticide loss from the site especially compared to present land use management.

Effluent Water Use and Recycling/Solid Waste Disposal

A water source now being used for irrigating golf courses and which will be of considerable interest in the future is effluent water. Turfs can accept effluent water containing moderate levels of heavy metals and other elements which cannot be used in crop production because of potential problems entering the human food chain or restricting crop yield. Thus, turf irrigation offers one of the best approaches to disposing of certain types of effluent water. In addition, many golf courses are in reasonable delivery distance of treatment plants. The proposed course should make use of this type of water, if available, in order to minimize pressure on limited groundwater supplies.

Sewage treatment plants have three levels of possible treatment. The primary level is concerned with solids removal. The secondary level removes many dissolved impurities, while the tertiary

level removes even more impurities. Each level is more expensive. In contrast, soils function as very efficient water filters and offer an economical means of advanced water treatment. Soils have a great capacity to handle organic wastes.

The reliability of an effluent water is a positive factor. In addition, the cost can be fairly attractive compared with that of other alternatives. In some areas, effluent water is available at no cost or at only the pumping charge involved. In other areas, effluent water is being sold for from 25 to 35 percent of the price of domestic water. The cost of effluent water will probably rise in the future but still remains an economically compared with that of other sources.

Chemical analyses of typical effluent have shown that nitrogen, chiefly in the form of ammonia, is present in an amount of 60 to 100 pounds per acre foot of water, while potassium is in the 200 pound range and phosphates between 60 and 100 pounds. Thus, each effluent water source may serve as a bonus source of N, P and K. Obviously, if effluent is used, it should be consistently monitored for these nutrients and figured in to the total nutrient requirement of the turf in order to avoid application of excess N and P.

Use of effluent water at the site will have to take into consideration the following factors related to safe use of effluent:

- Some chemicals present in effluent may be injurious to turfgrass growth, and for this reason the water used for irrigation should be continually monitored as suggested EPA regulations. The main chemical problems arise from industrial contaminants such as brine, heavy metals, and stable organic compounds.

- Five elements are of particular concern and should be frequently determined in the effluent water. These are cadmium (Cd), copper (Cu), nickel (Ni), zinc (Zn) and boron (B). Current guidelines suggest the following maximum levels for turfgrass:

Cd: 5 ppb	Zn: 5 ppm
Cu: 200 ppb	B: 1 ppm
Ni: 500 ppb	

- The site managers may want to consider complying with California regulations for Waster Water Reclamation Plants with Direct Filtration. This regulation will require a very high degree of effluent such that the water would be unrestricted in use.

In addition to effluent water use and reuse it is recommended that the proposed golf course development plan include appropriate protocols for solid-waste storage and disposal. The solid-waste at the site is likely to include both pesticide containers and remnants and turfgrass clippings. All pesticides at the site should be handled and stored according to manufacturers instructions and in compliance with all local, state and federal regulations. Turfgrass clippings from mowing operations can, in many cases, be directly returned to rough areas adjacent to the green or fairway from which they were removed or composted in a site remote from the playing area.

Turf Management System (TMS)

The report also presents guidelines for a TMS plan for the course. Items covered include:

- Pest/nutrient Usage Guidelines
- Alternate Pest Control Strategies
- Water Quality Guidelines
- Construction Guidelines

Summary of Hydrologic Modeling Results

Median annual runoff and sediment from the simulated USGA green is 3.9 cm yr^{-1} and 1.8 kg ha^{-1} yr^{-1}, respectively. Median annual runoff and sediment from the simulated fairways is 9.3 cm yr^{-1} and 85 kg ha^{-1} yr^{-1}, respectively. During the wet season (October through April) average monthly runoff and sediment transport are elevated on all soils. The range or variability of annual subsurface leaching of water is somewhat greater on the simulated putting green compared to the fairways. However, median annual movement of water beneath the root zone is similar for the green and fairways. Median annual recharge or leaching of water past the root zone was 55 cm yr^{-1} for the simulated green, 58 cm yr^{-1} for the simulated Wahiawa fairway, and 58 cm yr^{-1} for the simulated Kolekole fairway.

A single large precipitation event occurred on 4/19/74, which produced exceptionally large surface and subsurface transport during April of 1974. The massive loss of runoff water during this single event reduced the total annual movement of water beneath the root zone. Despite reduced movement of leaching water during 1974, this single large transport event contributed to the majority of runoff and leaching losses of applied chemicals. Application of pesticides within several days of such an event represents a "catastrophic" loss for this system. Simulation year 1974 should be considered a potential maximum pesticide and nutrient transport condition. This event demonstrates that timing of chemical application in relation to rain is a critical component for management of offsite chemical transport.

1.0 INTRODUCTION

This report is prepared in preparation for, and in support of, an overall Environmental Impact Statement (EIS) for the Hawaiian Trust Company's application for a Development Plan Amendment. This portion of the study focuses on the potential impacts of a proposed golf course that is included in the proposed development plan.

1.1 Purpose

The purpose of this phase of the EIS is to accurately assess the potential impacts of a golf course in the proposed development plan. The report presents the assessment of numerous impacts (deleterious as well as innocuous or beneficial impacts) anticipated at the site. Some of the major issues addressed in the report, on a site specific basis include:

1. Leaching and runoff losses of nutrients and pesticides from the golf course during construction and after turfgrass establishment,
2. Soil erosion and runoff losses of sediment and nutrient during construction and losses from disturbed riparian zones,
3. Exposure of beneficial nontarget soil organisms, wildlife, and aquatic systems to pesticides (where possible),
4. Development and resurgence of insect and disease populations resistant to current chemical management schemes,
5. Excessive use of water resources for irrigation, use of effluent water for irrigation, and water re-use issues, and
6. Degradation of stream and lake quality resulting from sediment, chemical, and thermal pollution.

Clearly, many of these issues are not limited to golf courses, but rather encompass concerns regarding intensive landscape management, production agriculture, and forestry. Many of these multiple use issues involve a core of emotional, philosophical, and technical questions. Development of new golf courses in areas with limited space for land development often confronts concerns and regulations surrounding conservation, reliance on chemical fertilizers and pesticides, and water quality and availability. Therefore, the social and environmental benefits of a golf course should be balanced with concerns regarding health and environmental quality.

As such, we have attempted to address these concerns with consideration of a wide range of possibilities and scenarios. We have tried to minimize assumptions in the assessment, and where they have been stated they are referenced with the best available published scientific information. In this way we have provided results that represent sound scientific judgement.

The report also presents the foundation of an Integrated Turf Management System (TMS). The use of TMS will be very effective for reducing detrimental nonpoint source environmental and water quality impacts.

1.2 Technical Approach

The technical approach is quite simple and involves three components. The first part of the assessment involves the identification of all potential impacts that the construction and management of a golf course could cause. Here we describe the major processes governing pesticide and nutrient impacts, factors effecting wind-drift potential, and factors effecting water quality. This information is first described in general, and then placed in a qualitative sense using site specific information. The second part of the report describes a quantitative assessment of pesticide and nutrient loss anticipated at the site under a number of different plausible scenarios. This is used to assess regulatory and public concerns regarding the impacts of both pesticides and fertilizer at the site. Finally the information from both parts one and two is used to develop the framework for an Integrated Turf Management System (TMS) for the site that will be effective in reducing or eliminating nonpoint source environmental impacts.

1.3 Site History and Location

The site under consideration is located in the central part of Oahu, Hawaii, approximately 15 miles from Honolulu in a north by northwesterly direction. The site is at an elevation of about 873 feet and increases to almost 1000 feet in a northeasterly direction. The site consists of approximately 2000 acres of land. The development plan includes residential areas, commercial areas, schools, parks, waterways and a golf course all of which amounts to about 900 acres of developed land. The proposed golf course covers approximately 200 acres. Most of the proposed development occurs in the southern half of the property which is partially bordered by the H-2 Freeway to the south and west. The property is currently leased to the Del Monte Corporation and is planted in pineapple.

2.0 BASIS OF RISK ASSESSMENT

2.1 Important Site Characteristics

The site features noted below will be updated and amended as information from other consultants becomes available.

2.1.1 Soils of the Study Area

The soils of the site belong to the Helemano-Wahiawa association. They are deep, nearly level to moderately sloping, well-drained soils that have a fine textured subsoil on uplands. They formed in material weathered from basalt. The association makes up 18 percent of the island. The elevation ranges from 100 to 1200 feet in annual rainfall areas of 20 to 50 inches but as much as 60 inches in some places. Most of the rain occurs in winter. Mean soil temperature is between 71 and 73°F and the natural vegetation includes guava, koa haole, lantana, joee, and bermudagrass.

In the association, Helemano soils make up about 40 percent of the association, and Wahiawa soils 30 percent. Kunia, Lahaina and Molokai soils make up the rest. Helemano soils are dark reddish brown silty clays. They occur on the sides of very steep gulches and have slopes of 30 to 90 percent. Wahiawa soils have a surface layer of very dusky red silty clay and a subsoil of dark reddish brown silty clay, and a substratum of soft weathered rock. These occur on uplands with slopes of 0 to 25 percent. Large acreage of Wahiawa soils are used for sugarcane and pineapple. Sugarcane is grown under irrigation while pineapple is only irrigated in the driest areas.

2.1.2 Soil Map and Occurrence of Associations

The soils and distribution of soils at the site are described in Appendix A, Figure A-1. As noted most of the site is occupied by WaA soils and WaB soils which are the Wahiawa soils with little to moderate slope (generally less than 6% as determined by on-site measurements). On the perimeter of the site there exist several soils of other series that are primarily differentiated with respect to slope. For example, the southern border of the property runs along the Wahiawa Reservoir and associated drainage areas. Here the soils slope steeply to the top of the reservoir from 25 to 90 percent in slope. The characteristics of the main soils occurring at the site are outlined in Appendix A, Table A-1 which note chemical, physical and land use characteristics and classifications. In general the soils are:

- Very productive, of near neutral pH, are well-drained with excellent permeability
- Suitability for grass land areas and turf appears to be excellent, this is reflected in the fact that bermudagrass is native to the area.

- There is one area that recent field sampling showed to have characteristics not previously mentioned. The KuB soil in the upper half of the property (noted in the map) was found to have a moderately well formed hard pan at about 18 inches in depth. The pan is several inches thick and likely has a quite different permeability and hydraulic conductivity compared to the soil above it. This will act as a barrier to downward water movement and could alter the hydrologic flow path in this particular area. Based on its location and the extent of the soil it is not expected to significantly alter the flow path on a site wide basis (especially given the layout of the proposed course).

2.1.3 *Topographic Features*

Topographic maps of the area are also included in Appendix A, Figure A-2. As noted, the maps indicate that the area has only moderate slope characteristics except for the exceptions noted above. In addition, there is a gully that has formed in the lower southwesterly section of the property that appears to act as a drainage way for excess rainfall. (See figure 3.1-1)

- The drainage gully likely seeps or empties into the Wahiawa reservoir. Based on the noted permeability of the majority of soils at the site (2-6"/hour), only rainfall in excess of this amount would contribute to significant drainage through the gully area.
- This area should be graded and leveled in the development to prevent runoff from reaching the reservoir.

2.1.4 *Climatic Features*

Climatic information at the site is described in detail in the Modeling Section of the report. The area is generally described as having:

- A mean annual temperature of 72°F.
- Mean rainfall between 40 and 60 inches per year with most of the rain occurring between November and April.

2.1.5 *Hydrologic Features*

Important hydrologic features at the site are also described in the Modeling Section of the report and in the soil descriptions. As noted, depth to groundwater is always greater than 6 feet. The terrain slopes gently in a generally southerly direction with major drainage occurring in this direction ultimately emptying into the Wahiawa Reservoir and associated drainage areas.

- The soils are deep, very well drained with moderate to moderately high hydraulic conductivities.
- Runoff potential at the site is low except in the southern boundary areas where slopes increase to almost 90%.

2.1.6 *Vegetation*

Vegetation at the site consists almost exclusively of pineapple. The only areas not in pineapple are those areas with slopes too severe to support production agriculture. These areas are confined to the immediate vicinity of the reservoir. These areas support an apparently diverse population of plant species.

- The current construction designs should have no effect on the area in terms of cutting/clearing or grading.
- The trees and shrubs in these areas may serve as effective barriers to any airborne, offsite transport of chemicals in the event that wind-drift becomes a significant problem. Use of Integrated Turf Management System (outlined in this report) will minimize or eliminate this possibility.

2.2 Identification of Potential Environmental Impacts

This report addresses several potential environmental impacts due to the proposed construction and maintenance of a golf course. These impacts have been identified from several sources (references) and also from the State of Hawaii's 12 conditions applicable to golf course development. Specifically these include:

- Water quality impacts and associated degradation. This includes deterioration of groundwater due to applied chemicals such as pesticides and fertilizers. It also includes assessment of surface water quality impacts that may occur during construction and maintenance. Surface water impacts would not only include pesticide and fertilizer that may runoff during irrigation or rain events but would also include increased sediment loading that may occur during construction activities such as grading, clearing and excavation.
- Air quality impacts. These impacts are expected to include volatilization of applied pesticides and nitrogen, drift during spray operations, and dust (PM10) that might escape the site during construction activities.

- Soil erosion. Soil erosive potential will be evaluated particularly with respect to construction activities anticipated at the site.
- Impacts that may effect wetlands in the area or other sensitive ecosystems near the proposed development.
- Impacts due to management operations at the golf course. These would include a number of activities but focus on minimization of solid waste production and reuse of waste water for irrigation purposes.
- Anticipated improvements to the site due to turfgrass/golf course development.

3.0 ENVIRONMENTAL IMPACT ASSESSMENT

3.1 Pesticides and Related Issues

The effects of pesticide, applied to agricultural and turfgrass systems, on environmental quality is one of the most holly debated issues of the last decade. In order to assess the potential for degradation of environmental quality due to applied chemicals, the processes governing their behavior in the environment need to be understood. This section provides the framework for evaluating the potential for offsite transport of applied chemicals from the site. The assessment begins with a discussion of candidate pesticides that might be used at the site. Their properties are noted and then evaluated for potential off site transport based on existing and assumed site conditions.

3.1.1 *Identification of Potential Pesticides to be Used*

Below is a list of pesticides that may be used at the proposed golf course. The list was selected based on information regarding use at other golf courses under similar climatic regimes:

TABLE 3.1-1 PESTICIDE SELECTION

Name	Trade Name	CAS Number	Category	Family
Bendiocarb	Dycarb	22781-23-3	I	Carbamate
Chlorpyrifos	Dursban	2921-88-2	I	Organo-phosphate
Fenamiphos	Nemacur	22224-92-6	N	Organo-phosphate
Trichlorfon	Proxol	52-68-6	I	Organo-phosphate
Benomyl	Tersan 1991DF	17804-35-2	F	Carbamate
Chlorothalonil	Daconil 2787	1897-45-6	F	Halo-benzene
Metalaxyl	Apron 25W	57837-19-1	F	Dithio-carbamate
Bensulide	Betasan	741-58-2	H	Organo-phosphate
2,4-D	Many	94-75-7	H	Organo-phosphate
DCPA	Dacthal	1861-32-1 1918-00-9 62610393	H	Arylaliph acid
Dicamba	Banvel	2300-66-5	H	Arylaliph acid

*I = Insecticide F = Fungicide H = Herbicide N = Nematocide

3.1.2 *Pesticide Characteristics*

Important chemical and physical properties of the proposed pesticides are noted below.

Bendiocarb: Bendiocarb is a residual insecticide used to control chinch bugs, mole crickets, certain species of white grubs, mites, aphids and white flies. It has a molecular weight of 223.2, a vapor pressure of 6.9E-4 Pa at 25°C, has a water solubility of 40 ppm, and soil adsorption coefficient (Koc) of 570.

Chlorpyrifos: Chlorpyrifos is also an insecticide widely used to control ants, armyworms, billbugs, chinch bugs, fall armyworms, cut worms, mole crickets, sod webworms, turfgrass weevil, and selected species of white grubs. It has a molecular weight of 350.6, a vapor pressure of 1.2-2.3E-3, a water solubility ranging from 0.3-4.8 ppm and a soil adsorption coefficient ranging from 2,500-14,800.

Fenamiphos: A nematicide used to control the major genera of nematodes. It has a molecular weight of 304, a vapor pressure of 1.3E-2 Pa, a water solubility of 400-700 ppm, and soil adsorption coefficient ranging from 26-249.

Triclorfon: Trichlorfon is an insecticide widely used to control infestations of armyworm, cutworm, fall armyworm, mole cricket, sod webworm and white grubs. Its molecular weight is 293.8, has a vapor pressure of 9.5E-4 to 1.1E-3 Pa, has an extremely high water solubility (120,000 to 154,000 ppm) and a low soil adsorption coefficient of about 6.

Benomyl: Benomyl is a systemic fungicide used to control diseases such as brown patch, dollar spot, Fusarium blight and typhula blight. Its molecular weight is 290.3, has a vapor pressure of <1.3E-3 Pa, and water solubility of only 0-8 ppm. Soil adsorption coefficient is 200-2100.

Chlorothalonil: Chlorothalonil is also a fungicide used to control brown patch, copper spot, dollar spot, Fusarium patch, Dreschlera and Bipolaris disease, Pythium blight, red thread, rust, slime mold, and Fusarium snow mold. Its molecular weight is 265.9, has a vapor pressure of 1.3 Pa, water solubility of 0.6 ppm, and soil adsorption coefficient of 1380-5800.

Metalaxyl: Is also a fungicide used to control Pythium blight. It has a molecular weight of 279.3, a vapor pressure of 2.9E-4 Pa, a water solubility of 7100-8400 ppm, and a soil adsorption coefficient of 29-287.

Bensulide: Bensulide is a selective pre-emergent herbicide used to control annual bluegrass, barnyard grass, crabgrass, fall panicum, and foxtail. Its molecular weight of 397.5, a vapor pressure of 1.1E-4-1.3E-4, 5.6-25 ppm, and a soil adsorption coefficient of 740-10,000.

DCPA: A selective pre-emergent for control of annual bluegrass, barnyard grass, crab grass, foxtail, goosegrass, carpetweed, purslane, spurge, common chickweed, and field sandbur. Its molecular weight is 332, vapor pressure 3.3E-4 Pa, water solubility of 0.5 ppm, and soil adsorption coefficient of 4000-6400.

Dicamba: Is a selective, systemic postemergent herbicide used to control mainly broadleaf species. Its molecular weight is 221.1, vapor pressure is 2.7E-3-4.9E-1, water solubility of 5000 to 850000 ppm (depending on form), a soil adsorption coefficient less than 6.

2,4-D: Also systemic, selective postemergent herbicide. Its molecular weight is 221-333 (depending on form), has a vapor pressure of 1.3E-5 to 1.1E-3 Pa, a water solubility of 900 (acid) ppm to 3,000,000 ppm (dimethyl amine salt). It has a soil adsorption coefficient of 20 for the acid form and from 1000 to 68000 for the ester forms.

3.1.3 *Decomposition and Persistence*

In terms of potential environmental impact, the use and application of pesticides is the single most crucial issue of concern to regulatory agencies and to the public at large. Choice of pesticide to be used, application practices and timing, and efficacy of the pesticide to be used must always be considered in conjunction with site specific characteristics in order to reduce or eliminate any potential health risk and offsite transport. One of the first evaluations that should be made with regard to pesticide choice and application is to determine the persistence and degradation rates of the compounds under consideration.

Degradation of applied pesticide is the only process that permanently reduces the total environmental load of pesticide. All pesticides applied to turfgrass are degraded, but their rates of degradation and hence persistence are variable. These rates are a complex function of soil, climatic, chemical, microbiological, and physical factors that should be evaluated based solely on the characteristics of the area of proposed application.

Chemical persistence of applied pesticides has a critical influence on their fate and movement in the environment. Degradation and sorption by organic matter and soil colloidal particles are two of the most critical processes controlling potential pesticide leaching and runoff losses. Chemical half-life serves as one yardstick for assessing potential environmental impacts of applied compounds. Short-lived compounds (those that degrade rapidly) are less likely to be transported in surface water runoff and groundwater than highly persistent compounds. Persistent compounds, including some highly adsorbed compounds, may eventually be leached to groundwater under certain conditions. The use of highly persistent chemicals should be avoided.

For this initial assessment of proposed pesticides, we have compiled a list of pesticide degradation rates from which five different categories or classes of persistence have been derived. The classes and ranges for each class expressed as Ks (where Ks is the rate of degradation in units of days-1). The smaller the number the slower the rate of degradation or the greater the persistence of the compound. The classes are:

Class 1: Highly persistent, Ks <0.007
Class 2: Moderately persistent, Ks=0.007 to 0.023
Class 3: Moderately short-lived, Ks=0.023 to 0.046
Class 4: Short-lived, Ks=0.046 to 0.139, and
Class 5: Very short-lived, Ks > 0.139.

For the chemicals noted above the following degradation rates and persistence classes are noted:

TABLE 3.1-2 PESTICIDES AND PERSISTENCE CLASSIFICATION

Pesticide	Ks (days-1)	Half-life (days)	Persistence Class
Bendiocarb	0.033-0.231	3-21	3-5
Chlorpyrofos	0.017-0.046	15-42	2-4
Fenamiphos	0.023-0.231	3-30	3-5
Trichlorfon	0.026-0.231	3-27	3-5
Benomyl	0.004-0.008	90-180	1-2
Chlorothalonil	0.008-0.05	14-90	2-4
Metalaxyl	0.004-0.099	7-160	1-4
Bensulide	0.004-0.023	30-180	1-3
2,4-D	0.023-0.139	5-30	3-4
DCPA	0.002-0.053	13-295	1-3
Dicamba	0.02-0.214	3-35	2-5

As noted in the Table, most of the compounds are moderately to very short-lived compounds. The projected persistence of each compound is discussed in the modeling section of this report. In that case, site characteristics are included in the simulations.

3.1.4 *Toxicity of Potential Pesticides*

Another consideration with respect to the application and use of pesticides is their toxicity to non target organisms in the area. These include both terrestrial and aquatic organisms. As information becomes available from other assessments on wildlife and aquatic organisms, the direct effect of the proposed chemicals can be assessed. In the duration, we have included in Appendix A toxicity tables for a number of aquatic and terrestrial organisms that can be used to evaluate the effect of pesticide on the dominant organisms at the site. Tables 3.1-3 and 3.1-4 summarize the Toxicity Tables in Appendix A.

TABLE 3.1-3 RELATIVE PESTICIDE TOXICITY RATINGS

Toxicity* Rating	LC_{50} (mg 1-1)	Class	LD_{50} (mg kg-1)	Class
1	< 0.1	Very highly toxic	< 5	Extremely toxic
2	0.1 - 0.99	Highly toxic	5 - 49	Very toxic
3	1 - 9.99	Moderately toxic	50 - 49999	Moderately toxic
4	10 - 99.99	Slightly toxic	500 - 4999	Slightly toxic
5	> 100	Practically nontoxic	> 4999	Almost nontoxic

*Adapted from EPA (1985a) and USDA (1969)

TABLE 3.1-4 Summary and Range of Turfgrass Pesticide Toxicity Tests

Chemical	CAS Number	Chemical Type	Species Class	Toxicity Test	Range of Concentration (µg L⁻¹)	Range of Toxicity Classes*
Atrazine	1912249	Herbicide	FISH	LC50	220->100000	2-5
Atrazine	1912249	Herbicide	INSECT	LC50	720	2
Atrazine	1912249	Herbicide	ANNELIDA	LC50	6300-9900	3
Atrazine	1912249	Herbicide	MULLUSCA	LC50	>100000	5
Atrazine	1912249	Herbicide	CRUSTACEA	LC50	94-54000	1-4
Atrazine	1912249	Herbicide	PROTOZOA	LC50	6-38	1
Atrazine	1912249	Herbicide	TRACHEOPHYT	LC50	100-540	2
Benefin (Benfluralin)	1861401	Herbicide	MAMMAL	LD50	790000	4
Benefin (Benfluralin)	1861401	Herbicide	FISH	LC50	800-<1000	2
Benefin (Benfluralin)	1861401	Herbicide	AMPHIBIA	LC50	11000	4
Benefin (Benfluralin)	1861401	Herbicide	CRUSTACEA	LC50	1100-8200	3
Bensulide	741582	Herbicide	FISH	LC50	379-970	2
Bensulide	741582	Herbicide	MAMMAL	LD50	241000-1470000	3-4
Bensulide	741582	Herbicide	CRUSTACEA	LC50	1400-7600	3
2,4-D Acid	94757	Herbicide	BIRD	LD50	472000-668000	3-4
2,4-D Acid	94757	Herbicide	FISH	LC50	208-7000000	2-5
2,4-D Acid	94757	Herbicide	FISH	LD50	1000000-2000000	4
2,4-D Acid	94757	Herbicide	INSECT	LC50	1600-91800	3-4
2,4-D Acid	94757	Herbicide	ANNELIDA	LC50	122200	5
2,4-D Acid	94757	Herbicide	AMPHIBIA	LC50	8050-13770	3-4
2,4-D Acid	94757	Herbicide	MULLUSCA	LC50	259000	5
2,4-D Acid	94757	Herbicide	CRUSTACEA	LC50	1000-1389000	2-5
2,4-D Acid	94757	Herbicide	PROTOZOA	LC50	104000-485000	5
2,4-D Amine	2008391	Herbicide	BIRD	LD50	2000->2025	1
2,4-D Butyl ester	1929733	Herbicide	BIRD	LC50	>5000	3
2,4-D Butyl ester	1929733	Herbicide	MAMMAL	LD50	380-848	1
2,4-D Butyl ester	1929733	Herbicide	FISH	LC50	303-43400	2-4
2,4-D Butyl ester	1929733	Herbicide	INSECT	LC50	1600-8500	3
2,4-D Butyl ester	1929733	Herbicide	MULLUSCA	LC50	740-740	2
2,4-D Butyl ester	1929733	Herbicide	CRUSTACEA	LC50	440->100000	2-5
2,4-D PCBE	1320189	Herbicide	FISH	LC50	170-9300	2-3
2,4-D PCBE	1320189	Herbicide	INSECT	LC50	2400-2600	3
2,4-D PCBE	1320189	Herbicide	CRUSTACEA	LC50	400->100000	2-5
2,4-D Sodium salt	2702729	Herbicide	FISH	LC50	12900-2971000	4-5
2,4-D Sodium salt	2702729	Herbicide	INSECT	LC50	>40000	4
2,4-D Sodium salt	2702729	Herbicide	MULLUSCA	LC50	64290->100000	4-5
2,4-D Sodium salt	2702729	Herbicide	AMPHIBIA	LC50	>40000	4
2,4-D Sodium salt	2702729	Herbicide	CRUSTACEA	LC50	2224-2644000	3-5

*Range of toxicity classes are defined in Table 1.

TABLE 3.1-4 Summary and Range of Turfgrass Pesticide Toxicity Tests

Chemical	CAS Number	Chemical Type	Species Class	Toxicity Test	Range of Concentration (µg L⁻¹)	Range of Toxicity Classes*
2,4-DP Dichlorprop	120365	Herbicide	MAMMAL	LD50	532	1
DCPA	1861321	Herbicide	MAMMAL	LD50	>10000000	5
DCPA	1861321	Herbicide	FISH	LC50	>10000-1000000	4-5
DCPA	1861321	Herbicide	ANNELIDA	LC50	286000	5
DCPA	1861321	Herbicide	CRUSTACEA	LC50	>40000	4
Dicamba	1918009	Herbicide	BIRD	LC50	>4640->10000	3-4
Dicamba	1918009	Herbicide	BIRD	LD50	>2510	1
Dicamba	1918009	Herbicide	MAMMAL	LD50	757	1
Dicamba, Acid	1918009	Herbicide	FISH	LC50	28000-516000	4-5
Dicamba, Acid	1918009	Herbicide	AMPHIBIA	LC50	106000-220000	5
Dicamba, Acid	1918009	Herbicide	CRUSTACEA	LC50	3900->100000	3-5
Dicamba, Sodium salt	62610393	Herbicide	FISH	LC50	30000-600000	4-5
DSMA	144218	Herbicide	MAMMAL	LC50	22100	4
DSMA	144218	Herbicide	MAMMAL	LD50	1800000	4
DSMA	144218	Herbicide	FISH	LC50	>10000-1500000	4-5
DSMA	144218	Herbicide	AMPHIBIA	LC50	271000-600000	5
DSMA	144218	Herbicide	CRUSTACEA	LC50	>40000	4
Endothall, disodium salt	129679	Herbicide	FISH	LC50	310->560000	2-5
Endothall, disodium salt	129679	Herbicide	MOLLUSCA	LC50	32500-48080	4
Endothall	145733	Herbicide	BIRD	LD50	229000	3
Endothall	145733	Herbicide	FISH	LC50	280-1740000	2-5
Endothall	145733	Herbicide	INSECT	LC50	3250	3
Endothall	145733	Herbicide	CRUSTACEA	LC50	50-510	1-2
Fenoxaprop-ethyl	1330207	Herbicide	FISH	LC50	8200-1080000	3-5
Fenoxaprop-ethyl	66441234	Herbicide	MAMMAL	LD50	3310000-3400000	4
Fenoxaprop-ethyl	1330207	Herbicide	CRUSTACEA	LC50	350-1000000	2-5
Glyphosate	1071836	Herbicide	BIRD	LC50	163->4640	2-3
Glyphosate	1071836	Herbicide	BIRD	LD50	>2000->3800	1
Glyphosate	1071836	Herbicide	MAMMAL	LD50	3800->7900	1-2
Glyphosate	1071836	Herbicide	FISH	LC50	12800-240000	4-5
Glyphosate	1071836	Herbicide	INSECT	LC50	673430	5
Glyphosate	1071836	Herbicide	CRUSTACEA	LC50	22000-47310	4
Glyphosate, Rodeo	1071836	Herbicide	MAMMAL	LD50	>5000-5400	2
Glyphosate, Roundup	38641940	Herbicide	FISH	LC50	1300-54800	3-4
Glyphosate, Roundup	38641940	Herbicide	INSECT	LC50	30000-43000	4
Glyphosate, Roundup	38641940	Herbicide	CRUSTACEA	LC50	43000-62000	4

*Range of toxicity classes are defined in Table 1.

TABLE 3.1-4 Summary and Range of Turfgrass Pesticide Toxicity Tests

Chemical	CAS Number	Chemical Type	Species Class	Toxicity Test	Range of Concentration (µg L⁻¹)	Range of Toxicity Classes*
MCPA	94746	Herbicide	BIRD	LC50	>5000	3
MCPA	94746	Herbicide	FISH	LC50	>10000-163500	4-5
MCPA	94746	Herbicide	INSECT	LC50	335000	5
MCPA	94746	Herbicide	CRUSTACEA	LC50	11000->40000	4
MSMA	4464522	Herbicide	FISH	LC50	74000-79000	4
MSMA + Surfactant	2163806	Herbicide	MAMMAL	LC50	>20000	4
MSMA + Surfactant	2163806	Herbicide	MAMMAL	LD50	300000-2738000	3-4
MSMA + Surfactant	2163806	Herbicide	FISH	LC50	1200-4700000	3-5
MSMA + Surfactant	2163806	Herbicide	CRUSTACEA	LC50	37600-5100000	4-5
Oxadiazon	19666309	Herbicide	FISH	LC50	1460-3200	3
Oxadiazon	19666309	Herbicide	AMPHIBIA	LC50	1300-2800	3
Pronamide	23950585	Herbicide	MAMMAL	LD50	5620000-10000000	5
Pronamide	23950585	Herbicide	AMPHIBIA	LC50	>40000	4
Simazine	122349	Herbicide	BIRD	LC50	8800-51200	3-4
Simazine	122349	Herbicide	MAMMAL	LD50	>4000	1
Simazine	122349	Herbicide	FISH	LC50	90-8100000	2-5
Simazine	122349	Herbicide	INSECT	LC50	1900->40000	3-4
Simazine	122349	Herbicide	MOLLUSCA	LC50	>100000	5
Simazine	122349	Herbicide	AMPHIBIA	LC50	>100000	5
Simazine	122349	Herbicide	CRUSTACEA	LC50	13000-424000	4-5
Triclopyr, Ester	55335063	Herbicide	BIRD	LC50	9026->10000	3-4
Triclopyr, Ester	55335063	Herbicide	BIRD	LD50	>4640	1
Triclopyr, Ester	55335063	Herbicide	MAMMAL	LD50	2140-2460	2
Triclopyr, Acid	55335063	Herbicide	BIRD	LC50	2935->5640	3
Triclopyr, Acid	55335063	Herbicide	BIRD	LD50	1698	1
Triclopyr, Acid	55335063	Herbicide	MAMMAL	LD50	310-729	1
Triclopyr, Acid	55335063	Herbicide	FISH	LC50	1200->100000	3-5
Triclopyr, Amine	57213691	Herbicide	BIRD	LC50	>10000-11622	4
Triclopyr, Amine	57213691	Herbicide	MAMMAL	LD50	2140-2830	2
Triclopyr, Amine	57213691	Herbicide	FISH	LC50	101000-498000	5
Triclopyr, Amine	57213691	Herbicide	CRUSTACEA	LC50	1140000-1170000	5
Trifluralin	1582098	Herbicide	FISH	LC50	10-28000	1-4
Trifluralin	1582098	Herbicide	AMPHIBIA	LC50	100-14000	2-4
Trifluralin	1582098	Herbicide	INSECT	LC50	3800->40000	3-4
Trifluralin	1582098	Herbicide	CRUSTACEA	LC50	50->40000	1-4
Trifluralin	1582098	Herbicide	ANNELIDA	LC50	>300	2
Trifluralin	1582098	Herbicide	MOLLUSCA	LC50	8000-35000	3-4

*Range of toxicity classes are defined in Table 1.

TABLE 3.1-4 Summary and Range of Turfgrass Pesticide Toxicity Tests

Chemical	CAS Number	Chemical Type	Species Class	Toxicity Test	Range of Concentration (µg L⁻¹)	Range of Toxicity Classes*
Bendiocarb	22781233	Insecticide	MAMMAL	LD50	40000-179000	2-3
Bendiocarb	22781233	Insecticide	INSECT	LC50	57-1700	1-3
Bendiocarb	22781233	Insecticide	CRUSTACEA	LC50	5550	3
Carbaryl	63252	Insecticide	MAMMAL	LD50	212000-588000	3-4
Carbaryl	73252	Insecticide	MAMMAL	LD50	1800000	4
Carbaryl	63252	Insecticide	FISH	LC50	140-204000	2-5
Carbaryl	63252	Insecticide	FISH	LD50	>10	1
Carbaryl	63252	Insecticide	INSECT	LC50	2-100000	1-5
Carbaryl	63252	Insecticide	ANNELIDA	LC50	7200-13000	3-4
Carbaryl	63252	Insecticide	ANNELIDA	LD50	>50000->100000	3
Carbaryl	63252	Insecticide	MOLLUSCA	LC50	1200-2000000	3-5
Carbaryl	63252	Insecticide	AMPHIBIA	LC50	4700-150000	3-5
Carbaryl	63252	Insecticide	CRUSTACEA	LC50	1-22900	1-4
Carbaryl	63252	Insecticide	PROTOZOA	LC50	7900-105000	3-5
Chlorpyrifos	2921882	Insecticide	FISH	LC50	0.8-8950	1-3
Chlorpyrifos	2921882	Insecticide	INSECT	LC50	0.16-71	1
Chlorpyrifos	2921882	Insecticide	CRUSTACEA	LC50	0.035-6	1
Chlorpyrifos	2921882	Insecticide	MOLLUSCA	LC50	>806	2
Diazinon	333415	Insecticide	BIRD	LC50	47000-245000	4-5
Diazinon	333415	Insecticide	BIRD	LD50	3540-4330	1
Diazinon	333415	Insecticide	FISH	LC50	1-23400	1-4
Diazinon	333415	Insecticide	FISH	LD50	310	1
Diazinon	333415	Insecticide	INSECT	LC50	0-6700	1-3
Diazinon	333415	Insecticide	ANNELIDA	LC50	3160	3
Diazinon	333415	Insecticide	MOLLUSCA	LC50	48-20000	1-4
Diazinon	333415	Insecticide	AMPHIBIA	LC50	14000	4
Diazinon	333415	Insecticide	CRUSTACEA	LC50	0->20000	1-4
Ethoprop	13194484	Insecticide	BIRD	LD50	4210-12600	1-2
Trichlorfon	52686	Insecticide	MAMMAL	LD50	866-726970	1-4

*Range of toxicity classes are defined in Table 1.

TABLE 3.1-4 Summary and Range of Turfgrass Pesticide Toxicity Tests

Chemical	CAS Number	Chemical Type	Species Class	Toxicity Test	Range of Concentration (µg L⁻¹)	Range of Toxicity Classes*
Anilazine	101053	Fungicide	FISH	LC50	8.5-675	1-2
Anilazine	101053	Fungicide	CRUSTACEA	LC50	0.27-5550	1-3
Anilazine	101053	Fungicide	MOLLUSCA	LC50	580-1800	2-3
Benomyl	17804352	Fungicide	FISH	LC50	6-2200	1-3
Chlorothalonil	1897456	Fungicide	MAMMAL	LC50	310	2
Chlorothalonil	1897456	Fungicide	MAMMAL	LD50	>10000000	5
Chlorothalonil	1897456	Fungicide	FISH	LC50	8-170	1-2
Chlorothalonil	1897456	Fungicide	INSECT	LC50	1800	3
Chlorothalonil	1897456	Fungicide	MOLLUSCA	LC50	9000-37000	3-4
Chlorothalonil	1897456	Fungicide	AMPHIBIA	LC50	160	2
Chlorothalonil	1897456	Fungicide	CRUSTACEA	LC50	240->10000	3-4
Etridiozole	2593159	Fungicide	MAMMAL	LD50	1077000-4000000	4
Etridiozole	2593159	Fungicide	AMPHIBIA	LC50	12000	4
Mancozeb	8018017	Fungicide	MAMMAL	LD50	11200000	5
Mancozeb	8018017	Fungicide	FISH	LC50	400-2600	2-3
Mancozeb	8018017	Fungicide	CRUSTACEA	LC50	1300	3
Maneb	12427382	Fungicide	MAMMAL	LD50	7990000	5
Maneb	12427382	Fungicide	FISH	LC50	165-6000	2-3
Maneb	12427382	Fungicide	MOLLUSCA	LC50	100000-330000	5
Maneb	12427382	Fungicide	AMPHIBIA	LC50	25000-125000	4-5
Maneb	12427382	Fungicide	CRUSTACEA	LC50	110-10000	2-4
PCNB	82688	Fungicide	MAMMAL	LD50	1700000	4
PCNB	82688	Fungicide	FISH	LC50	1000-40000	3-4
Thiophanate-methyl	23564058	Fungicide	MAMMAL	LD50	790000-7500000	4-5
Thiophanate-methyl	23564058	Fungicide	FISH	LC50	7800-130000	3-5
Thiophanate-methyl	23564058	Fungicide	CRUSTACEA	LC50	16000	4
Thiram	137268	Fungicide	FISH	LC50	0.3-430	1-2
Thiram	137268	Fungicide	AMPHIBIA	LC50	13-35	1
Thiram	137268	Fungicide	ANNELIDA	LC50	670	2
Thiram	137268	Fungicide	PLATYHELMI	LC50	48-530	1-2
Thiram	137268	Fungicide	INSECT	LC50	390-1920	2-3
Thiram	137268	Fungicide	CRUSTACEA	LC50	8-1882000	1-5

*Range of toxicity classes are defined in Table 1.

3.1.5 *Application of Pesticides*

Another dimension in use of a pesticide is selection of the proper rate of application. This should be base on consideration of the above discussion regarding potential toxicity, persistence, and with regard to the manufacturers label recommendations. Increasing the rate above that recommended on the label will not enhance control in most cases and may even decrease the effectiveness of the pesticide as well as increase the potential injury to desirable turfgrass species. In addition, the total pesticide loading will be increased which may have serious consequences regarding mobility, transport, water quality degradation and toxicity.

The method of application of a particular pesticide formulation may be dictated by the type of equipment available, assuming equal effectiveness of different methods in pest control. It is imperative that the pesticide be applied in the manner described on the label to insure effective pest control and safety to humans and the environment. Furthermore, the rate of travel over an area with a particular type of applicator should be within the range prescribed on the label, as this is important in achieving the specified application rate.

Occasionally, the golf course superintendent wishes to combine several pesticides or a pesticide with another chemical, such as fertilizer or wetting agent, to reduce the cost of application in relation to the upcoming turfgrass maintenance requirements. Some pesticides and/or other chemicals can be mixed compatibly. Mixing of others can result in chemical reactions that greatly alter the potential for effective pest control and may increase phytotoxicity. In some cases a precipitate may occur that can clog the sprayer apparatus. Thus it is important that, before any pesticides or chemicals are mixed, the label on the pesticide container is checked to insure that this approach is feasible.

Finally, proper pesticide selection and use involves following the manufacturer's directions on the label concerning the proper time and conditions under which the application should be made. It is not unusual for the label to specify the particular time of day, temperature range and stage of turfgrass or weed growth when the pesticide should be applied. In addition, applications of pesticides under minimal wind velocities is always advisable so that problems of drift can be avoided.

Specific recommendations for the proposed course regarding pesticide timing and application are noted in the TMS.

3.1.6 *Offsite Transport Potential*

The quantitation of offsite transport potential is fully described for each of the chemicals for greens and fairways under different climatic scenarios in the Modeling Section of this report. This section describes, in general terms, the factors associated with offsite transport and how they relate to the site specific characteristics.

The effects of turfgrass, farm and forest management on environmental quality have received considerable attention over the past few years. The movement of pesticide and pesticide residues into surface water and groundwater has been documented extensively from agricultural fields, but prediction of movement and transport from turfgrasses and urban landscapes is still difficult to predict. Transport distance, dilution, sorption process, influence of thatch, degradation and the ability of surface waters to recover from pulses of contamination are all factors confounding the establishment of relationships between field losses in water and contamination of surface and/or groundwater.

From studies surveying the presence of pesticides in surface water samples, the major compounds found are heavily used, persistent, and relatively soluble pesticides. These compounds include atrazine, simazine, alachlor, metolachlor, linuron, 2,4-D and Dicamba. Two of these compounds, 2,4-D and Dicamba, are pesticides that may be potentially useful at the proposed golf course.

Pesticides detected in groundwater are usually herbicides or soluble insecticides associated primarily with agriculture. Several recent reviews on water quality report regional contamination of groundwater at low concentrations throughout the United States. Persistent and relatively mobile compounds such as atrazine, aldicarb, alachlor, DCPA metabolites, and simazine are those most often found. Atrazine, DCPA, and simazine are all major use golf course herbicides. Of these only DCPA is proposed for use at the site.

The effects on water quality from pesticide use in turfgrass systems is not well documented. Research on pesticide losses from pastures, grassed waterways, and reduced tillage systems provide the best surrogate information for assessing the potential losses from golf course watersheds.

The potential for pesticide transport to surface water and groundwater is determined by the interaction of factors including partitioning in the soil-air-water continuum, environmental persistence, climate and management practices. Adsorption, mobility and persistence of pesticides are the primary factors that determine their effectiveness as pest control agents, as well as their potential for surface and groundwater contamination. Although research on surface water quality is often separated from groundwater quality, both are linked in certain regions. For example, depending on hydraulic gradients and regional geology, surface water may directly recharge groundwater.

Loss of pesticides in surface water runoff, subsurface drainage to surface water and subsurface leaching directly effect the quality of water associated with golf course turfgrass. The following discussion pertains to the movement of pesticide from turfgrass by surface and subsurface transport.

Runoff and Surface Water Quality

Pesticide runoff includes dissolved, suspended particulate, and sediment adsorbed pesticides that are transported by water from a treated land surface. Although sediment and runoff losses from turfgrass systems are small compared to agricultural systems, surface transport processes must be understood for sound management of construction, renovation and turfgrass establishment projects.

The principal factors determining runoff losses of pesticides include rainfall characteristics, interval between pesticide application and onset of runoff, pesticide chemical properties, rate and method of pesticide application, rate of field degradation, soil properties and antecedent moisture conditions, ground cover, and transport distance. Partitioning of pesticides between surface transport and subsurface transport depends on chemical characteristics and soil properties. The high variability of pesticide losses observed in runoff generally result from:

1. the complexity of precipitation and erosion processes,
2. foliar washoff patterns,
3. spatial heterogeneity of soil physical and chemical parameters,
4. differences in experimental monitoring techniques, and
5. differences in management objectives.

Below is a table that describes the different factors affecting runoff and pesticide losses. We have added a column describing how specific site conditions at Wahiawa may affect runoff.

TABLE 3.1-5 FACTORS AFFECTING RUNOFF AND PESTICIDE LOSSES

Factors	General Effect	Site Specific Effect
Rainfall/Pesticide and nutrient application.	Highest pesticide runoff occurs during first major runoff event.	Same. TMS will seek to minimize through proper application technique and timing.
Rainfall intensity.	Runoff occurs when rainfall rate exceeds soil infiltration rate.	Soils at the site have excellent permeability (2-6"/hour). If pesticide and nutrients are applied properly, then runoff potential decreases.
Rainfall amount and duration.	Affects runoff volume and leaching potential. Foliar pesticide washoff related to amount of rain.	Pesticide timing and placement are again factors that the TMS will address to minimize this effect.
Soil texture and organic matter content.	Infiltration rates are affected. Texture affects erodibility and particle transport potential. Organic matter usually increases pesticide adsorption.	Infiltration at site is good due to silty clay texture. Runoff expected to be low under most conditions. However, the soils are high in Al and Fe oxides and could erode if saturated. Presence of turf will minimize this. Organic matter content is 1-3% in most cases, which will aid in adsorption processes.
Soil water content.	High water content will decrease time to runoff.	Not a factor. Soils are very well drained and deep.
Slope.	Increasing slope will increase runoff potential.	Most of the acreage has only 1-6% slopes. Small pockets of the area increase to 10-25%. These can be graded or used as areas with less intensive management (e.g. fairways).
Pesticide solubility.	Soluble pesticides tend to be more readily leached into soil and not removed via runoff. Low solubility pesticides more likely to wash off (if rain duration is significant).	A few of the compounds suggested for use are soluble(eg. 2,4-D, Dicamba, and Trichlorfon). TMS will carefully monitor use and application timing. If timing is not followed by rainfall, then leaching and runoff potential reduced.
Pesticide sorption.	Pesticides strongly adsorbed near soil or plant surface more likely to wash off. Runoff off amounts will then depend on particle or sediment transport.	Sorption properties of the soils are moderate to high due to amphoteric surfaces and organic matter. However, soil is well aggregated and tends not to erode easily unless saturated.
Persistence of chemicals	High probability of runoff with use of persistent compounds.	Minimize use of these compounds.
Irrigation practices	Sprinkler irrigation may move soluble pesticides into soil and thatch reducing runoff potential.	Addressed in TMS. This will likely be a reasonable approach for reducing runoff. Timing will still be a factor.

Loss of sediment and surface water runoff from established turfgrass is limited compared to agricultural systems. The primary mode of pesticide loss from turfgrass is in runoff water, however, under intensive rainfall conditions soil may still be lost from the systems. During golf course construction, renovation of existing facilities, or during turfgrass establishment, bare soil surfaces are exposed to considerable loss of runoff water and eroded soils. Research has shown that considerable sediment and runoff water is lost from construction sites or sites with bare compacted soils compared to sites with established turfgrass. Use of pre-emergent herbicides and preventative application of insecticides or fungicides on areas under construction on golf courses may result in pesticide losses in runoff water and entrained as a particle bound phase.

Several studies indicate that the greatest losses of pesticide in runoff occur soon after initial applications. Since turfgrasses often receive several applications per year, the potential for loss of pesticides may actually be greater than from agricultural systems (Watschke et al., 1988). For example Hall et al. (1987) conducted experiments under controlled indoor growth chambers and outdoor conditions to determine the amount of 2,4-D recovered in Kentucky bluegrass sod. When runoff was collected immediately after application of 1 kg of 2,4-D ha^{-1} under controlled and outdoor conditions, 91 and 71% of the 2,4-D was found in the effluent. After 10 days, the amount decreased to 32% and after 14 days, the amount decreased to 10% of the total. On the other hand, Rhodes and Long (1974) studied the runoff characteristics of benomyl and found that less than 0.1% of the amount applied was found in the effluent. They concluded that benomyl is immobile in soil and turfgrass and does not move significantly from the site of application.

A wide variety of cultural practices have been suggested to reduce the amount of nonpoint contamination of surface and groundwater by pesticides. Management practices that reduce or minimize runoff of pesticides are noted in the TMS.

Subsurface Movement of Pesticides

Research on leaching of pesticides from the soil surface to the groundwater is limited in comparison to studies on surface transport. The lack of published research on pesticide management practices for turfgrass and their impact on groundwater quality reflects the recent attention these issues have received (Walker et al., 1990). Present evaluation of pesticide contamination of groundwater resources has relied heavily on limited field studies, soil column studies and computer simulation.

The potential for transport of pesticides from the root zone to groundwater is also determined by a complex interaction of chemical, soil, climatic and management factors. The chemical factors that influence leaching potential include the rate of application, application technique and timing, water solubility, adsorption properties, volatility, persistence and degradation characteristics. Critical soil properties that are related to subsurface movement of pesticides include texture, organic matter content, exchange capacity, soil structure and porosity, and soil moisture conditions. On-site factors include depth to groundwater, geologic substrate, turfgrass cover and type, and cultivation practices. Other factors, such as climatic ones, also influence potential for subsurface leaching.

The variation and timing of precipitation or irrigation in relation to pesticide application, occurrence of preferential flowpaths, pesticide handling and practices, and well location have profound effects on pesticide transport. These factors are associated with increased leaching potential despite chemical and soil properties that attenuate pesticides within the root zone. Fractured aquifers, shallow aquifers, and intensified irrigation practices are additional unique concerns for nonpoint impacts on groundwater quality. Development of golf courses on sites with shallow sandy soils, shallow aquifers, or karst topography have greater potential for subsurface loss of applied chemicals.

Below, we have again constructed a table that relates different factors related to subsurface pesticide losses to conditions at the site. Quantitative assessment of the movement of pesticides is presented in the modeling section of this report.

TABLE 3.1-6 FACTORS RELATED TO SUBSURFACE PESTICIDE LOSSES

Factor	Impact on Subsurface Transport	Site Specific Effect
Soil Water Content	Soil water ultimately transports pesticides not absorbed to soil surfaces. Increased soil water levels will increase both water and chemical flux beyond the root zone.	Due to the fact that the soils are very well drained at the site, high rainfall influx can be counter balanced with a rational approach to application and timing.
Hydraulic conductivity	Measure of soil's ability to transmit water and entrained solutes. Soils with high conductivity in relation to initial infiltration (sands) have a greater potential for mass transport of solutes.	Soils are silty clays with many fine pores in the upper soil profile. Conductivity is expected to be moderate and present as manageable in relation to leaching.
Organic Matter and Clay Content	Effect pesticide adsorption, which attenuate leaching potential.	Soils have relatively high adsorption capacity with 1-3% organic matter. Both will aid in reducing subsurface leaching. Adsorption surfaces capable of adsorbing most pesticides chosen.
Thatch Layer	The thatch layer is a continuous organic medium which may form between the turf canopy and the soil. It can act as an effective barrier to pesticide entering soil.	Magnitude of effect in many cases is unknown. In general thatch will decrease amount of pesticide available for subsurface leaching.
Depth to Groundwater	Shallow aquifers more likely to be contaminated.	Unknown at this time.
Pesticide Sorption Properties	High Kd values suggests that pesticide strongly adsorbed and the potential for leaching is thereby reduced.	Pesticides suggested for use have fairly high Kd values. Should be strongly adsorbed. Most pesticides found in groundwater have Kd values less than 1. Pesticides chosen, easily exceed this value.
Application Rate	Amount of pesticide applied is directly proportional to amount transported.	Reduce application rates and repeated use. Use only on areas requiring treatment. Both will reduce this potential.

There is a wide range of field and chemical conditions that influence potential transport of pesticides to groundwater. When persistent compounds that have high or intermediate mobility are applied to soils with minimal adsorptive capacity and shallow water tables, the leaching process may result in groundwater contamination. On the opposite end of the risk spectrum is the use of pesticides that are rapidly decomposed and/or strongly adsorbed. When these chemicals are applied to soils with high adsorptive capacity, deep water tables, and appropriate water management, the probability of pesticide leaching is significantly reduced. However, under certain conditions, even very persistent and immobile compounds, such as chlordane, can be leached to groundwater (Cohen et al., 1990). Therefore, the complex suite of conditions controlling the movement of chemicals must be evaluated on a site specific basis. These conditions and how they interact at the site are more fully described in the Modeling Section of the report.

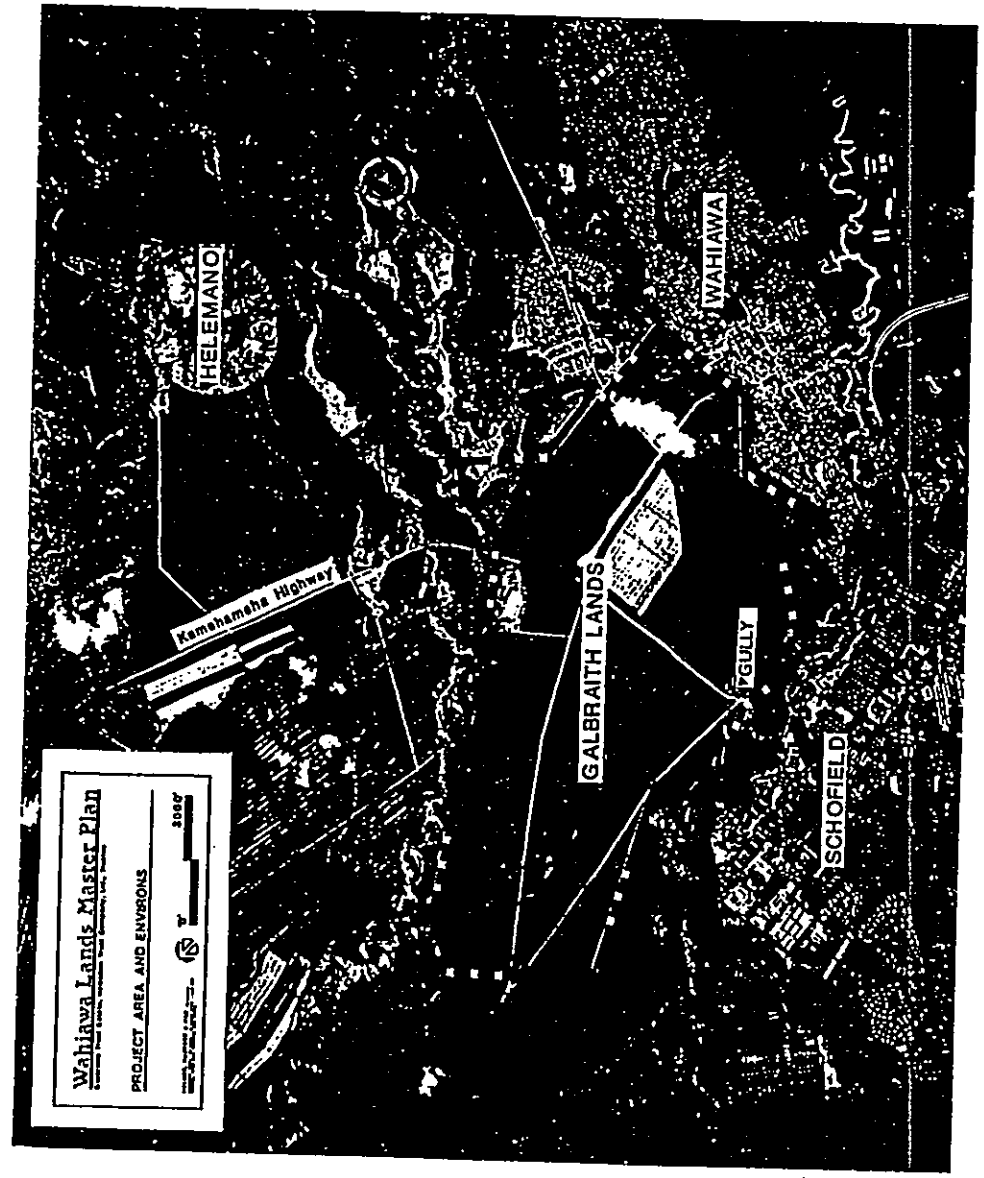
3.1.7 *Comparison of Offsite Transport Potential of Chemicals Due to Golf Course Construction/Management and Present Site Conditions*

Based on the review of the processes governing the offsite transport of pesticides from the site, it is possible to compare the effect of constructing and managing a golf course to the current agricultural practices at the site.

1. **Surface Water Transport:** Surface water transport potential (runoff) will be reduced due to the presence of turfgrass over much of the southern part of the site (see map) compared to runoff under the present pineapple cultivation practices. This will occur through several likely mechanisms. The site at present has significant gully erosion occurring in the southwesterly section of the acreage (See Figure 3.1-1). Since the topographic features of the area suggest that this represents a significant drainage pathway for the site, the gully acts as a conduit for removal of runoff water from the site. This is further substantiated by the large amount of sediment observed leaving the site with runoff water. Sediment from the site covers the faces of roadcuts and parts of the highway around the reservoir. Development of the site with a turf cover should provide an additional absorptive surface for water, will increase soil stability and infiltration. Re-grading the gullied area will minimize or possibly recapture runoff for storage and possible re-use.

2. **Pesticide Transport via Runoff:** This should also be reduced due to golf course development for similar reasons affecting the quantity of water leaving the site as noted above. However, it is also true that pesticide application site wide will be reduced due to the implementation of the TMS program which will seek to reduce the quantity of pesticide applied, will allow application only when needed, and will be timed to avoid predictable climatic situations that could lead to runoff. Present pesticide application at the site appears to be by schedule rather than by need.

FIGURE 3.1-1



3. **Pesticide Transport via Erosion (Sediment):** The establishment of turfgrass at the site will definitely decrease the extent of erosion and particle bound pesticide at the site. Turf will cover large areas of now bare soil and overall will provide a "soil cover" for much of the site. Establishment of turf for erosion control is a common and recommended practice of the USDA and SCS.

4. **Pesticide Leaching:** Leaching of pesticide at the site should also be reduced compared to the present cultivation practices. Establishment of turf will provide a buffer zone for capture of leachable pesticide presumably due to the high adsorptive capacity of the turf thatch layer. Presently, soluble pesticide that reaches the bare soil is free to leach to the extent determined solely by soil physical parameters.

3.2 Nutrient/Fertilizer Impacts

3.2.1 Use of Turfgrass Fertilizer and Environmental Impacts

The use of fertilizers is an important turfgrass management practice required to maintain the aesthetic quality and turfgrass growth rate to accommodate wear. Public concern is growing regarding the use of fertilizers for turfgrass management and the potential contamination of water supplies associated with golf courses. The following sections review turfgrass nutrient requirements, fertilizer application practices, and potential environmental impacts resulting from these practices.

3.2.2 Use of Fertilizers in Golf Course Construction and Maintenance

Growth of turfgrass requires an adequate supply of all essential plant nutrients, in addition to many other cultural and edaphic factors (Davis 1969; Beard 1982). Of the 16 elements essential for plant growth and development, nitrogen, phosphorus, and potassium are generally the most important with respect to turfgrass fertilization (Hughes and Henson 1965; Matches 1979). Use of fertilizers and nutrient requirements of turfgrass systems has been reviewed by Beard (1973, 1982), Davis (1969), Murray and Powell (1979), Petrovic (1990), and Wilkinson and Mays (1979). Use of nitrogen and phosphorus is a concern from a water quality and environmental impact perspective (Petrovic 1990; Schuler 1987).

In general, turfgrass is most responsive to nitrogen fertilization (Beard 1982). Nitrogen is the essential element considered to control growth when other elements are maintained at adequate levels. Nitrogen can be added or withheld to regulate both growth and color of turfgrass (Street 1988). Nitrogen is very dynamic in the soil system. Its concentration is constantly changing, usually decreasing, and therefore, must be routinely added to maintain a soil level sufficient for turfgrass growth (Wilkinson and Mays 1979). Nitrogen deficiency occurs frequently and is characterized by stunting of shoot growth in the initial stages of deficiency, followed by a yellowish chlorosis across the entire leaf blade in intermediate stages. In the advance stages of

nitrogen deficiency, necrosis of the leaves occurs (Beard 1982). This condition is exacerbated on course, sandy soils and on soils subject to leaching from intensive rainfall or irrigation (Beard 1982).

Turfgrasses need potassium in relatively large amounts, second only to nitrogen (Wilkinson and Mays 1979). On low potassium soils, addition of potassium may be necessary. Recent research has demonstrated that increasing potassium levels result in improved root growth, an enhancement of heat, cold, and drought tolerance and reduced incidence of disease (Street 1988). Potassium deficiency in turfgrass systems occurs less frequently than nitrogen. It is characterized by excessive tillering in initial stages and by leaf scorching in advanced stages. Potassium deficiency is also exacerbated by conditions favoring losses of nitrogen; excessive leaching in coarse textured soils (Hughes and Henson 1965).

Phosphorus usually enhances the rate of turfgrass establishment from seed or vegetative plantings and enhances root growth. Phosphorus deficiency does not occur as commonly as nitrogen or potassium deficiencies. Reduced levels of phosphorus is usually related to low soil levels or to soil pHs that are either too low (acid) or too high (alkaline) (Beard 1982). Deficiency symptoms include a darkening of leaves followed by the appearance of blue green or purplish coloration followed by leaf tip withering and necrosis.

Other essential elements of importance to turfgrass systems include sulfur, calcium, magnesium and micronutrients. Sulfur deficiency recurs at a frequency similar to potassium. Deficiency of sulfur is characterized by loss of green color from older leaves in the initial stages. Sulfur deficiency has been noted to occur on coarse sandy soil, low in organic matter, and subject to intensive leaching. Calcium and magnesium deficiencies are extremely rare, but are more likely to occur in coarse, acid soils. Micronutrient levels are usually adequate in most soils. In addition, micronutrients are needed in very small quantities and are often supplied as impurities in commonly used fertilizers, liming materials, top dressing, certain pesticides and irrigation water. Sandiness increases the possibility for micronutrient deficiency. However, most sands used for soil modification are not pure and are usually modified to some extent with soil or organic matter. In general, micronutrient deficiencies are most likely to occur in alkaline soils. They are further aggravated by high soil phosphorus and high soil levels of other micronutrients (Beard 1982).

The most common approach to prevention of nutrient deficiency is through soil testing. Evaluation of soil nutrient levels insures the best possible efficiency and economy of fertilization (Turner and Waddington 1983). Addition of soil nutrients far in excess of plant growth and uptake requirements has been associated with nonpoint source pollution in intensely managed pasture and forage systems (Anderson et al. 1989). Use of soil testing is considered a best management practice for reduction of potential movement of applied nutrients in surface runoff or leaching (Anderson et al. 1989; Koehler et al. 1982a).

Soil testing is the best means of assessing phosphorus and potassium needs, but is ineffective for determining the nitrogen status of soils. Soil tests are usually made prior to establishment of turfgrass and then conducted during annual establishment or until soil levels stabilize. After pH levels and micronutrients have been brought into the desired range, a soil test is needed at one to three year intervals. Longer intervals are usually followed for fine textured soils, while more frequent intervals are required for greens and tees constructed of a sandy root zone mix. The sandy mix has a low nutrient capacity and is prone to nutrient leaching, which causes rapid depletion of nutrients (Beard 1982).

3.2.3 Environmental Issues Related to Fertilizer Use in Turfgrass Systems (Golf Courses)

Turfgrass is often maintained in or near areas of high population where the need for efficient, safe, and effective management is important. Improper use of pesticides or fertilizers in these systems may result in lowering of water quality (Watschke and Mumma 1990). In areas where groundwater is used for domestic and commercial purposes, there exists a potential for contamination through improper land use, especially if the groundwater is found in shallow aquifers. The use of high rates of fertilizer is often cited as being incompatible with sound groundwater management strategies (Potter et al. 1989).

Surface water is another valuable water resource and its quality also is affected by land use (Daniel et al. 1982). Urban and suburban environments contain a high percentage of runoff surfaces (Schuler 1987). It has been suggested that recharge from these areas make a considerable contribution to the need for improving the safety of potable water supplies. Collection and storage of stormwater runoff has been attempted on a limited scale in some metropolitan areas. However, recent studies have shown that water quality tends to decline as urbanization increases. This decreased water quality has been associated with the movement of undesirable sediment deposited on impervious surfaces.

A parallel concern has been expressed relative to the quality of water emanating from landscaped surfaces that have received nutrient and pesticide applications (Potter et al. 1989). The placement of chemicals on turfgrass systems often differs from the methods commonly employed on cultivated croplands, where chemicals are sometimes mixed with the soil (Anderson et al. 1989; Koehler et al. 1982a; Smolen et al. 1984). Surface application of chemicals to turfgrass or any other crop reduces the potential for soil adsorption or deactivation. Therefore, surface applied nutrients and pesticides have increased potential for losses in runoff.

3.2.4 Health Issues of Inorganic Fertilizers and Nitrate in Drinking Water

Potential adverse effects of nitrogen on health and the environment have been identified (Table 3.2-1). Health issues and environmental impacts of nitrate-nitrogen have been extensively reviewed by Brezonik (1978), Cantor et al. (1988), Keeney (1982) and Pratt (1985). Environmental impacts of nitrogen include changes in productivity of natural and managed ecosystems, potential eutrophication of surface waters, a role in acid deposition, and partial depletion of stratospheric ozone by nitrous oxides.

TABLE 3.2-1 POTENTIAL ADVERSE EFFECTS OF NITROGEN

EFFECT	CAUSATIVE AGENTS
Human Health	
Methemoglobinemia in infants	Excess NO_3^- and NO_2^- in water and food.
Cancer	Nitrosamines from NO_2^-, secondary amines.
Respiratory illness	Peroxyacyl nitrates, alkyl nitrates, NO_3^- aerosols, NO_2^-, HNO_3 vapor in urban atmospheres.
Animal Health	
Environment	Excess NO_3^- in feed and water.
Eutrophication	Inorganic and organic N and P in surface waters.
Material and ecosystem damage	HNO_3 aerosols in rainfall.
Plant toxicity	High levels of NO_2^- in soils.
Excessive vegetative growth	Excess available nitrogen.
Stratospheric ozone depletion	Nitrous oxide from nitrification, denitrification, and stack emissions.

The potential adverse human health effects of nitrates in drinking water include birth defects, cancer, nervous system impairment, and methemoglobinemia. The inorganic forms of phosphorus are not toxic. The environmental problems associated with phosphorus are concerned with control of undesirable fertility levels and eutrophication of surface waters (Taylor and Kilmer 1980).

Acute nitrate poisoning of humans is rare (Keeney 1983b), requiring a single oral ingestion of 1 to 2 g of nitrate by an adult. Chronic health effects of nitrates have been attributed to reduction of nitrate to nitrite by saliva and intestinal flora of some animals and of infants during the first 3 to 4 months of life. Newborn infants are susceptible to this condition, although clinical reports of infant mortality from methemoglobinemia current are rare (Keeney 1986). Physicians usually recommend use of bottled water in areas with excess nitrate-nitrogen in drinking water supplies (Pratt 1985).

The relationship of nitrates in drinking water and methemoglobinemia is the only human health effect that has been well verified (Cantor et al. 1988). The degree of risk to human health from moderate to high levels of nitrate concentration in drinking water is still being debated (Keeney 1983). The current U.S. Public Health Service drinking water standard and U.S. EPA Maximum Contaminant Level (MCL) for nitrate-nitrogen is 10 mg L^{-1} (45 mg L^{-1} as nitrate). This standard has withstood several critical examinations and current evidence suggests the nitrate standard provides reasonable protection to newborns against methemoglobinemia (National Research Council 1978).

Evidence linking nitrate or nitrite to subclinical effects in humans has not been definitely established. However, there are an increasing number of studies that indicate an association between consumption of nitrate\nitrite and incidents of cancer and other subclinical effects (Cantor et al. 1988). Exposure to high levels of nitrate in drinking water has been linked by some studies to gastric cancer, however, other investigations have not confirmed this association (Fraser et al. 1980). Most positive evidence of nitrate\nitrite and stomach cancer results from circumstantial evidence and geographic correlations (Cantor et al. 1988). In general, strong epidemiologic association of nitrates in drinking water and health risks has been inconclusive. Although trace amounts of nitrosamines have been detected in foods and wastes applied to soils, currently there is no conclusive causal evidence linking cancer and teratogenesis incidence to nitrates in drinking water (Anderson et al. 1989).

Even at excess concentrations, there is limited evidence that nitrate\nitrite is toxic to animals with the exception of ruminants. Moderate levels of nitrate poisoning of livestock from drinking water has been associated with poor growth, infertility, abortions, and general unhealthiness. Further research is needed to substantiate the response of livestock to moderate and low levels of nitrate contamination (Hansen et al. 1987).

3.2.5 *Environmental Effects of Inorganic Fertilizers*

Eutrophication is the overenrichment of lakes, bays, and slow moving streams with nutrients causing subsequent proliferation of aquatic plants (Frere 1976). In addition to nutrient content, lake productivity is the result of basin, water, and limnological properties (Vollenweider and Kerekes 1980). The natural progression of lakes from oligotrophic to eutrophic status may be greatly accelerated by human activities and non-point source nutrient loading (Daniel et al. 1982;

Keeney 1983; Schuler 1987). The concepts, processes, and nutrient sources responsible for eutrophication have been extensively reviewed (Loehr 1974; National Academy of Sciences 1969; Vollenweider and Kerekes 1980). The undesirable symptoms of eutrophication are algal blooms, algal mats, luxuriant development of certain aquatic macrophytes, depletion of oxygen on lake bottoms, and a decrease in water clarity (Brezonik 1969). Depletion of oxygen on lake bottoms and subsequent release of toxins has been associated with fish kills (Fry 1969).

Nutrients available for algal growth and eutrophication are of greater concern for water quality than total nutrient loading. Phosphorus, and to a lesser extent, nitrogen are associated with eutrophication of surface water. The role of soluble and sediment bound phosphorus in algal growth and eutrophication has been reviewed by Kramer et al. (1972) and Lee (1973). Soluble polyphosphates are regarded as completely available for algal growth, but are rapidly converted to orthophosphorus (Frere 1976). Phosphorus has been consistently found to be almost totally sediment bound rather than dissolved in surface runoff (Reddy et al. 1978). The bulk of phosphorus is transported to surface water by sediment transport during runoff. However, depending on timing of application and phosphorus content of surface vegetation and organic residues, soluble phosphorus losses in surface runoff may be relatively high (Anderson et al. 1989).

Depending on sediment composition, recent studies suggest that 10 to 20% of sediment bound phosphorus is available for algal growth (Taylor and Kilmer 1980). Sediment low in phosphorus will usually remove phosphorus from solution. When sediments have high concentrations of adsorbed phosphorus, some phosphorus will be released to solution. Water quality criteria for phosphate - phosphorus (PO_4^{3-}) have not been established. Average PO_4^{3-} concentrations of 25 ug L^{-1} and entry values of 50 ug L^{-1} in lakes and reservoirs are considered the upper limits for protection against biological nuisances (Koehler et al. 1982a).

The complex role of nitrogen in aquatic systems is difficult to quantify (Keeney 1982). In addition to nonpoint sources of nitrogen, natural fixation of nitrogen by algae and current inputs of atmospheric nitrogen may provide sufficient nitrogen to offset management reductions of nitrogen inputs. Total nitrogen concentrations as low as 1 - 2 ppm will support prolific algal growth when other conditions are satisfied. As with phosphorus, establishing water quality criteria to control nitrogen induced eutrophication of surface waters has been difficult. The maximum permissible nitrate-nitrogen concentration in domestic water supply is 10 ppm.

3.2.6 *Nitrogen: Chemical Properties*

Nitrogen is one of the essential plant nutrients required in substantial amounts to maintain adequate crop growth. Nitrogen is contained in turfgrass protein, nucleic acids, and protoplasm. It is absorbed by turfgrass primarily through the roots as ammonium (NH_4^+) or as nitrate (NO_3^-). Nitrogen promotes above ground vegetative growth, regulates phosphorus and potassium uptake, and turfgrass color (Beard 1973). Oversupply of nitrogen delays maturation, causes stem weakness, possible accumulation of thatch, and increases nitrogen available for offsite transport to surface water and groundwater (Aldrich 1984; Keeney 1983; White and Dickens 1984).

One of the guiding principles of sound nutrient management is to provide sufficient nutrient to meet turfgrass needs while minimizing surface and subsurface losses.

The chemical form of the different nitrogen species determines the mode of nitrogen transport from the field to surface water or groundwater. The inorganic forms in soil and water include nitrate, nitrite, ammonium, N_2O and N_2. Nitrate is chemically unreactive in dilute solutions and has a relatively low tendency to form complexes with dissolved metals or to sorb on the surface of soil colloids.

The high solubility of nitrate in soil solutions make it particularly susceptible to subsurface leaching and surface transport in the solution phase of runoff (Nielson et al. 1982). Once past the zone of biological activity at the soil surface, there are few mechanisms that will attenuate the transport of nitrates to groundwater. Limited levels of denitrification have been observed in the lower portion of the vadose zone and groundwater. Although initial infiltration during storm events generally leach nitrates in beyond the surface zone, changing form and application techniques, amount of thatch, root uptake activity, and incorporation practices will affect the levels of nitrate lost in surface runoff (Koehler et al. 1982a; Petrovic 1990).

Over 90% of nitrogen occurring in the surface layer of soils is in the form of organic nitrogen (Volk and Loeppert 1982). Organic nitrogen is directly available for release into soil solution, but has a microbially mediated exchange with inorganic soil nitrogen through the processes of mineralization and immobilization. Organic nitrogen is a component of all phases of soil organic matter including humin, humic and fulvic acids and is often the primary form of nitrogen in surface runoff (Frere 1976).

3.2.7 *Phosphorus: Chemical Properties*

Phosphorus and nitrogen combined are the two most critical nutrient elements required for turfgrass development. Phosphorus is a key element in plant RNA and DNA molecules and an integral component of plant energy reactions, photosynthesis, and respiration mediated through phosphorylation and conversion of adenosine triphosphate (Munson 1982). Low phosphorus concentrations generally result in delayed maturity, reduced yields, and stunted leaf growth (Munson 1982). The addition of phosphorus fertilizer to deficient soils generally enhances plant productivity. The importance of phosphorus in agriculture has been reviewed by Fox (1981) and Khasawneh (1980). Use of phosphorus in turfgrass has been reviewed by Beard (1973, 1982) and Wilkinson and Mays (1979).

Sources of phosphorus include geological and soil minerals, commercial fertilizer, animal manures, plant residues, and waste materials. Phosphate concentrations in soil solution are

usually quite low, ranging from 0.01 to 0.1 ppm, although total soil levels may range from 100 to 1000 ppm (Anderson et al. 1989). During soil development, phosphorus is initially derived from parent material in inorganic form. As organisms become established, requiring phosphorus as a nutrient, it becomes immobilized in biological tissue. Phosphorus is taken up by plant roots as the orthophosphate form ($H_2PO_4^-$ or HPO_4^{2-}). When organisms die, phosphorus is released. The conversion of organic forms to inorganic is the mineralization process.

In solution, inorganic orthophosphate is subject to several chemical reactions that reduce solubility and availability (Sample et al. 1980). Although soils vary considerably in their ability to retain or adsorb phosphates, phosphate availability in soil decreases exponentially over time (Anderson et al. 1989). Precipitation reactions, adsorption on mineral surfaces, and retention by soil constituents will immobilize more than 50% of soluble phosphate within a few hours of application (Sample et al. 1980). Rapid retention of initially soluble phosphates accounts for observation of low concentrations in soil solution (Frere 1976; Sample et al. 1980).

Given the uncertainty of phosphate chemistry in soil and the dynamics of the phosphorus cycle; few generalities are possible in regard to the state of phosphorus in soil (Anderson et al. 1989). Phosphate (PO_4^{3-}) is the only stable oxidation state of inorganic phosphorus under a wide range of soil conditions. In the pH ranges commonly encountered in soils, PO_4^{3-}, HPO_4^{2-}, and $H_2PO_4^-$ are the predominant forms of inorganic phosphorus. In acid soils the concentrations of these species are governed by solid phases of Fe and Al, while in alkaline soils, solubility is governed by calcium phosphate solid phases.

Except for very coarse textured soils, phosphate fixation is significant. Both Langmuir and Freundlich adsorption isotherms have been used to describe phosphate adsorption reactions by soil (Sample et al. 1980; Stuanes 1984). The Langmuir model implies that all increments of adsorbed phosphorus have the same surface bonding energy and that the surface reaches a maximum coverage with respect to adsorbed phosphorus. The Freundlich model implies that the energy of adsorption decreases with increasing levels of added phosphate and that no maximum is reached, a condition commonly observed in soils (Olsen and Khasawneh 1980). The Freundlich model is often incorporated into transport models for describing phosphate adsorption (Mansell et al. 1985).

Although successful for site specific analysis and use in assessment of localized waste treatment, isotherms tend to oversimplify phosphate dynamics. Equilibrium techniques tend to neglect the influence of changing solution pH, oxidation-reduction potential, and speciation on adsorption maxima of phosphates. Adsorption isotherms assume that phosphate adsorption is achieved under equilibrium conditions and is completely reversible, conditions rarely met in natural systems (Barrow and Shaw 1975). Combinations of kinetic and transport models may eventually have better success in describing the fate of phosphate in soil (Enfield and Ellis 1983).

Biological immobilization of phosphorus fertilizers in soil organic matter and organic forms of soil phosphorus have been reviewed by Alexander (1977) and Anderson (1980). Naturally occurring organic forms of phosphorus include a wide range esters, inositol phosphates, nucleic acids, and phospholipid. Net mineralization of organic phosphorus does not occur until phosphorus constitutes about 0.2 to 1% of organic carbon content and 5 to 20% of the organic nitrogen content (Alexander, 1977). Mineralization is favored by conditions that encourage microbial activity.

Phosphorus is rapidly retained as insoluble inorganic compounds and sorbed to soil surfaces, therefore soluble losses of phosphorus in subsurface flow and runoff tend to be quite low. Offsite transport of phosphorus tends to be associated with sediment erosion (Taylor and Kilmer 1980; Koehler et al. 1982b).

3.2.8 *Nutrient Losses from Turfgrass Systems*

Nitrogen will escape from local nutrient cycling systems in turfgrass through a) gaseous processes including volatilization of applied fertilizer and denitrification; b) leaching from the root zone; and 3) surface runoff. Subsurface and surface runoff transport of soluble and sediment bound phosphorus are the primary mechanisms of phosphorus loss from turfgrass systems. Removal and offsite disposal of grass clippings is potentially another significant source of nutrient loss from the turfgrass nutrient cycle.

Nitrogen Loss Through Subsurface Drainage

The general process and description of subsurface transport of soil nutrients and solutes have been extensively reviewed by Davidson et al. (1983), Ellis et al. (1983), Enfield and Ellis (1983), Keeney (1982, 1983, 1986), Nielsen et al. (1982, 1983), Starr (1983). Several methods have been utilized to study leaching of fertilizer nitrogen. In most of these studies, it has been assumed that nitrate leached past the root zone will eventually move to the groundwater. This concept is true under conditions with minimal upward movement of water from below the root zone. A majority of studies determined the degree of fertilizer nitrogen leaching by adjusting the values for background leaching from unfertilized plots. Starr and DeRoo (1981) used ^{15}N to accurately determine the fate of applied nitrogen in turfgrass systems.

The degree of nitrate leaching from turfgrass systems is variable (Petrovic 1990). Some researchers report little or no leaching while others suggest leaching of 80% or more of applied nitrogen. Factors that influence the degree of nitrate leaching include soil type, irrigation, N source and rate, and season of application.

Soil texture has a direct effect on leaching losses of nitrate because of its influence on the rate and amount of water moving through the turfgrass system. On an irrigated site, Rieke and Ellis (1974) monitored the movement of nitrate in a sandy loam soil to a depth of 60 cm by periodic sampling. During the 2 year study, application of nearly 300 kg N ha^{-1} elevated nitrate levels

only in 2 of the 20 samples at the 60 cm depth. Elevated levels of residual nitrate were primarily observed in the top 30 cm of the plots. Applying the same amount of fertilizer in three applications showed similar results.

Sheard et al. (1985) observed that creeping bentgrass sand greens only lost a maximum of 2% of applied nitrogen in the drainage water after application of nitrogen at levels similar to Rieke and Ellis (1974). The results of leaching from a U.S. Golf Association specification putting green were somewhat higher. These greens have a minimum of 93% sand, a maximum of 3% silt and 5% clay, and an infiltration rate of at least 5 cm hr^{1}. Brown et al. (1982) noted that 22% of ammonium nitrate leached as nitrate in the drainage water when nitrogen was applied in February at 163 kg ha^{-1}. However, the results from a Florida study (Snyder et al. 1981) with bermudagrass sand greens revealed that average nitrate leaching loss from urea over a 2 year period was only 1% of the applied nitrogen. The mean nitrate concentration was only 0.2 mg L^{-1}, much less than the drinking water standard of 10 mg L^{-1}.

The information on nitrate leaching from cool and warm season grasses is more extensive. Brown et al. (1982) studying nitrate leaching from bermudagrass greens built with a sandy loam soil, found that 9% of the ammonium nitrate leached as nitrate from a single application of 163 kg N ha^{-1}. In the previously described study, Rieke and Ellis (1974) observed limited nitrate leaching in a sandy loam soil even at high application rates. Elevated nitrate concentrations were observed in the upper soil, but deeper leaching did not occur during the experimental period. Long term monitoring of the fate of nitrate was not reported. Starr and DeRoo (1981) also found little or no nitrate leaching into groundwater using ^{15}N techniques. They concluded that annual total application of ammonium nitrate at 180 kg ha^{-1} for fertilization of Kentucky bluegrass-red fescue turfgrass would not result in contamination of groundwater.

In a monitoring study of nitrate leaching beneath golf courses on the sandy soils of Cape Cod, MA, Cohen et al. (1990) observed a wide range of nitrate concentrations in groundwater. They observed a wide range of nitrate concentrations from less than 0.1 to 30 mg L^{-1}. Nitrate concentrations did not exceed the drinking water standard of 45 mg L^{-1} (10 mg L^{-1} nitrate-nitrogen). In general, decreased subsurface losses of nitrogen were directly related to decreased fates of application and use of slow release formulations.

Information on nitrate leaching from application of nitrogen fertilizer to fine textured turfgrass systems is more limited. In general, the studies were short term growth experiments that lack information regarding the long-term fate of field applied nitrogen. Nelson et al. (1980) studied the leaching potential of urea and isobutylidene diurea (IBDU) applied to Kentucky bluegrass underlaid with 5 cm of silt loam or thatch. Application of 253 kg urea ha^{-1} resulted in 32 to 81 percent of the applied urea to leach from the soil or thatch, respectively. Only 5 to 23% of the IBDU was leached. Nitrogen leaching losses from the thatch were lower than from the soil. Decreased leaching in thatch was probably due to its lower moisture retention capacity and subsequent inability to efficiently hydrolyze the applied IBDU.

The impact of the source and rate of nitrogen on the leaching of nitrogen has received considerable attention. In worst case scenario studies (sandy soils, high application rates, heavy irrigation), it has been shown that as the rate of nitrogen applied increases, the percent of total nitrogen leached decreases. However, the total amount of nitrate leaching on an area basis increases with increasing rates of application. Brown et al. (1977) observed that on putting greens containing root zone mixtures of 80 to 85% sand, 5-10% clay, and 10% peat, the percent of nitrogen from ammonium sulfate that leached decreased from 38 to 16% as the rate of nitrogen applied was increased from 24 to 98 kg ha^{-1}. However, the amount of nitrate that leached increased from 9 to 15 kg ha^{-1}. The volume of water and mass of nitrate lost by subsurface movement are the important factors related to the nitrate concentration in drainage water. Brown et al. (1977) also noted that when a fine sandy loam was used as a root zone mix, the percent of fertilizer nitrogen lost by leaching was reduced from 15 to 5% as the rate of applied nitrogen increased. With a finer textured root zone mix, it is important to note the amount of nitrate lost by subsurface movement on an area basis was basically unchanged with increasing nitrogen application rates.

Snyder et al. (1981) studied the nitrogen leaching potential from sand as influenced by the source and rate of nitrogen. At a low rate of 39 kg ha^{-1} applied bimonthly, very little leaching of nitrate was observed with any nitrogen source. The greatest leaching occurred with calcium nitrate as the source and only 2.9% of the total leached over a two year period. At a higher rate of nitrogen application (78 kg ha^{-1}) applied bimonthly, leaching losses of nitrate was 9 and 5% of the total applied from calcium nitrate and IBDU, respectively. Apparently at the higher application rate the amount of nitrogen from these two sources was applied in excess of turfgrass uptake capacity, soil sorption, or nitrogen lost to the atmosphere. The residual soil p42 nitrogen was available for leaching. Less than 1% of the nitrogen from ureaformaldehyde, sulfur-coated urea (SCU), and urea was last by subsurface movement. The mean concentration of nitrate found in the leachate was 2.4 and 1.4 mg L^{-1} for the calcium nitrate and IBDU, respectively. These concentrations are still well below the drinking water standard of 10 mg L^{-1}.

Sheard et al. (1985) monitored nitrogen in the drainage water from creeping bentgrass sand greens. They found only 1.2 and 2.0% of the applied nitrogen (293 kg ha^{-1} yr^{-1}) leached to the drainage water from greens fertilized with SCU or urea, respectively. The investigators also observed insignificant differences between nitrogen leaching from acid and alkaline greens when urea was applied. They attributed the lower leaching from urea to the greater ammonia volatilization on the slightly alkaline sands. Gross et al. (1990) observed limited leaching losses of nitrogen leached from turfgrass grown on sandy loam soil. Average nitrate-N concentrations in subsurface leachate ranged from 0 to 3.2 mg L^{-1} on plots fertilized with granular and liquid formulations of urea applied at 220 kg ha^{-1} yr^{-1}. However with an infrequent and fixed sampling protocol, the investigators may have missed significant leaching events associated with heavy precipitation.

Rieke and Ellis (1974) also assessed the subsurface movement of nitrate in relation to fertilizer rate and source. A sandy soil (91%) received 122 cm of rainfall plus supplemental irrigation the

first year and 83 cm the second. Four nitrogen sources were applied in the spring at eight times the normal rate, 378 kg ha^{-1}. Nitrate concentrations in the upper 30 cm of soil were high throughout the year. At the deepest sample, 45-60 cm, nitrate concentrations were significantly higher than the controls only one sampling day throughout the year. In this case it was noted that more nitrate leached from the ammonium nitrate, ureaformaldehyde, and IBDU than from activated sewage sludge.

Brown et al. (1982) studied the interaction of nitrogen source and soil texture on nitrate leaching from U.S. Golf Association specification bermudagrass greens with some irrigation. With root zone mixtures containing greater than 80% sand, leaching losses were 22% from ammonium nitrate, 9% from sludge, and less than 2% from ureaformaldehyde or IBDU. On greens constructed from sandy loam, the losses were 9% from ammonium nitrate, 1.7% from sludge, and <1% from IBDU or ureaformaldehyde. In an incubation study, Bredakis and Steckel (1963) observed that in the first 3 weeks after fertilization of turfgrass, inorganic sources of nitrogen resulted in higher amounts of residual nitrate in soil as compared to organic and slow release sources of nitrogen. Elevated levels of leachable nitrogen in soil, especially nitrate, increase the risk of subsurface losses of nitrogen from turfgrass.

Several reports discuss the effect of irrigation practices and the potential for leaching of fertilizer nitrogen. Morton et al. (1988) studied the effect of two nitrogen rates and two irrigation regimes on the leaching of nitrate from a Kentucky bluegrass-red fescue lawn. The nitrogen rate was typical of a moderate to high lawn fertility program of 50% urea and 50% flowable ureaformaldehyde applied at 98 and 244 kg ha^{-1} yr^{-1}. Two irrigation regimes were used. The first regime applied 1.2 cm of water when the tensiometer readings reached -0.05 MPa. The second regime applied 3.75 cm of water per week. The first irrigation treatment, irrigation on the basis of soil moisture status, did not result in water drainage out of the root zone. The second irrigation treatment, irrigation on a fixed schedule, did result in subsurface drainage of water. The first irrigation regime did not cause a significant increase in nitrogen leaching for either nitrogen source. Irrigating at the higher rate did result in measurable leaching losses of nitrogen, although the observed nitrate levels were still well below the drinking water standard.

Snyder et al. (1984) studied the interactive effect of irrigation and nitrogen source on seasonal nitrogen leaching from sand under bermudagrass. Ammonium nitrate and SCU were applied at 98 kg ha^{-1} to plots that were irrigated either on a fixed daily schedule or by tensiometer activated irrigation. Nitrogen was also supplied in the irrigation water, a fertigation treatment. The percent of applied nitrogen leached ranged from 0.3 to 56 percent. The level of subsurface loss of nitrogen was highly influenced by nitrogen source, irrigation schedule, and season. The greatest leaching occurred in February and March, less in April and May, and the least in June and July. The decline in leaching was attributed to increased plant growth and evapotranspiration. In every case, leaching of nitrogen was greater from the daily irrigated plots compared to the tensiometer sensored plots. Generally, leaching was greater from plots treated with ammonium nitrate than SCU.

Brown et al. (1977) also evaluated the effect of nitrogen source and rate of irrigation on leaching. Irrigation had little effect on nitrate leaching from plots treated with very high rates of nitrogen from sludge or ureaformaldehyde. When ammonium nitrate was applied, however, substantial increases in nitrate movement occurred.

In a study comparing surface and subsurface irrigation, chemigation practices, and sources of nitrogen, Mitchell et al. (1978) monitored nitrogen concentrations in drainage water from creeping bentgrass greens. The observed pattern of nitrogen movement was similar for the surface and subsurface irrigation systems, but concentration of nitrate and ammonium in drainage water was generally higher from greens fertilized through the subsurface irrigation system. The low initial cost of nitrogen applied through a subsurface irrigation system should be balanced against the high rate of subsurface nitrogen losses. Solubility of nitrogen source did influence the pattern and total losses of nitrogen. Compared to slow release forms of nitrogen, soluble sources of nitrogen had greater and more rapid losses of nitrate in drainage water. Activated sewage sludge and anhydrous ammonia with nitrapyrin were the slow release formulations of nitrogen. A solution of urea (15%) and ammonium nitrate (15%) was the soluble formulation. Immediately after application of the soluble nitrogen formulation, the concentration of nitrate in drainage effluent (96-109 mg L^{-1}) temporarily increased to a level well above the drinking water standard for nitrate (45 mg L^{-1}). Peak nitrate concentration from greens fertilized with anhydrous ammonia and anhydrous ammonia with nitrapyrin was delayed by two weeks. The delay in release of nitrogen resulted in greater concentrations of nitrate (126-148 mg L^{-1}) in the effluent water. The onset of dormancy may have decreased the ability of the bentgrass to utilize the slowly released nitrate. Overall, the level of nitrate in drainage water was more closely related to environmental conditions favoring nitrification of residual and added nitrogen than to the sources of nitrogen, green mix, or timing of application.

The season at which the nitrogen is applied has a direct effect on leaching potential. Leaching can be significant during periods of low temperature and high precipitation. Cool temperatures reduce denitrification and ammonia volatilization, limit microbial immobilization and plant uptake. Since evapotranspiration is also low, with relatively high precipitation, more subsurface drainage occurs. In a ten week growth chamber study, Mosdell and Schmidt (1985) determined leaching potential from pots of Kentucky bluegrass containing a silt loam soil. At cool temperatures leaching occurred only from IBDU treated soils and at higher temperatures both the IBDU and ammonium nitrate treated soils leached nitrate. However, the levels never exceeded 3% of the total nitrogen application.

Late fall fertilization of turfgrass with nitrogen has become an important nutrient management practice for cool season grasses (Street 1988). If nitrogen uptake by turfgrass does not continue through this period, there will be high potential for nitrate leaching. When applied in the fall, Petrovic et al. (1986) found that soluble nitrogen sources such as urea can lead to significant nitrate leaching. Depending on site characteristics, estimates of nitrogen leaching ranged from 21 to 47 percent of applied soluble nitrogen. On gravelly sand, there was more nitrate leaching from urea than from sludge or SCU.

The use of computer simulation for assessing subsurface movement of nitrogen at the site is discussed in the modeling section of this report.

Nitrogen Loss Through Surface Runoff

The generalized process of surface transport of nutrients and pesticides was described in Section 2.3.1. Nutrients lost in runoff include dissolved, suspended particles, and those adsorbed on sediment. These nutrient phases all potentially move in water from fertilized land surfaces (Anderson et al. 1989; Daniel et al. 1979; Koehler et al. 1982a, 1982b). Runoff occurs when precipitation, less interception, exceeds the rate of infiltration. Surface applied nutrients are dissolved in runoff water and transported on the surface of entrained sediment (Keeney 1983; Taylor and Kilmer 1980). Initial extraction and movement of nutrients from the soil surface layers is controlled by 1) diffusion and turbulent movement from soil pores and surfaces to runoff; 2) desorption of nutrients on soil exchange sites; 3) dissolution of fertilizer granules; 4) entrainment of undissolved fertilizer elements into runoff; and 5) entrainment of organic and inorganic nutrients adsorbed to soil particles moving on eroded sediment in runoff water. The amount of fertilizer lost in runoff is determined by a combination of factors including: 1) the volume of runoff water; 2) the timing, amount, and placement of fertilizer in relation to subsequent runoff events; and 3) the magnitude of immobilization, adsorption, volatilization, and cycling processes.

The EDI, effective depth of interaction, is the thickness of the surface soil in which the degree of chemical and physical interaction between soil and runoff is equal to the interaction at the soil surface. The EDI is the depth in the soil that is subject to extraction of nutrients by runoff processes. Sharpley (1985a) observed a range of 1.3 to 37.4 mm for the effective depth of interaction between runoff water and adsorbed chemicals. Both Ahuja et al. (1982) and Sharpley (1985a) demonstrated a direct relationship between rainfall intensity, slope, soil structure and runoff energy with the depth of the active mixing zone. The amount of surface cover or crop residue was inversely related to the EDI. Rainfall intensity, slope, soil structure, and surface residue affect the energy of runoff. Runoff energy is directly related to the amount of sediment transport and depth of interaction for solution transport of nutrients. Accurate EDIs have not been estimated for turfgrass systems. Considering the limited sediment and soluble losses of nutrient from natural grasslands and unfertilized pastures (Anderson et al. 1989), the depth of interaction for developed turfgrass should be quite small.

When fertilizer nitrogen or phosphorus is applied to any site, there is potential for some to runoff into surface waters. A limited number of studies have investigated this process in turfgrass systems. In a two year field study in Rhode Island, Morton et al. (1988) observed only two natural events that resulted in runoff of any water. One was from frozen ground and the other from plots that received 12.5 cm of water in one week. The runoff drainage was noted to contain a concentration of nitrate from 1.1 to 4.2 mg L^{-1} for the two events. In another study investigating the impact of source, rate, and soil texture, Brown et al. (1977) observed only one case of nitrate concentration in runoff water from turfgrass exceeding the 10 mg L^{-1} drinking water standard.

In an unpublished thesis from the Pennsylvania State University, Harrison (1989) observed low runoff volumes and nutrient concentrations from irrigated lysimeters of Kentucky bluegrass grown on clay soil. Concentrations of soluble-nitrogen and soluble phosphorus in runoff rarely exceeded 5 mg L^{-1} and 2 mg L^{-1}, respectively.

Gross et al. (1990) also observed limited soluble and sediment losses of phosphorus and nitrate in runoff from Kentucky bluegrass plots fertilized at a rate of 220 kg N ha^{-1} yr^{-1}. The maximum loss of nitrogen in runoff was observed when a runoff event occurred the day after fertilization. However, the loss of nitrogen in the surface runoff was less than 0.1 percent of the applied granular formulation of urea. A large portion of soluble-nitrogen losses in runoff water occurred when a significant precipitation event occurred shortly after fertilizer application. Total and soluble losses of phosphorus were not significantly different between fertilized and control plots. Significant losses of phosphate for a liquid treatment was associated with high amounts of runoff from the turfgrass plots in December. This loss accounted for 73 percent of total runoff losses of phosphorus. Timing of fertilizer application to avoid precipitation and runoff events will reduce potential surface losses of nutrients.

3.2.9 *Nutrient Loss at the Site*

On the basis of the review of the scientific literature and site specific information, nitrogen, and in particular, nitrate, is the nutrient that would pose the most serious threat from an environmental impact and water quality perspectives. Several conclusions can be inferred:

1. Nitrogen (N) is a relatively easily managed component at the site. It is expected that N fertilization at the site will entail use of relatively insoluble (slow-release) materials for fertilization of turf. Application will be based on initial soil test results, turf requirement, and turf condition throughout the year. TMS strategies will reduce both luxury consumption of N and subsurface leaching. If industrial or municipal effluent are available, these could be used as both a source of water at the site and as an additional source of nitrogen. Application of soluble N compounds for "quick" green up is not recommended.
2. If nitrogen residues are present in a soluble form above a concentration that can be used by the turfgrass and if water moves through thatch or soil, leaching of nitrogen past the root zone can occur. If the nitrogen is not in a soluble form, such as IBDU, leaching losses of nitrogen are significantly reduced.

3. Increasing the rate of nitrogen application to highly sandy greens will lead to a deterioration in drainage water quality. On sandy loam greens, increased nitrogen fertilization commensurate with uptake capacity of specific turfgrass species should not

further reduce water quality.

4. Late fall is a common time for nitrogen fertilization. However, the agronomic benefits derived from this practice may be lost by the adverse environmental impacts in areas with vulnerable groundwater characteristics. Heavy fall fertilization is to be avoided.

5. Establishment of turfgrass at the site will result in soils with a high infiltration capacity thereby reducing the potential for nutrient loss and subsequent water quality deterioration by runoff. Numerous studies demonstrate that runoff of water from turfgrass is limited. Even on sites with 9 to 12 percent slopes with silt loam soil, runoff loss of N is rarely observed. It should be noted that high rates of infiltration will reduce surface runoff, but in exchange the rates of subsurface movement of water is increased. Timing of fertilizer application against the needs of the grass will reduce or eliminate subsurface leaching.

6. The leaching of fertilizer nitrogen applied to turfgrass at the site will be related to: soil texture and degree of conductivity of soil water; the amount of subsurface movement of water; nitrogen source, formulation, rate, and timing; and irrigation and rainfall. Significant leaching of nitrate will occur when soluble nitrogen is applied at a rate higher than normal on turfgrass grown on sandy soil. The potential for subsurface loss of nitrogen is further increased when the turfgrass is irrigated at a rate in excess of plant use, evapotranspiration, and soil storage.

7. If fertilization of turfgrass at the site does pose a threat to surface water and groundwater quality, several management options are available to minimize or eliminate the problem. Limiting irrigation to replacement of soil moisture used by the cover, use of slow release sources of nitrogen, and less sandy soils would significantly reduce or eliminate nitrate leaching from turfgrass. Timing of fertilizer application in relation to active uptake and potential runoff events as well as the use of realistic nitrogen application rates are primary methods to reduce nonpoint source losses of nitrogen from turfgrass systems. These recommendations are clarified in the Turf Management System.

8. Phosphorus (P) fertilization will not pose a groundwater quality threat at the site. The soils of the area have an extremely high P adsorption capacity which will prevent subsurface leaching. Fertilization will be based on soil test results and turf requirement. Phosphorus enrichment of catchments and waterways in the vicinity of the proposed course could occur during construction phase where bare soil could be exposed to erosion. This will be minimized or eliminated by using barriers (fences) or other trap devices for preventing offsite movement of soil lost during excavation or grading activities.

3.3 Selection of Candidate Turfgrasses

3.3.1 *Warm Season Turfgrasses*

Warm season turfgrasses are those species having a temperature optimum of 80 to 95°F. They are widely distributed throughout the warm humid, warm subhumid, and warm semiarid climates. The winter temperature is a very important influence on the distribution and use of warm season turfgrasses. Approximately 14 warm season species are utilized for turfgrass purposes throughout the world.

A general comparison between such cool season turfgrasses as the bluegrasses, fescue and ryegrasses and such warm season turfgrasses as bermudagrass and zoysiagrass reveals the following general differences. The low growing, warm season turfgrasses are substantially more tolerant of close mowing; are deeper rooted; and are more drought, heat, and wear tolerant as a group than the cool season turfgrassses. However, the former are less temperature hardy and will discolor at low temperatures. Most of the cool season species are seeded while most of the warm season species are established vegatatively. Of the different potential warm season grasses, it is likely that the best candidates for the proposed golf course at the site would be bermudagrass or Zoysiagrass. Bermudagrass appears to be the most likely candidate since the it is native to the area and hence expresses adaptability to the climatic/soil/environmental conditions of central Oahu. A comparison of the two types of turfgrasses is presented in the following Table.

Bermudagrass is best adapted to moderately well drained, fertile soils of relatively fine texture but will tolerate a wide range of soil types. Bermudagrass growth is usually better on fine textured than coarse textured soils because of the higher fertility level and soil moisture retention associated with fine textured soils. Bermudagrass tolerates a wide range in soil pH (usually 5.5 to 7.5). Salt tolerance is also quite good.

3.3.2 *Use*

The improved bermudagrasses form a very dense, uniform turf of high quality when grown under proper conditions (climatic and cultural). It is utilized in the warm humid regions on lawns, parks, golf courses (fairways, greens, tees, roughs), roadsides, airfields, athletic fields, general lawn areas. It is especially suited for golf courses due to its excellent wear tolerance and recuperative potential.

TABLE 3.3-1 COMPARISON OF BERMUDAGRASS AND ZOYSIAGRASS

Characteristic	Bermudagrasses	Zoysiagrasses
Plant description:		
leaf texture	Fine	Medium to fine
shoot density	High	Medium to high
Growth Habit	Rhizomes and stolons	Rhizomes and stolons
Seed Head	Short, few to numerous	Short and minimal
Adaptation:		
heat hardiness	Excellent	Excellent
low temperature hardiness	Poor	Poor to intermediate
drought resistance	Excellent	Excellent
shade tolerance	Very poor	Good
soil adaptation	Wide range	Wide range
salt tolerance	Good	Good
wear tolerance	Very good	Excellent
Establishment		
method	Vegetative	Vegetative
rate	Excellent	Poor
recuperative potential	Excellent	Excellent, but slow
Culture:		
intensity	High to medium	Medium
cutting height (in)	0.25-1.0	0.5-1.0
mower type	Reel	Reel
nitrogen needed (lb/1000sqft/month)	0.8-1.8	0.5-1.0
thatching tendency	High	Medium to high
Pest:		
diseases	Brown patch, dollar spot, spring dead spot, Helminthosporium	Brown patch, dollar spot, rust, Helminthosporium
insects	Sod bedworms, armyworms, mole crickets, bermudagrass mite, fruit fly	Hunting billbugs, army worms, mole crickets, sod bedworms
other	Nematodes	Nematodes

3.3.3 *Culture*

Bermudagrass does require a medium to high intensity level of cultivation. Tolerance to close mowing is good because of its prostrate growth habit. Since bermudagrass is responsive to fertilization and irrigation, a high intensity of culture is generally needed to obtain optimum turfgrass quality. Bermudagrass is quite prone to thatching because of the vigorous growth rate. Common disease problems of bermudagrass include Helminthosporium, brown patch, dollar spot, Fusarium patch, Pythium blight, and spring dead spot. Common pests include sod bedworms, armyworms, mole crickets, mites, fruit flies, and nematodes. It is also intolerant of the triazine herbicides.

3.3.4 *Cultivar Selections*

Several possible cultivars could be used at the site. For example, fairways and tees could be composed of Tifway bermudagrass, while greens could be composed of Tidwarf or Tifgreen cultivars. Some of the characteristics of these cultivars is noted below.

TABLE 3.3-2 COMPARISON OF CULTIVAR CHARACTERISTICS

Cultivar	Characteristics	Use
Tidwarf	Dark green color, fine texture, high shoot density, slow growth rate. Medium culture intensity.	Improved shade tolerance, superior tolerance to low mowing, used on greens.
Tifgreen	Dark green color, very fine texture, high shoot density, high intensity culture.	Excellent drought and wear tolerance, good recuperative potential, prone to 2,4-D injury, used on greens.
Tifway	Dark green, medium texture, high shoot density, vigorous growth, prone to thatching.	Used widely on fairways and tees.

Based on this initial assessment, we would probably recommend Tidwarf for use on greens, since selection of a cultivar that can be maintained with lower inputs of fertilizer and pesticide is a desirable quality from an environmental perspective. If the course were in an a more arid region, we would have selected the more drought tolerant Tifgreen cultivar.

3.3.5 *Use of Zoysiagrass at the Site*

Zoysiagrass forms a uniform, dense, high quality turf with excellent drought and heat hardiness. It grows well on soils similar to those of the site (moderately acid to neutral with fine texture and moderate to excellent drainage characteristics). It also exhibits excellent salt tolerance. Its most desirable feature for this site, would be the moderate level of cultivation required to maintain high quality. Its N requirement is much lower than bermudagrass (roughly one-half to two-thirds) and as such may be used in buffer strips, in areas around sandtraps, and even around the aprons of bermudagrass greens. Zoysiagrass is also free of major disease problems relative to the other turfgrasses. As such it could be used in many areas on the course to decrease the overall input of water, fertilizer and pesticide at the proposed golf course site.

3.4 Integrated Turf Management System (TMS)

3.4.1 *Concept of Integrated Management Systems for Turfgrass*

Management of water, nutrients, pests, and diseases is essential for production and maintenance of high quality turfgrass on golf courses. Depending on the intensity of golf course management, several potentially adverse environmental impacts have been identified in other sections of this report. These effects include: 1) contamination of surface water and groundwater resources with nitrates and residual pesticides; 2) contamination of surface water with sediment during construction and interference with natural drainage systems; 3) actual and perceived health effects on humans, wildlife, and other nontarget organisms; 4) development of insect and disease populations resistant to currently used pesticides.

Reduction in the use of pesticides, fertilizers, and irrigation water is not a direct economic issue to many golf course managers. However, the perception that these materials as well as construction and cultural have adverse effects on the environment has led to concerns about their use and to intense opposition to the construction of new golf courses. This has made it essential that golf course architects, developers, and managers consider programs designed to reduce water use and adverse environmental effects. These actions will reduce potential financial losses resulting from litigation, detrimental publicity, construction delays, and loss of permits for development of new golf courses in addition to the positive environmental quality benefits (Cohen at al. 1990; Grant 1989; Leslie 1989a).

It is relatively easy to identify environmental issues. It is much more difficult to develop economically feasible systems to mitigate or resolve environmental problems related to turfgrass management. The systems approach to turfgrass management and to reduction of potentially adverse environmental effects requires a significant basic and applied research effort. Current initiatives in agricultural research are directed toward reduction of nonpoint source pollution problems in production agriculture. This research has focused on development of integrated crop management (ICM) systems (USDA 1989a, 1989b). Integrated crop management is an important conceptual expansion of integrated pest management (IPM) practices. ICM integrates all production factors in order to sustain long-term productivity, optimize yields and profitability, and maintain the integrity of the local ecosystem. Critical ICM factors include crop and cultivar selection; crop rotations; soil building practices; tillage systems; nutrient management; chemical, biological, and cultural pest management; livestock management; and soil, water, energy, and natural resource conservation.

The concepts originally developed for agricultural IPM programs have been suggested as a format for ecologically sound management of turfgrass pests (Potter and Braman 1991; Raupp et al. 1989). The implementation of ICM concepts for integrated management of turfgrass pests, nutrients, and water could be just as effective for reducing the perceived adverse environmental impacts associated with management of golf courses and other lawns. This integrated systems approach is defined as turfgrass management systems (TMS). TMS combines all water, cultural, nutrient, and pest management factors for sustained productivity of an acceptable level of quality for turfgrass, course profitability, and the integrity of ecosystems on and in the vicinity of the golf course.

IPM programs developed for turfgrass are a significant component of turfgrass management. However, traditionally defined IPM protocols are only a part of the expanded functional concept of TMS. Critical components of TMS include selection of 1) turfgrass species and cultivars; 2) soil management practices; 3) clipping and cultivation practices; 4) nutrient management; 5) irrigation and drainage management; and 6) chemical, biological, and cultural pest management. Conservation of soil, water, energy, and other natural resources during construction and maintenance of golf courses is one of the primary goals of TMS. The following discussion of TMS concepts are derived from research on turfgrass IPM programs and agricultural ICM systems. These programs may serve as a model for development of profitable and environmentally sound integrated systems for golf course management. Ultimately, the goal of TMS is to balance costs, benefits, public health, and environmental quality with acceptable levels of playability.

The principles of IPM are not new and were originally developed by Forbes (1880) over one hundred years ago. Many of the IPM concepts were practiced prior to introduction of wide-spectrum pesticides in the 1940s (Metcalf 1980). The IPM concepts of economic thresholds, chemical management, and biological control originally were systematized in the late 1950s by Stern et al. (1959). By the mid 1970s IPM was recognized as an economically and ecologically sound system for insect control in agriculture (Wearing 1988). Most agricultural scientists and many producers recognize that total reliance on broad spectrum insecticides, and even herbicides, is not necessarily the only effective pest management strategy (Allen and Bath 1980; Metcalf 1980; Leslie 1989b).

Intensive use and overuse of pesticides, fertilizers, and irrigation water in agriculture and turfgrass management are major factors in the rapid growth of interest in IPM and, more

recently, ICM (Leslie 1989a). The concept of IPM, ICM and TMS seeks to minimize the disadvantages associated with intensive nutrient, pesticide, and water inputs and to maximize the advantages of their use (Allen and Bath 1980; Leslie 1989c). Development of site specific TMS programs offers one of the few comprehensive solutions for systematic control of environmental problems related to management of ecosystems. These integrated approaches offer systematic options for selection of alternate control strategies and to maximize chemical efficiency. TMS does not preclude the use of pesticides and inorganic fertilizers when needed. The basic components of TMS are:

1. A system using multiple control methods.
2. A decision process based on intensive use of information.
3. A risk reduction system.
4. A cost effective and site specific management strategy (Table 3.7-1).

The operational strategies used for ICM programs in agriculture could be used as a model for expansion of turfgrass IPM concepts for development of TMS (Allen and Bath 1980; Metcalf 1980; Wearing 1988). Development of TMS programs should progress through three iterative phases: 1) basic and applied research, 2) development of field programs, and 3) implementation and economic assessment of field programs (Table 3.4-1). Utilizing a systems analysis approach will help avoid significant lag periods between initial research and final field implementation of TMS programs (Allen and Bath 1980). TMS combines pest and nutrient control, irrigation scheduling, other cultural practices, and golfer use patterns. When properly implemented, the systems approach will produce turfgrass programs that are economically feasible, profitable, and acceptable to turfgrass managers. Compatibility with the game of golf is another long-term objective in development of TMS for golf courses. All integrated management approaches should be compatible with long-term water quality, ecological, and societal goals (Dalton 1975).

Basic and applied research at an interdisciplinary level is currently required for development of practical IPM and TMS programs (Potter and Braman 1991). Limited initial research and pilot programs have shown that IPM systems in urban settings reduce overall use of insecticides without compromising the quality of turfgrass or landscape plants (Brown et al. 1989; Grant 1989; Raupp et al. 1989; Smith and Raupp 1986). However, broad scale effectiveness and acceptance of IPM and alternate control methods have yet to be demonstrated (Potter and Braman 1991). Interdisciplinary research, extension, and education programs are required to expand the current single or multiple pest control strategies on golf courses.

STAGES IN DEVELOPMENT OF TMS PROGRAMS

A. Basic and Applied Research

1. Generate or compile information on:
   a) ecology of turfgrass, weed insects, and diseases;
   b) nutrition;
   c) water relations; and
   d) cultural practices.

2. Conduct applied research to develop specific control techniques and related methods including breeding resistance, pest control strategies and modifications of existing cultural practices.

3. Conduct systems research to integrate nutrient and cultural requirements for quality turfgrass. Establish action thresholds.

4. Establish training and education programs.

5. Incorporate field results into research results.

B. Components of Field Programs

1. Define roles of all people involved.

2. Determine pest and nutrient objectives for specific areas on site (greens, tees, fairways, roughs etc.)

3. Establish action and economic thresholds for cultural practices, nutrient and pesticide use, and irrigation.

4. Monitor for nutrients, pests and diseases on a well defined, consistent schedule.

5. Use appropriate controls to reduce deficiencies and infestations.

6. Evaluate results of actions and maintain written records.

C. Implementation/Education/Assessment

1. Develop effective education programs for site specific conditions.
2. Disseminate education material.
3. Integrate information from basic research and field results.

Within 30 years, over 85 percent of the North American population will be concentrated in urban areas (Potter and Braman 1991). This urban population is likely to have a strong desire for quality turfgrass with minimum adverse effects on the environment. The growing concern for environmental quality and expanding urban populations should strongly motivate turfgrass researchers and managers to develop IPM and TMS approaches for golf courses and lawns. Greater research on the ecology of turfgrass and pests in relationship to water use, cultural practices, and fertility is needed to meet the objectives of integrated management programs (Potter and Braman 1991). Understanding the interrelationship of turfgrass management, pests, water, and nutrients requirements will reduce dependence on chemical control methods. Also, the enhanced efficacy of chemical treatments in a systems approach will reduce the frequency of chemical application and environmental loading of pesticides and fertilizers (Leistra and Green 1990).

3.4.2 Components of Integrated Management Systems (TMS) for Turfgrass

Development of economically feasible programs compatible with long-term environmental and societal goals is an essential ingredient for the success of IPM and TMS. The basic steps in development of site specific IPM programs for turfgrass management have been outlined by Leslie (1989b, 1989c). These IPM components should be expanded to a systems management level for TMS. Systems type research for ICM has been defined by recent water quality and environmental research programs (USDA 1989a, 1989b). Using ICM as a model, TMS has eight basic components.

System Component 1. Definition of the roles of all people involved in the management of turfgrass assures understanding of goals and promotes communication. Important individuals in development of TMS on golf courses are the superintendent, members of the green and golf committees, the golf professional, the golfers, and possibly adjacent landowners. During golf course design or improvements the golf course architect should be informed of site-specific conditions required for systematic development of TMS programs.

System Component 2. Establish objectives for realistic cultural, water, nutrient, and pest management of specific areas on the course. These objectives will serve as the basis for establishing control methods and action thresholds. Management of tees and greens will require different control strategies than for fairways and rough. Integration of cultural, irrigation, fertilization, and pest control methods is essential even for preliminary development of IPM and TMS programs.

System Component 3. Establish action thresholds based on regional research and prevailing economic conditions. In TMS programs, action thresholds are expanded beyond the traditional definition used for IPM practices. They are based on pest populations, turfgrass/soil nutrient tests, soil water conditions, soil and thatch physical properties, turfgrass playing conditions, and environmental conditions. All of these conditions indicate whether action must be taken to maintain turfgrass quality. No action, whether chemical, physical, or cultural is taken until the predetermined action point is reached. Actions are taken when the impact of pest populations or nutrient/water deficiency affect turfgrass quality sufficiently to threaten the biological and economic viability of the turfgrass. These effect levels are defined by TMS objectives.

System Component 4. Monitoring the golf course for climatic conditions, soil condition, pest populations, and turfgrass quality on a periodic and consistent basis determines when the action thresholds are reached. Monitoring also may be used to determine whether a specific set of practices has been successful. Monitoring and identification of pests and deficiencies is the cornerstone of integrated management technologies. Use of automatic monitoring equipment, innovative identification techniques, climatic phenological indicators, and use of computer simulation models provide assistance in determining when action thresholds have been reached (Fermanian and Michalski 1989; Fermanian et al. 1989; Miller et al. 1989; Nyrop et al. 1989; Snyder et al. 1984; Vargas et al. 1989; Villani and Wright 1988a).

Potter and Braman (1991) have suggested that simple, reliable, and cost effective monitoring techniques other than visual inspection are lacking for pest control. Survey techniques based on research include direct soil sampling; flotation; irritant drenches; pit-fall traps; sound, sweep, suction, food, and pheromone sampling traps; and heat extraction (Potter and Braman 1991). Direct insect population survey techniques are suitable for research, but are too time consuming and destructive for practical use on golf course and lawn turf. The utility of current monitoring techniques is further compromised by the lack of established damage or action thresholds (Potter 1986). Additional research on the ecology of turfgrass and turf pests is needed to establish the relationship of the distribution of pest populations, turfgrass quality, and sample strategies.

System Component 5. Specific management practices to suppress pest populations, reduce nutrient and water deficiencies, or maintain turfgrass quality for playability should be selected from a range of options. Depending on site specific conditions, management options include physical, cultural, biological or chemical treatment. Habitat modification and understanding the relationship of nutrient, water, and climatic conditions is especially important for control and prevention of conditions conducive to pest and disease infestations. Use of alternate nutrient and pest control options should always be considered. Alternate biological and cultural options are discussed in the following section.

System Component 6. Chemical usage. When necessary, appropriate chemical control, alternate control, irrigation, or cultural action should be taken. Preferred chemical practices would reduce movement of the applied chemical off the target site, provide maximum contact with the intended pest (pesticide) or root system (fertilizer) while presenting the least possible hazard to non-target organisms. Chemicals should be applied on the basis of need. Fertilizers should be applied during periods of active uptake (growth) and pesticides should be applied when the pest or disease is in its most vulnerable life stage. Calendar, global broadcast, and preventative

applications are not always consistent with integrated systems, economic, environmental quality, or societal goals.

System Component 7. Maintaining written records of course management objectives, monitoring methods, data collection, management actions, and the results of management practices is essential for evaluation of TMS and development of future plans.

System Component 8. Evaluation of the results of pest habitat alteration, pesticide application, use of alternate control options, fertilization, and water management (irrigation/drainage) should be conducted periodically to assess the success of the TMS program. The results of the evaluation are used to modify the initial program to meet changing environmental, cultural, and pest conditions. Flexibility and economic feasibility ultimately determine the long-term success of TMS (Smith and Raupp 1986; Wearing 1988).

Management Guidelines in TMS for the Wahiawa Development

Selection of appropriate chemical practices for nutrient and pest management is an essential component of TMS (Metcalf 1980; Leslie 1989b). Continued availability of both multicomponent chemical and nonchemical control strategies are necessary to avoid future pest resistance, pest resurgence, and to maintain turfgrass health and quality. The aesthetic standards for turfgrass in North America are so high that even limited insect and disease damage is considered intolerable (Beard 1982; Potter and Braman 1991). Despite advances in alternate control strategies, application of insecticides and fungicides may still be the only effective response to heavy infestations of insects and disease (Leslie and Metcalf 1989; Potter and Braman 1991). Pesticides and fertilizers can be applied using management practices to reduce adverse water quality and environmental effects. Many of these practices have been proposed for use in agricultural, urban, and turfgrass systems (Anderson et al. 1989; Metcalf 1980, 1989, Leslie 1989c).

The following discussion of management practices is intended as an outline of general principles that should be incorporated at the site. Specific management of pesticides and fertilizers must be designed based on site specific conditions, as well as federal, state, and local regulations. Managing the type, amount, formulation, placement, and timing of pesticide and fertilizer applications will help to accomplish pest control, nutrient, water quality, and environmental goals. The following methods have been considered useful in meeting agronomic and environmental goals (Anderson et al. 1989; Koehler et al. 1982; Leslie and Metcalf 1989; EPA 1988; Metcalf 1980, 1989; Pratt 1985; Stewart et al. 1975; Smolen et al. 1984; Walker et al. 1990). The critical principles of pest management consistent with TMS concepts are:

1. Label. Only pesticides specifically labeled for application should be applied; and then only by properly registered, certified, and trained personnel. All pesticide use should comply strictly with local, state, and federal regulations. Following label recommendations,

obtaining certification to apply pesticides, and training in the appropriate pesticide application techniques are essential components for continued use of pesticides in TMS.

2. Selection criteria for the type of pesticide should include consideration of the target species or disease, pesticide characteristics, and site characteristics. Important pesticide properties include efficacy, solubility, formulation, degradation rate, volatility, adsorption, potential toxicity to natural pest enemies, and toxicity to wildlife, nontarget or beneficial organisms. Critical site characteristics and soil properties related to pesticide efficacy and fate are soil texture and organic matter content, local and regional geology, depth to groundwater, proximity to well heads and surface water, topography, and climate. Pesticides that minimize the pollution potential should be selected.

Site Recommendations:

- Construction phase: Since the site has been under intensive crop production it possible that pesticides injurious to the proposed turf (bermudagrass) may have been used. All records concerning the application of pesticides, frequencies and amounts should be recovered from Del Monte. If topsoil is brought in for green construction, then a fumigant may be needed. Based on pesticide history at the site, a pre-emergent pesticide may be necessary during construction. In general, it would be advisable to avoid this practice.
- Maintenance phase: Pesticide selection should be based on criteria noted above and after consultation with experts from the University of Hawaii Cooperative Extension and the Golf Course Supervisor.

3. Reducing the frequency of pesticides applied to turfgrass may be the single most effective practice to reduce potential adverse environmental effects.

4. Selection of less toxic, less mobile, and less persistent pesticides, or use of alternate control strategies will help reduce potentially adverse environmental effects. Depending on site characteristics, consideration of the potential mode of chemical loss could reduce environmental loading, potential for contamination of water resources, and adverse effects on non-target organisms.

5. Controlling the timing and amount of a pesticide application in relation to local environmental conditions, especially rainfall, determines the potential for offsite movement and degradation characteristics. Restricting application prior to anticipated storm events is effective in reducing surface and subsurface losses of pesticides. Loss of wildlife can

be avoided, in part, by restricting application of chemicals with high toxicity during critical migratory or lifestage periods. Selection of less toxic compounds during the period wildlife are using golf courses is another consideration in timing of applications.

6. Action thresholds permit control of pests within economic constraints and reduced levels of pesticides. Other factors to consider are the use of resistant turfgrass species and cultivars and TMS concepts. Applying pesticides only when and where necessary will significantly decrease chemical loading and adverse effects on the environment.

7. Selection of pesticide formulations also influences pesticide fate and losses. Wettable powders, dusts, and microgranules are generally most susceptible to surface and leaching losses.

8. Application methods influence the partitioning and potential effectiveness of pesticides. Proper application rates, equipment selection and calibration, and careful application to the target site will insure effective use of the applied pesticide. Spot applications will reduce the amount of chemical applied to turfgrass and limit total environmental loading.

9. Incorporation of pesticides, placement below the soil/thatch surface, and 'watering in' reduces exposure to runoff process and enhances soil adsorption.

10. Proper equipment maintenance and calibration is essential for even applications at the volumes intended by the user. All label instructions, storage requirements, and regulations must be followed to insure safe handling of pesticides. Proper mixing, handling, and loading prior to application will reduce fill-site contamination. Closed systems for loading and mixing pesticides are especially useful in reducing contamination of the site and nearby waters.

11. Proper disposal of unused chemicals and containers will ensure safety of the user, water resources, and non-target organisms. Pesticide applicators should avoid chemical exposure by safe handling practices including use of protective clothing, respirators, gloves, and shoes.

Site Recommendations:

- Specific recommendations pertaining to items 3-11 should be based on site conditions as they occur. A prescription approach to problem solving will result in an inflexible schedule that cannot incorporate new information or case by case assessments. Guidelines have been established for these concerns by the Golf Course Superintendents Association and can be incorporated based on the judgement of the Golf Course Supervisor. We have enclosed a set of pest control guidelines that offer suggestions for different problems that may arise. This kind of document can be developed with advice from local experts once the course design has been completed.

12. Chemigation. Use of anti-back-siphoning devices in chemigation equipment will reduce potential for pesticide contamination of groundwater or other water supplies during irrigation. Pesticides should be applied through irrigation equipment only when appropriate and when specific label instructions are available. Environmentally safe chemigation practices include: 1) flushing of injection equipment to prevent pesticide accumulation; 2) flushing the irrigation system after pesticide injection; 3) use of properly calibrated equipment; 4) preventing runoff of water-pesticide mixture; 5) avoiding application to permanent or semi-permanent standing water on or near fields; and 6) periodic monitoring of equipment to ensure proper application to the intended target.

13. Assessment of potential offsite transport of chemicals by runoff or leaching losses prior to application will provide essential information on selection of pesticides appropriate for a specific site. Computer models and qualitative indexes could be adapted for this approach (See Modeling Section).

14. Karst Topography. Application and handling of pesticides in regions of karst topography should be conducted with care to avoid movement of chemicals into fractures and sinkholes via surface runoff.

15. QA/QC. Development and implementation of quality control and quality assurance guidelines for pest management will ensure that TMS practices are used with reasonable accuracy by field personnel.

The critical principles of nutrient management at the site consistent with TMS programs are:

1. Using minimal rates of nitrogen and phosphorus to maintain nutrient levels needed to sustain turfgrass quality is one of the primary management practices used to minimize both surface and subsurface losses of nutrients.

2. Improved Efficacy. Decreased environmental loading of nutrients requires improvements in turfgrass uptake efficiency. This is achieved through a) selection of realistic goals for turfgrass quality; b) selection of application rates to meet these quality goals; c) use of soil and tissue tests to establish proper application rates; and d) use of nutrient application history or credits. Records of all forms and sources of nutrients applied to turfgrass is essential to determine rates of fertilizer application. Records of nutrient applications should include the types and amounts commercial fertilizers, clippings returned, effluent water used, as well as other organic sources such as compost and topdressing.

3. Timing. Application of nutrients at the times and amounts commensurate with turfgrass growth requirements is one of the single most important management practices used for reduction of offsite transport of nutrients and mitigation of adverse environmental effects. The optimum time of application depends on turfgrass species and cultivar, climate, soil conditions, and chemical formulation of the fertilizer. Application of nitrogen after turfgrass uptake of nitrogen has ceased may lead to possible surface and subsurface losses of nitrogen. In agricultural systems fall application of nitrogen for the next growing season remains controversial in cold moist climates (Beauchamp 1977; Keeney 1982, 1986; Pratt 1985). Considerable leaching and runoff losses of fall and winter applied fertilizer has been observed in pasture, forage and row crop systems (Anderson et al. 1989; Gilbertson et al. 1979; Kamprath 1973; Klausner et al. 1974; Koehler et al. 1982; Zwerman et al. 1971). Although, fall application nutrients has become an important turfgrass management practice (Street 1988), Petrovic et al. (1986) has shown that fall application of soluble forms of nitrogen (urea) can lead to significant nitrogen leaching. Fall applied inorganic nitrogen and residual soil nitrates are at risk of leaching past the root zone during the fall and early spring, especially on coarse texture or shallow soils (Keeney 1982; Pratt 1985). Fall application of nitrogen has been discouraged as an environmentally unsound practice by the National Research Council (1978). Application of nutrients, especially organic wastes in the late fall or winter, increases the risk of loss in snowmelt and spring runoff (Anderson et al. 1989; Gilbertson et al. 1979; Timmons et al. 1970). Although turfgrass is very efficient in uptake of nutrients, leaching of nutrients from living and dead grass and other vegetation during snowmelt and storm flow may be a significant source of both soluble nitrogen and phosphorus (Balogh and Madison 1985; Koehler et al. 1982; Timmons and Holt 1980; Timmons et al. 1970; White and Wiliamson 1973). Fate and potential losses of nutrients applied to turfgrass is discussed in detail by Walker and Branham (1992).

4. Patterns and intensity of traffic on golf courses can affect turfgrass density, soil compaction, and the rates and timing required for fertilization. These factors could affect pollution potential, especially for surface runoff. Management of traffic on golf courses to minimize surface runoff, soil compaction, pest infestations, and the need for frequent fertilizer and pesticide applications will reduce potential losses of water and applied chemicals.

5. Application techniques that will reduce surface and leaching losses include nutrient incorporation into soil when possible and frequent applications of reduced amounts of fertilizer. These techniques reduce movement of nutrients in solution and increase application efficiency.

6. The source and formulation of fertilizer used also influences the potential for offsite transport. Where leaching is a problem, slowly available sources of nitrogen should be used in place of readily available sources. Urea, though chemically an organic compound,

is readily available and subject to movement in water. Many organic sources of nutrients offer slower release and may delay nutrient availability until required for turfgrass growth. The organic forms of nitrogen are released at rates commensurate with the rate of turfgrass growth. However, appropriate rates and placement are critical even for organic sources of nutrients. Overapplication of slow release and organic forms of nitrogen must be avoided to reduce the long-term potential for groundwater contamination.

7. Slow release nitrogen fertilizers and nitrification inhibitors have potential for reducing the environmental impacts resulting from losses of nitrates. However, slow release fertilizers may have problems in matching timing of release with critical turfgrass growth periods. Some nitrification inhibitors (e.g. nitrapyrin) have proven effective in slowing conversion of ammonium to nitrate. However, the effectiveness of the inhibitor for reducing nitrogen losses in runoff, leaching, and by volatilization is dependent on climatic conditions, soil conditions, and water management practices.

8. Proper calibration of equipment will ensure proper placement and rate of nutrient delivery. Improper calibration and equipment maintenance will result in over or under application and uneven distribution of nutrients. Appropriate handling and loading procedures will prevent localized spills and concentrations of fertilizers.

9. Irrigation, drainage, water management, and traffic effects are critical factors in potential leaching and surface runoff of nitrogen. Leaching losses are increased with irrigation of shallow rooted crops on sandy soils. Accumulated nitrates in irrigated soils will be leached past the rooting zone when excess irrigation water is applied to reduce salt accumulation in the surface soil. On sandy soils excess nitrates will accumulate in the soil during years with normal fertilizer application, but with low moisture input and poor turfgrass development. In subsequent years with normal levels of precipitation or irrigation, excess nitrates accumulated in the soil may be available for leaching. Subsurface losses are reduced if turfgrass or microbial population recovers the nitrogen from the soil or adequate nutrient credits are applied in determining rates of additional nitrogen application.

10. Karst Topography. Application and handling of organic and commercial fertilizers in regions of karst topography should be conducted with care to avoid movement of chemicals into fractures and sinkholes via surface runoff.

11. Maintaining good turfgrass growing conditions will reduce both surface runoff losses and subsurface losses of plant nutrients. Preventing pest damage to turfgrass, adjusting soil pH for optimum growth, providing good soil tilth for root development, planting suitable turfgrass species and cultivars, and improving water management practices will increase turfgrass efficiency of nutrient uptake.

12. Assessment of potential offsite transport of chemicals by runoff or leaching losses prior

to application will provide essential information on selection of nutrient management practices appropriate for a specific site. Site characteristics such as soil texture and organic matter content, geology, depth to groundwater, proximity of loading areas to well heads, proximity to surface water, topography, climate, and the effect of traffic on turfgrass density and soil compaction provide qualitative indications of site potential for runoff and leaching losses of nutrients. Computer models and qualitative indexes currently could be adapted for this approach (e. g. Vargas et al. 1989).

13. QA/QC. Again, development and implementation of quality control and quality assurance guidelines for nutrient management will insure that integrated practices are used with reasonable accuracy by field personnel.

3.4.3 Suggested Fertilization Guidelines

The following is a summary of typical fertilizer management practices used for different parts of a golf course.

The Putting Green. Preplant incorporation of fertilizer into the putting green zone is required in almost all situations. The specific rate of application and ratio of fertilizer incorporated is usually based on soil test guidelines. Phosphorus and potassium are the two nutrients whose application rates should be based on soil test results. Nitrogen is usually applied at a rate between 1.5 and 3 pounds of nitrogen per thousand square feet (Blue et al. 1983). Beard (1982) suggests a range of nitrogen application from 0.3 to 1.2 pounds of nitrogen per thousand square feet per growing month. Actual rates of application depend on turfgrass species, climatic conditions, and cultural management objectives. The higher rate of nitrogen is preferred, with 40 to 60 percent of the nitrogen being in a slow release form (Burton et al. 1952; Blue 1974; Halevy 1987). Fertilizer is usually applied just prior to planting and incorporated into the upper 3 to 4 inches of the soil root zone (Hill and Tucker 1968).

The nutrient requirements of established putting greens vary with the amount of water applied, nutrient holding capacity, climate, and turfgrass species/cultivar. No one fertilizer program will cover all situations; specific application procedures for turfgrass situations will be described in subsequent sections. Some of the common characteristics, can, however be summarized.

Nitrogen must be applied to maintain turfgrass shoot density, adequate recuperative potential, moderate shoot growth rate, and to lesser extent, color. Fertilization rates typically range from 3 to 6 pounds/1000 sq. ft. per year for bentgrass and annual bluegrass greens and from 6-18 pounds per year on bermudagrass greens (Impethuska et al. 1979; Landschoot and Waddington 1987). Application is usually at one to three week intervals during periods of normal shoot growth. Specific intervals depend on type of nitrogen carrier used (Jackson and Burton 1982; Hummel and Waddington 1984; Lamond and Moyer 1983).

Potassium is prone to leaching through the soil, especially in sand root zones. Potassium fertilization is best determined by the results of soil test (Woodhouse 1968, 1969). Potassium is often applied at 75% the level of applied nitrogen, although higher levels are sometimes applied (Adams et al. 1967; Belesky and Wilkinson 1983). Spring and late summer-early fall are the times when potassium applications are most commonly made. Potassium can also be applied at 20 to 30 day intervals during heat, drought, and water stress periods (Nelson et al. 1983).

Compared to nitrogen and potassium, phosphorus is required in much smaller amounts on greens (Jackson et al. 1959). The rate should be based on soil test results. Phosphorus is usually applied one or two times per year as one component of a complete fertility treatment (Juska et al. 1965; King and Skogeley 1969). Phosphorus is usually applied during spring and late summer or early fall. Application of phosphorus fertilizers is preferable just after coring to achieve deep soil penetration of this relatively immobile nutrient (Varco and Sartain 1986). It is sometimes questionable whether application of phosphorus is required, particularly since visible growth responses are seldom observed. High phosphate levels are quite common on older greens.

<u>The Tee</u>. The philosophy of tee fertilization is slightly different from that of greens. Extensive damage caused by divots dictates the need for rapid shoot growth rate to enhance turfgrass recovery (Beard 1982). Sufficient nitrogen must be applied to maintain adequate turfgrass color, shoot density, and recuperative rate in terms of lateral shoot growth and tillering. The nitrogen fertilization rate ranges from 3-6 pounds/1000 sq. ft. per year on bentgrass, Kentucky bluegrass, and annual bluegrass tees and from 5-10 pounds/1000 sq. ft. on bermudagrass (Beard 1982). The frequency of application typically ranges from 15 - 30 growing days. The rate of fertilization utilized on individual tees also may vary even though root zone mix and irrigation practices are similar for all tees. Tees that receive exhaustive divots, such as the par 3s and the first tee, may require up to twice the amount of nitrogen applied to larger tees. The larger tees are subject to considerably less stress. Seasonal timing of application are essentially the same as those described for putting tees.

<u>The Fairway</u>. The nutrient requirements for fairways vary with soil type, soil nutrient holding capacity, amount of water applied, climate, turfgrass species, and amount of play. Sufficient nitrogen must be applied to fairways to maintain proper turfgrass density, recuperative potential, moderate shoot growth rate, and to a lesser extent, color. Among the cool season grasses, the bentgrasses and Kentucky bluegrasses usually require 80 - 160 pounds of nitrogen/acre per year. In contrast, the fine leafed fescues require only 40 to 120 pounds of nitrogen/acre per year. Small amounts or no nitrogen should be applied during heat stress periods for cool season turfgrasses (Hathcock et al. 1984). Among the warm season grasses, bermudagrass requires 10 to 40 pounds of nitrogen per acre per growing month. The higher level of nitrogen fertilizer is commonly used on coarse textured soils, where leaching is a greater problem (Burton and Devane 1952). This practice may be associated with undesirable loss of nitrogen, constituting a potential nonpoint pollution problem in natural or designed subsurface drainage systems.

Phosphorus application is based, as before, solely on the results of soil tests and applied 1 or 2 times per year as part of a complete fertilizer. Potassium applications may be made at supplemental rates above the level indicated by soil tests. The same rules for supplemental phosphorus and potassium application to greens generally are followed on fairways.

<u>The Rough</u>. Optimum fertilizer treatment should be applied during the establishment of roughs (Beard 1982). A relatively high fertility level is maintained through the first growing season or until a mature sod is established. At this point, fertilization is reduced to a lower level. The fertility level required for maintenance of the rough depends on species, soil conditions and climate. Roughs on fertile soils not prone to nutrient loss usually require less fertilization than roughs on sandy soils with intense nutrient leaching losses. A typical fertilization program on high quality rough turfgrass is one application per year of a complete fertilizer. This single application is usually applied in the fall in the case of cool season species and in the spring in the case of warm season turfgrasses (Beard 1982).

3.4.4 *Adoption of Integrated Systems for Turfgrass Management*

IPM and recently ICM have received acclaim as part of systems required for cost effective solutions to pest management and environmental problems (e.g. Anderson et al. 1989; Leslie and Metcalf 1989). However, as early as 1965 proponents of integrated management of biological systems observed a slow rate of adoption (Wearing 1988). Systematic studies on the process of IPM implementation has been limited (Leslie and Metcalf 1989; Smith and Raupp 1986; Wearing 1988). Most of the literature on adoption of IPM in urban settings is anecdotal (e.g. Grant 1989; Raupp et al. 1989). Information on development of TMS for management of pests, nutrients, irrigation, and protection of wetlands and wildlife on golf courses is very limited (Walker et al. 1990).

Problems associated with implementation, education, and transfer of integrated management technology have been identified as the principal obstacles limiting progress of integrated programs in agricultural and turfgrass systems (Corbet 1981; Lincoln and Blair 1977; Raupp et al. 1989; Wearing 1988). Difficulty with technology transfer, slow acceptance by superintendents, and conceptual complexity has limited implementation despite rising chemical costs, pest resistance, and societal concerns related to environmental impacts.

Successful implementation of TMS requires education of both turfgrass managers and individuals using golf courses. Education and provision of comprehensive source material on development of IPM, ICM, and TMS are the key components to successful implementation of working programs (Lincoln and Blair 1977; Poe 1981; Wearing 1988). Written and verbal communication on the concepts and integrated control tactics are essential components of educational programs. Success in previous IPM programs involved a high level of technical coordination and a strong cooperative attitude by producers (Grant 1989; Raupp et al. 1989; Reardon et al. 1987; Wearing 1988). Fragmented technical and scientific reviews developed for academics, scientists, and regulatory agencies do not provide information in a format usable by turfgrass managers. The lack of organized educational and technical assistance on monitoring, selection of chemicals, and selection of cost effective-alternate control options can be a formidable obstacle to acceptance of IPM and TMS by golf course and turfgrass managers.

Demonstration that TMS are cost effective strategies for maintaining turfgrass quality is necessary for its general acceptance. Despite the potential of IPM and TMS for reduction of adverse environmental impacts (Leslie and Metcalf 1989), these approaches will not be used to maintain the quality of golf course turfgrass without appropriate training and marketing. Cost advantage, long-term maintenance of turfgrass quality, reduction of pesticide resistance, and reduction of risk associated with environmental and human health issues are the primary motivation for implementation of integrated programs (Norton 1982; Wearing 1988). Onsite assistance by technical experts has been cited as essential for adoption of system management approaches (Wearing 1988).

A large number of technical, financial, educational, institutional, and social/marketing constraints to implementation of TMS have been identified (Corbet 1981; Wearing 1988). The primary technical obstacle is the lack of simple monitoring techniques to establish action thresholds (Potter 1982; Potter and Braman 1991; Wearing 1988). There is a critical need to simplify current TMS monitoring methodology. In order to implement effective monitoring programs, there is a need for considerable enhancement of 1) immunoassay methods (Miller 1988; Miller and Martin 1988; Miller et al. 1989); 2) effective trapping devices (Raupp 1985); 3) scouting and counting services (Cooper et al. 1987); 4) diagnosis of deficiencies and pest symptoms (Dernoeden 1989; Metcalf 1980); 5) documentation for climate and pest infestation relationships (Davidson et al. 1972; Nus and Hodges 1985; Potter and Braman 1991; Regniere et al. 1981); 6) identification and application of appropriate alternate control methods (e.g. Klein 1989; Poinar 1979; Siegel et al. 1989); and 7) development of effective computer assisted technology to monitor climate conditions, soil moisture, and soil nutrient status (Carrow et al. 1990; Nyrop et al. 1989; Welch 1984).

Establishment of economically based action thresholds for pest control, water management, and nutrient management is a complex issue for turfgrass managers. The complexity and expense of developing integrated systems on golf courses is confounded by the financial risk associated with maintaining high quality turfgrass. The complexity of integrated systems for pest, crop, and turfgrass management is widely acknowledged as a major obstacle to implementation (Potter and Braman 1991; Wearing 1988). The organization and operation of the multicomponent innovations required for TMS to succeed on golf courses requires a high level of participation among golf course superintendents, USGA Green Section technical staff, local, state and federal regulators, cooperative extension specialists, turfgrass researchers, and golf course users.

Current lack of financing at the state and federal level limits education, IPM and TMS training, and the necessary basic and applied research. The current strong recommendations by regulatory agencies for implementation of IPM as a component of overall TMS programs should

be backed by financial assistance, at least for the necessary educational and applied research programs (Leslie 1989c). Information on specific criteria for development of IPM and TMS programs is fragmented in detailed technical publications and reviews (e.g. Beard 1982; Gibeault and Cockerham 1985; Hanson and Juska 1969; Leslie and Metcalf 1989). Although current sources, including this book, contain the necessary information to develop regional TMS guidelines, it is necessary to tailor the information for local turfgrass requirements. Without development of detailed training programs, instructional manuals, and on-site technical assistance, TMS will not be successfully marketed to turfgrass and urban landscape managers (Holmes and Davidson 1984; Koehler et al. 1985; Raupp and Noland 1984; Raupp et al. 1989).

Development of educational and marketing strategies should be based on interagency cooperation of the USGA, Golf Course Superintendents Association (GCSAA), state and U. S. Environmental Protection Agencies, and scientists in academia and the private sector. Unless TMS programs are tailored to the needs of local turfgrass managers, current chemical and cultural management practices will continue to be used despite societal and environmental problems.

3.4.5 *Alternate Methods of Pest and Disease Control*

The choice of the best method to suppress turfgrass pests and diseases in TMS programs depends on careful monitoring, knowledge of cultural practices and ecological relationships, and access to information on both chemical and nonchemical control options. Although chemical pesticides are currently the primary defense against pests and disease, fewer compounds are being developed for use on turfgrasses. Public concern over the potential health effects and relatively small market for recovery of massive development and registration costs limit incentives for development of new turfgrass pesticides (Potter and Braman 1991). These conditions provide incentives for development and use of alternate control strategies for turfgrass management. Biological control options are being stressed as an important component of the IPM systems in literature published by the U. S. Environmental Protection Agency (Leslie and Metcalf 1989). The role of alternatives and biological control options has been reviewed by Baker (1986) and Potter and Braman (1991).

Some of the possible nonchemical options for management of turfgrass pests and diseases include: 1) use of biological control agents such as microorganisms, endophytic fungi, nematodes, and parasitoids (e.g. Funk et al. 1989; Klein 1988, 1989; Poinar 1979); 2) use of traps and attractants (Klein 1982, 1989); 3) encouragement of natural pest predators (Cockfield and Potter 1985; Reinert 1978); 4) selection and breeding of pest and disease resistant turfgrass species and cultivars (Busey 1989; Meyer and Funk 1989); 5) use of growth regulators (Kageyama and Widell 1989); 6) modification of pest and disease habitat using cultural treatments (Colbaugh and Elmore 1985); and 7) incorporation of turfgrass ecological and allelopathic relations into TMS planning (Potter et al. 1989; Schmidt and Blaser 1969). The following is a brief summary of several of these alternatives and biological control options.

Microorganisms. Biological control of insect and disease pests using microorganisms has been extensively reviewed (Baker 1986; Cook and Baker 1983; Klein et al. 1976, 1981a, 1982, 1989). Bacterial pathogens used in commercial formulations for successful control of scarab grubs, sod webworms and other insect pests include the milky disease bacteria (*Bacillus popillae* Dutky) and BT (*Bacillus thuringiensis* Berliner) (Klein 1988, 1989) (Table 3.7-3). Numerous studies have shown successful control of scarab grubs with *B. popillae*. Factors influencing the efficacy of commercial formulations of *B. popillae* and other milky disease bacteria are 1) rate and extent of application; 2) method of application; 3) timing of treatment in relation to soil incorporation and life stage of grubs, 4) soil temperature, and 5) long-term attenuation of spores (Hanula and Andreadis 1988; Klein 1988; Ladd and Klein 1982a; Tashiro 1987; Tashiro and Steinkraus 1966; Warren and Potter 1983). Unfortunately, the cost of formulating and registering strains of *B. popillae* for control of turfgrass grubs and other organisms may not be supported by the turfgrass market (Klein 1989). Although BT has proven successful for control of sod webworms (Reinert 1976), it has not been effective against other soil inhabiting insect pests (Klein 1989). Other potential microorganisms being considered as biocontrol organisms include the bacteria *Serratia* spp. (Jackson et al. 1986), fungal species *Beauveria* and *Metarhizium* (Klein 1988), and the protozoan *Ovavesicula popilliae* (Hanula and Andreadis 1988).

Microbial based inoculants have considerable potential for reducing fungicide usage. This alternate control approach uses introduced microbial antagonists that interfere with pathogen populations and reduce disease development through several modes of action. Commonly studied antagonists include fungi in the genera *Gliocladium, Laetisaria, Penicillium, Sporidesmium, Talaromyces, Trichoderma,* and *Verticillium* and bacteria in the genera *Bacillus, Enterobacter, Erwinia,* and *Pseudomonas* (Cook and Baker 1983). Currently, several types of biological control products are commercially available for control of plant pathogens on agricultural crops.

Although the use of microbial antagonists for biological control of turfgrass diseases is still in the early stages of development, preliminary research has demonstrated some initial success. Laboratory and greenhouse studies have described microbial antagonists suppressive to pythium blight caused by *Pythium aphanidermatum* (Nelson and Craft 1989a; O'Leary et al. 1988; Wilkinson and Avenius 1984), brown patch caused by *Rhizoctonia solani* (Burpee and Goulty 1984; Nelson 1988; O'Leary et al. 1988), gray snow mold caused by Typhula incanata (Harder and Troll 1973), and take-all patch caused by *Gaeumannomyces graminis* var. *avenae* (Wong and Baker 1984; Wong and Siviour 1979). In field studies applying preparations of *Typhula phacorrhiza* to creeping bentgrass swards provided up to 74% control of gray snow mold caused by *T. incarnata* and *T. ishikariensis* (Burpee et al. 1987). Isolates of binucleate *Rhizoctonia* spp. and *Laetisaria arvalis* provided up to 90% control of brown patch on creeping bentgrass greens and tall fescue turfgrass (Burpee and Goulty 1984; Sutker and Lucas 1987). Isolates of *Gliocladium virens* have been effective in suppressing dollar spot on bermudagrass (Haygood and Mazur 1990). Strains of *Enterobacter cloacae* have been effective in suppressing dollar spot on creeping bentgrass in the field (Nelson and Craft 1991) and pythium blight and brown patch

in greenhouse trials (Nelson 1988; Nelson and Craft 1989a). *Fusarium* spp. isolates provided up to 87% control of dollar spot in turfgrass field trials in Ontario, Canada (Goodman and Burpee 1987, 1988).

Composts have proven to be the best sources of complex mixtures of antagonistic microorganisms used for disease control. Monthly applications to greens of composted topdressing are effective in suppressing diseases such as dollar spot, brown patch, gray snow mold, and red thread (Nelson and Craft 1989a, 1989b, 1990a, 1990b). The reason that composts are such a rich source of microbial antagonists is that composting relies on a diverse assemblage of microorganisms to carry out the process of decomposition. The composting process involves successions of both moderate (mesophilic) and high (thermophilic) temperature microorganisms during various stages of organic decomposition (Alexander 1977). The mesophilic microflora, predominant during the later stabilization phase of decomposition, are the most important in suppressing turfgrass diseases (Hoitink and Fahy 1986; Nelson and Craft 1990a, 1990b). Microbial activity is critical for expression of disease-suppressive properties in composts (Hoitink and Fahy 1986). However, the specific disease-suppressing microorganisms have not been identified in turfgrass composts. Identification of specific organisms in composts with biological activity is an important research objective in order to understand the disease-suppressive properties of compost applied to turfgrass.

Entomogenous Nematodes. Parasitic entomogenous nematodes are recognized as excellent candidates for agents of biological control for turfgrass pests (Table 3.7-3) (Gaugler 1981; Georgis and Poinar 1989; Klein 1990; Sheltar 1989). Nematodes are soil microfauna living freely in the soil or as parasites in plants, insects, and other animals. Entomophilic nematodes of the genera Neoaplectana and Heterorhabditis are regarded as good candidates as biological control agents (Georgis and Poinar 1989; Kaya 1985). These nematodes have a mutualistic association with bacteria in the genus Xenorhabdus (Poinar 1979). The infective and ensheathed juvenile nematodes enter the hosts via natural body openings. Some Heterorhabditis will directly penetrate the insect cuticle. Once the infective nematode enters the host insect, the bacteria are liberated causing septic death of the infected insect within 24-48 hours. The nematodes feed on the bacteria and the dead insect tissue. The nematodes pass through several generations in which their abundance increases enormously. Eventually, ensheathed juveniles emerge from the depleted cadaver, carrying the bacteria in their guts (Poinar 1979).

TABLE 3.4-1 SUMMARY OF ALTERNATE CONTROL OPTIONS FOR CONTROL OF TURFGRASS PESTS AND DISEASES

Alternate Control Agent or Turfgrass Species	Typical Target Pest Species	General References
Microorganisms		
Bacillus popillae *Bacillus thuringiensis*	Scarab grubs, sod webworm	Klein 1982, Klein et al. 1976, Tashiro 1987
Antagonistic microbial based inoculants and composts	Pythium blight, brown patch, gray snow mold, dollar spot, pythium root rot, summer patch, red thread, necrotic ringspot	Cook and Baker 1983, Nelson 1988, Nelson and Craft 1989a, 1989b, 1990a, 1991b
Entomogenous Nematodes		
Neoaplectana spp. *Heterorhabditis* spp.	Japanese beetles, masked and European chafer, mole crickets, cutworms, armyworms, billbugs, sod webworms	Georgis and Poinar 1989; Klein 1990; Poinar 1979
Other Parasitoids		
Parasitic wasps *Neodusmetia sangwani* (Rao)	White grubs, southern chinch bugs, mole crickets, Rhodesgrass mealy bugs	Klein 1982, 1989
Endophytic Fungi		
Acremonium spp.	Argentine stem weevil, sod websorms, aphids, chinch bugs, and billbugs, possible tolerance to pathogenic fungi, summer stress, and weeds; imparts increased vigor, persistence, and tolerance to wear, summer, and winter stress	Siegel et al. 1989 Funk et al. 1989 Bacon et al. 1986
Natural Predators		
Birds, mammals, amphibians Invertebrates: ants, mites, & other predatory arthropods	Broad range of insect pests Broad range of insect pests: e.g. chinch bugs, sod webworms, mole crickets	Klein 1982 Reinert 1978 Potter et al. 1989 Crocker and Whitcomb 1980
Traps and Attractants	Japanese beetle	Klein 1981h

TABLE 3.4-1 SUMMARY OF ALTERNATE CONTROL OPTIONS FOR CONTROL OF TURFGRASS PESTS AND DISEASES

Alternate Control Agent or Turfgrass Species	Typical Target Pest Species	General References
Breeding and Cultivar Selection		
Kentucky bluegrass	*Bipolaris* and *Drechslera* diseases, smut, rust, powdery mildew, dollar spot; Chinch bug, billbugs, sod webworms	Meyer 1982 Meyer and Funk 1989
Perennial Ryegrass	Brown patch, stem rust, snow mold, net blotch; Greenbug aphids, Argentine stem weevil, billbugs, sod webworm	Meyer 1982 Meyer and Funk 1989
Turf-type Fescues	Brown patch, dollar spot, net blotch, rusts; Resistant to a wide range of insect pests.	Meyer 1982 Meyer and Funk 1989
Bermudagrass	Mole crickets, ectoparasitic nematodes, tropical sod webworm, bermudagrass mite, spittlebugs	Busey 1989
St. Augustinegrass	Gray leaf spot, downy mildew, Panicum mosaic virus; Southern chinch bugs	Busey 1989
Zoysiagrass	Sod webworms, nematodes	Busey 1989
Allelopathy		
Grass root exudates	Tall fescue exudates suppress a wide range of weeds; Seed leachants of ryegrass, annual bluegrass, and Kentucky bluegrass may suppress some broadleaf plants; Root exudates of various grasses suppress growth of trees and woody ornamentals	Rice 1976, 1979
Ecological & Competitive Relationships		
Manipulation of species mixes or cultural practices	Manipulation of competitive relationships used to control annual ryegrass	Schmidt and Blaser 1969
Nontoxic Compounds Lime and suffocants	Japanese beetle grubs	Klein 1982

Attempts to control foliar insects with entomophilic nematodes has not been successful (Kaya 1985). Poor control was attributed to drying of spray formulations and surface exposure to sunlight and extreme temperatures (Gaugler and Bousch 1978; Georgis and Poinar 1989; Shetlar 1989). Nematodes occur naturally in moist, dark soil environment (Alexander 1977). Therefore, soil inhabiting pests are most likely to be effectively controlled by entomophilic nematodes. Entomogenous nematodes have been reported to control European chafer and Japanese beetle larvae in turfgrass as effectively as chemical pesticides (Villani and Wright 1988b). Under controlled conditions, nematodes have been demonstrated as an effective alternative to turfgrass insecticides for broad spectrum control of Japanese beetles, masked and European chafer, mole crickets, black cutworms, armyworms, billbugs, sod webworms. Improved nematode formulations and application technologies are needed before nematodes will be effective for control of social insects such as ants, wasps, and yellow jackets (Poinar and Georgis 1989). Problems of storage, cost, availability, handling, compatibility with other turf pesticides, and reliability of nematode formulations must be resolved before they will be widely accepted by the turfgrass industry (Potter and Braman 1991; Zimmerman and Cranshaw 1990).

Efficacy of field application of nematodes is dependent on:

1. Nematode strain and specific target pest (e.g. Georgis and Poinar 1989; Shetlar 1987).
2. Sufficient spray volume, concentration of organisms, thatch conditions, irrigation practices (Georgis and Poinar 1989; Shetlar et al. 1988).
3. Persistence of formulation, soil texture, and soil moisture conditions (Georgis and Poinar 1983; Molyneux and Bedding 1984; Schroeder and Beavers 1987).
4. Temperature (Molyneux 1984; Schmiege 1963).
5. Effects of solar radiation (Gaugler and Boush 1978).
6. Compatibility with other pesticides (Zimmerman and Cranshaw 1990).
7. Timing, placement, and method of application (Georgis and Poinar 1989; Morris 1987).

Surface spraying of nematodes is the most widely used application technique (Georgis and Poinar 1989; Shetlar et al. 1988). A high concentration of nematodes in the spray is required to ensure that a sufficient number of surviving nematodes come in contact with pest targets. Other methods of application have been devised to assist in nematode survival. These techniques include use of injection techniques, baits, encapsulated formulations, and application through irrigation systems (Georgis et al. 1989; Glaser and Farrell 1935; Kaya 1985; Kaya and Nelson 1985; Reed et al. 1986). Additional research is needed to improve production of commercial

nematode formulations and application techniques under different habitat conditions.

Parasitiods. Other parasitic organisms with potential for control of selected turfgrass pests have been identified by Fleming (1968) and Klein (1982). Parasitic wasps have been observed and used to suppress white grub populations (Fleming 1968; Jarvis 1966), southern chinch bugs (Reinert 1972), and mole crickets (Wolcott 1941). A well known successful use of biological control involved introduction of a parasitoid, Neodusmetia sangwani (Rao), from India for control of Rhodesgrass mealybugs in Texas. This organism has been described as having completely controlled the mealybug (Dean et al. 1979; Schuster et al. 1971). Approximately $17 million/year was saved as a result of this biological control agent.

Endophytic Fungi. The relationship of nonsporulating endophytic fungi with forage and turfgrasses has been known for many years. However, only recently has research on the association of endophytic fungi with animal toxicoses, stimulation of growth, and insect resistance received attention (Bacon et al. 1986; Bush et al. 1979; Johnson et al. 1985; Latch et al. 1985; Newton et al. 1987; Read and Camp 1986; Saha et al. 1987; Siegel et al. 1989). Endophytic fungi are contained or grow entirely within the infected grass species and usually produce no external symptoms of infection. Currently no measurable detrimental effects of the fungi on grass hosts have been observed (Siegel et al. 1987; 1989). Several endophytic fungi form mutualistic relationships with grass species. The fungi receive nutrition, enhanced protection and survival, and dissemination through seed from the host grass. The beneficial endophytes impart improved growth and persistence to the host plants, tolerance to herbivore feeding, tolerance to winter and summer stress, and improved resistance to diseases and pests (Funk et al. 1989; Latch et al. 1985; Siegel et al. 1985, 1987, 1989).

Five species of Acremonium are known to infect turfgrasses as endophytes. The association of these fungal endophytes is considered a desirable attribute in conservation and turfgrasses (Funk et al. 1989; Siegel et al. 1987). Increased resistance of fescues and perennial ryegrasses to Argentine stem weevil (Prestidge et al. 1982; Stewart 1985), sod webworms (Funk et al. 1983), aphids (Johnson et al. 1985), chinch bugs (Funk et al. 1985; Saha et al. 1987), and billbugs (Ahmad et al. 1986) has been attributed to their association with endophytic fungi.

The endophytes produce a wide range of alkaloid compounds within the host grasses (Siegel et al. 1985; 1987). The clavine ergot and pyrolizidine alkaloids have insecticidal properties and have been isolated from endophytes in association with tall fescue (Siegel et al. 1985). The technology currently exists for production of synthetic grass-endophyte complexes capable of producing these natural insecticides. The synthesis involves transfer of endophytic fungi to grasses by 1) inoculation of one-week old seedlings (Latch and Christensen 1985); 2) inoculation of callus tissue (Johnson et al. 1986); and 3) selection of infected maternal lines (Funk et al. 1985).

Currently, breeding research is being conducted to select infected varieties and improve methods to incorporate endophytes into existing turfgrass cultivars (Funk and Clarke 1989; Funk et al.

1989). This research has focused on improvement of turfgrass germplasm and enhancement by endophytic infection. Promising turfgrass species are perennial ryegrass and hard, chewings, fine, and tall fescues. White (1987) observed infection of other important conservation grasses and turfgrasses including Agrostis, Bromus, Cinna, Digitaria, Elymus, Festuca, Lolium, Melica, Poa, Sitanion, and Stipa. Endophytic infection of Cynodon and Zoysia grasses has not been observed (Newton et al. 1987).

In addition to the intrinsic resistance to insects imparted by the endophytic fungi, increased tolerance to insects by infected turfgrass results from 1) enhancement of genetically mediated resistance, 2) growth enhancement of healthy dense turfgrass, and 3) increased tolerance to weed and moisture stress (Funk et al. 1985, 1989; Read and Champ 1986). Preliminary results from laboratory trials suggest that infection with endophytic fungi may increase tolerance of turfgrass to disease inducing fungi (Bayaa et al. 1987; White and Cole 1985).

Natural predators. Natural predator-prey relationships are an important factor in suppression of insect pests in turfgrass (Arnold and Potter 1987; Crocker and Whitcomb 1980; Klein 1982; Reinert 1978). Although at times problematic, birds and mammals are the most visible predator of turfgrass insects (Klein 1982; Reinert and Short 1980). The giant toad, Bufo marinis, was successfully introduced into Puerto Rico for suppression of June beetles and mole crickets (Klein 1982). Invertebrate predators are also critical for control of insect pests in turfgrass. Several researchers have demonstrated the importance of predatory arthropods and mites for active control of chinch bugs, sod webworms, and other soft bodied turfgrass pests (Arnold and Potter 1987; Cockfield and Potter 1984a; Crocker and Whitcomb 1980; Reinert 1978).

Maintenance of balanced turfgrass ecosystems is an important strategy for control of undesirable insect pests. Pesticides applied for control of turfgrass insect pests are also toxic to beneficial insect and spider predators and parasites. Removal of effective predator populations with pesticides may result in long term increases in prey/pest populations. Cockfield and Potter (1984b) observed that a single surface application of chlorpyrifos reduced the insect predator-induced mortality of sod webworm eggs for at least three weeks after treatment. In another study, Cockfield and Potter (1983) observed that populations of predatory mites, spiders, and insects in Kentucky bluegrass were reduced by 60% after a single application of chlorpyrifos or isofenphos. Predatory arthropods were found to be less abundant and diverse on Kentucky bluegrass sites subject to high maintenance levels of pesticides and fertilizers (Arnold and Potter 1987; Cockfield and Potter 1985).

Direct evidence does exist, although limited, suggesting that repeated pesticide treatments could reduce the stability of turfgrass communities resulting in increased pest infestations (Cockfield and Potter 1984b; Reinert 1978; Streu 1969; Streu 1973; Streu and Cruz 1972; Streu and Gingrich 1972). Reinert (1978) observed low levels of southern chinch bugs in untreated lawns in Florida where insect predators and parasite populations were high. However, lawns receiving repeated insecticide treatments had chinch bug densities reaching outbreak levels. Resurgence of hairy chinch bug populations following years of chlordane treatments was attributed to

reduction in predatory pressure from mites and predatory hemipterans (Streu 1969, 1973). Timing of insecticide applications should be adjusted to minimize adverse effects on natural insect predators. Use of selective insecticides or introduction of insecticide resistant predators are alternate methods to avoid disruption of beneficial prey populations (Graves et al. 1978; Klein 1982).

Traps and Attractants. Traps and attractants have been used for suppression of Japanese beetles (Hamilton, et al. 1971; Klein 1981b, 1982; Ladd and Klein 1982b; Langford et al. 1940; Tumlinson et al. 1977). Commercial beetle traps are used in combination with a food-type (floral) lure alone or in combination with a sex attractant. Food attractants are floral lures and are effective for capture of both males and female beetles (Ladd et al. 1981). The sex attractant, or pheromone, has been isolated from female Japanese beetles. The pheromone has been synthesized and made commercially available for traps (Tumlinson et al. 1977). When the sex attractant is used in combination with a food attractant, both females and males are lured to traps at rates 2 to 3 times higher than either attractant used alone (Ladd et al. 1981).

The utility of mass trapping of Japanese beetles for suppression of grub populations was demonstrated in Massachusetts by Petraitis (1981). Using a dual bait system in 47 traps, the need for insecticidal suppression of grubs was eliminated. However, a recent study of a heavy infestation of Japanese beetles in Kentucky showed increased damage to plants in the vicinity of the beetle traps (Gordon and Potter 1985). It was suggested that despite trapping of thousand of beetles per day, the traps attracted more beetles to an area than could be caught. Although turfgrass damage in the vicinity of the traps did not increase, damage to foliage of other desirable plants did increase. Research is currently being conducted to develop a commercial trapping/attractant system for sod webworms, masked chafers and green June bugs (Banerjee 1969, Klein 1989; Domek and Johnson 1987, 1988; Potter 1980, 1989). Pheromone attractants also have been identified for fall armyworms, armyworms, black cutworms, and bluegrass webworms (Clark and Haynes 1990; Hill et al. 1979; Kamm 1982). Use of pheromone attractants and food baited traps may be more significant for insect monitoring technology, than as a means of direct insect control (Clark and Haynes 1990; Potter and Braman 1991).

Breeding and Selection. Breeding and selection of turfgrass to be free or tolerant of pests and diseases are integral components of most breeding programs (Busey 1989; Meyer 1982; Meyer and Funk 1989). The potential benefits of selecting pest and disease resistant turfgrasses were not addressed in recent literature regarding alternate strategies in turfgrass IPM programs (Leslie and Metcalf 1989). Research is currently needed to improve methods for screening turfgrass cultivars with resistance to diseases and pests (Johnson-Cicalese et al. 1989). In a review of turfgrass insect management, Potter and Braman (1991) suggest that greater research and development should be placed on combining genetic insect resistance with other desirable turfgrass traits.

Substantial success has been achieved in breeding Kentucky bluegrass for resistance to many important turfgrass diseases. Bluegrass cultivars have been developed to resist or tolerate leafspot and melting out disease; stripe smut; leaf, stem, and stripe rusts; powdery mildew; and dollar spot (Meyer 1982; Meyer and Funk 1989). Several Kentucky bluegrasses have been identified with significant levels of tolerance to damage by billbugs, chinch bugs, green bug aphids, and sod webworms (Johnson-Cicalese et al. 1989; Meyer and Funk 1989). Although relatively stable genetic resistance has been developed for the cool-season turfgrasses, additional research is needed to blend resistant strains for increased stability (Meyer and Funk 1989; Smiley and Craven-Fowler 1984). Natural mutations in pest populations often overcome resistance in turfgrass species with "single gene" resistance. Breeding for multigene resistance in turfgrass would slow down the natural process of pest acclimation to resistant turfgrass varieties.

Perennial ryegrass is another important cool-season turfgrass species. However, susceptibility to disease and poor performance under heat and drought conditions in warmer climatic regions has been a problem (Funk et al. 1985). Clark et al. (1989) has reported development of a perennial ryegrass with improved resistance to brown patch. Several turf-type perennial ryegrasses also have been developed with improved genetic resistance to winter diseases and stem rust (Rose-Fricker et al. 1986; Meyer and Funk 1989). Improved resistance of perennial ryegrass cv. Derby to damage by greenbug aphids was demonstrated by Jackson et al. (1981). Enhancement of ryegrass performance by selection of cultivars infected with endophytic fungi has increased ryegrass resistance to stem weevils, sod webworms, and billbugs (Ahmad et al. 1986; Funk et al. 1983). Reduced invasion by weeds and improved summer and winter recovery has been reported in perennial ryegrass and several fescues selected for endophyte-enhanced performance (Funk et al. 1985).

Progress has been made to improve the disease and insect resistance of the lower maintenance fine, hard, chewings, and tall fescue turfgrasses (Meyer 1982; Meyer and Funk 1989; Murray and Powell 1979). Improved cultivars have shown resistance to brown patch, net blotch, powdery mildew, red thread, dollar spot and several rusts (Berry and Gudauskas 1972; Clarke et al. 1989; Meyer 1982). Additional research is needed to develop resistance to a number of Pythium spp., stem and crown rusts, and brown patch diseases (Meyer and Funk 1989). Improved resistance to drought stress could reduce damage of tall fescues from brown patch. Many of the tall fescue species have good overall resistance to insect damage (Johnson-Cicalese et al. 1989; Jackson et al. 1981; Meyer and Funk 1989).

Published research on breeding of disease resistant bentgrasses and many warm-season turfgrasses is limited compared to the cool-season turfgrasses (Busey 1989; Meyer and Funk 1989). Creeping, colonial, and velvet bentgrasses are very susceptible to fungal diseases (Beard 1982). Research is needed to develop disease and insect resistant varieties of these important golf course turfgrasses.

Several species of warm-season turfgrasses are considered resistant to insect infestation (Busey 1989). Additional research is needed to demonstrate that host resistance to insects observed in the laboratory is associated with field tolerance to insect damage. There is considerable

undocumented field information on insect resistance of bermudagrass cultivars (Busey 1989). This information is not useful to turfgrass managers until it is made available. Nonpreference screening trials have limited utility considering the monoculture conditions on many golf courses (e.g. Jackson et al. 1981; Leuck et al. 1968; Reinert and Busey 1983). Maintenance of genetic purity of clonal selections is also a problem encountered by turfgrass managers (Busey 1989).

Despite these technical difficulties, several cultivars of bermudagrass have shown potential resistance to mole crickets (Reinert and Busey 1984); ectoparasitic nematodes (Tarjan and Busey 1985); tropical sod webworm (Reinert and Busey 1983), bermudagrass mite (Reinert et al. 1978), and spittlebugs (Stimmann and Taliaferro 1969). A genotype of Bell rhodesgrass resistant to rhodesgrass mealybug has been released (Reinert 1982). Different genetic resistance to sod webworms and sting nematodes was reported for zoysiagrass. The level of resistance was related to quality of zoysiagrass performance in selection trials conducted by Busey et al. (1982).

Cultivars of St. Augustinegrass have shown resistance to gray leaf spot, downy mildew, and Panicum mosaic virus (Atilano and Busey 1983; Bruton et al. 1983; Reinert et al. 1981; Toler et al. 1983, 1985). Cultivars of Floratam and Floralawn St. Augustinegrass with genetic resistance to damage by southern chinch bugs have been released (Dudeck et al. 1986; Reinert and Dudeck 1974). Recently, extensive southern chinch bug damage to previously resistant Floratam and Floralawn turfgrass has occurred in Florida (Busey and Center 1987). However, several St. Augustinegrass cultivars have retained their resistance to damage by the southern chinch bug (Crocker et al. 1989; Reinert and Dudeck 1974; Reinert et al. 1981, 1986). Overcoming the genetic resistance to insect damage demonstrates the ability of genetically variable pest populations to overcome biological control options. Resistance to biocontrol options would be similar to development of pest resistance to chemical control strategies as described by Balogh and Anderson (1992).

<u>Allelopathy</u>. Allelopathy is the direct or indirect effect of one plant on another through production and release of natural compounds (Rice 1974, 1979). Allelopathy and competition for light, water, and nutrients are both components of plant interference interactions. The effects of allelopathy have been recognized as a growth factor in both manipulated and natural ecosystems (Rice 1979). Mechanisms of action responsible for allelopathy include 1) effects on cell elongation and root tip structure; 2) effects on hormone production; 3) effects on membrane permeability; 4) impact on mineral uptake and nutrient availability; 5) detrimental effects on physiological processes; and 6) clogging of the xylem. Rice (1974, 1976, 1979) has reviewed allelopathy in agriculture, forestry, and natural grassland ecosystems.

Allelopathic relationships are often difficult to separate from the effects of competition. However, researchers have demonstrated that various crops, barley in particular, successfully suppress weeds through inhibition by root exudates (Glass 1973; Overland 1966; Peters 1968). Detrimental allelopathic effects have also been observed in crop rotations (Kimber 1973; Tamura et al. 1969). Suppression of weeds in thin and dense fields of Kentucky-31 tall fescue (Festuca arundinacea Schreb.) has been attributed to root exudate of toxic materials (Peters 1968).

The potential of allelopathy for biological control of weeds has been recognized in agriculture and aquatic systems (Fay and Duke 1977; Rice 1974, 1979; Robson 1977; Schweizer 1988). Research is relatively limited on development of allelopathy as an alternate control technique for control of weeds in agriculture and turfgrass management (Rice 1976, 1979). Recent reviews of biocontrol options for turfgrass management have not included allelopathy as a management option (Leslie and Metcalf 1989). However, under natural conditions and forage management, several grass species have exhibited allelopathic relationships (Cope 1982; Newman and Miller 1977; Newman and Rovira 1975; Rice 1976, 1979; Tang and Young 1982). For example in laboratory assays, seed leachates of tall fescue, perennial ryegrass, Kentucky bluegrass, and annual bluegrass inhibited growth of lettuce seedlings (Buta et al. 1987). Organic fractions of grass seed leachate were inhibitory to lettuce growth. Inorganic fractions of grass seed leachates inhibited lettuce growth at high concentrations, but stimulated growth at low concentrations.

Growth of trees and ornamental shrubs may be adversely affected by turfgrass and sod. This effect may result from competition for growth resources or exudates of allelopathic compounds by grass roots (Fales and Wakefield 1981; Nielsen and Wakefield 1978; Whitcomb and Roberts 1973). It is difficult to separate the effect of competition for growth resources and root exudates in research on suppression of trees by grass. Allelopathic suppression of trees and shrubs grown in sod is usually identified by unsubstantiated inference (Fales and Wakefield 1981).

Competitive Relationships of Turfgrasses and Associated Cultural Practices. Understanding and manipulating the competitive ecology of turfgrass and weed species is an important component in maintenance of high quality turfgrass. Ecological factors in the development and maintenance of single species or complex mixtures of turfgrass change progressively as microclimate, nutrient, and cultural conditions change (Potter and Braman 1991; Schmidt and Blaser 1969). Grasses that become dominant in turfgrass mixtures are characterized by 1) wide adaption to natural and imposed environmental conditions, 2) excellent persistence under stress, and 3) a rhizomatous or stoloniferous growth habit.

Initial seeding ratios, clipping schedules and techniques, soil fertility, irrigation practices, seasonal variation in light and temperature, and use of growth regulators will affect the competitive relationship of turfgrasses. Mowing practices altered the competitive relationship of seedling mixtures of Kentucky bluegrass and perennial ryegrass (Brede and Duich 1984a). Close mowing after planting favored the bluegrass and aided in its establishment. However, early emergence of the ryegrass did stabilize the seedbed allowing mowing to begin sooner than would have been possible with other turfgrasses. Brede and Brede (1988) observed early soil stabilization after rapid establishment of annual ryegrass in a tall fescue-annual ryegrass mixture. A close clipping shortly after emergence of the ryegrass allowed the slower developing tall fescue to achieve at least 50 percent ground coverage within 60 days.

Brede and Duich (1986) also observed the competitive interaction of Kentucky bluegrass and perennial ryegrass with the grass weed species, annual bluegrass. The investigators observed that dominance of a turfgrass species in this mixture results from their interaction above ground,

below ground, or both. The competition for light, moisture, and nutrients tends to induce cyclic declines among the competitors. Kentucky bluegrass dominated the ryegrass when competition was confined to above ground factors. When interaction was below ground, ryegrass out-competed Kentucky bluegrass for moisture and nutrients. The ability of ryegrass species to aggressively compete for moisture and nutrients has been well documented (King 1971; Milthrope 1961; Rhodes 1968). Under good growth conditions Kentucky bluegrass dominates both annual bluegrass and ryegrass. However, rapid tiller growth of both annual bluegrass and ryegrass give these species a competitive advantage during initial stand establishment or under resource stress conditions (Brede and Duich 1984b, 1986).

Gaussoin and Branham (1989) observed that removal of clippings, overseeding, without a growth regulator significantly reduced the density of annual bluegrass in creeping bentgrass plots. Use of high nitrogen fertility levels with a growth regulator (mefluidide) significantly increased the competitive ability of annual bluegrass compared to creeping bentgrass.

Seasonal variation in temperature will influence the ability of grasses to compete for dominance. Cultivars of Kentucky bluegrass have differential tolerance to heat stress, while several cultivars of perennial ryegrass had little significant difference to changing heat stress (Minner et al. 1983). Tolerance to heat stress may change seasonally within a single cultivar (Wehner et al. 1985). Selection of cultivars and species mixtures with stress tolerance to regional and local climatic patterns will minimize the decline of turfgrass quality (Holt 1969; Juska et al. 1969; Keen 1969; Minner et al. 1985; Youngner 1985; Wehner et al. 1985). Additional research to establish competitive patterns and the ecology of turfgrass species and cultivars is needed. Ecological and environmental information should be used to establish turfgrass mixes and cultural practices to maintain high quality turfgrass without implementation of chemical management strategies.

Use of turfgrass growth retardants has been suggested as a management option for manipulation of competitive turfgrass growth (Devitt and Morris 1989; Haley and Fermanian 1989; Kageyama and Widell 1989). Growth regulators or retardants are a diverse group of compounds used to block the plant hormone activity such as gibberellic acid synthesis (Kane and Smiley 1983; Shive and Sisler 1976). Use of growth retardants results in shortened stem internodes and reduced elongation of leaves and rhizomes (Kageyama and Widell 1989). Examples of growth retardant compounds include ethephon, flurprimidol, mefluidide, malic hydrazide, metsulfuron methyl, paclobutrazol, and sulfometuron methyl (Farm Chemicals Handbook 1991).

Growth retardants have been used in an attempt to 1) control the invasion of annual bluegrass in creeping bentgrass (Haley and Fermanian 1989; Kageyama and Widell 1989); 2) retard growth of warm-season turfgrass to reduce frequency of mowing (Devitt and Morris 1989; Rogers et al. 1987); 3) increase seed yields (Buettner et al. 1976); 4) reduce turfgrass growth and demand for water during drought periods (Mathias et al. 1971; Nielsen and Wakefield 1975; Watschke 1981); and 5) suppress the growth of overseeded cool-season species for conversion of greens to warm-season summer species (Fry and Dernoeden 1986; Mazur 1988). Suppression of annual bluegrass and eliminating the potential of weed invasion during seasonal species conversion will reduce the need for herbicide treatments.

Long-term quality of turfgrass has not been consistently improved with the use of growth retardants (Fry and Dernoeden 1986; Mazur 1988). Often additional nitrogen fertilization is required to offset damage to the turfgrass caused by use of growth retardants (Devitt and Morris 1989; Gaussion and Branham 1989; Kageyama and Widell 1989). Use of organic compounds for growth suppression has the potential for generating the same environmental and societal problems associated with the use of chemical pesticides. Assessment of the environmental impacts from the use of growth retardants should be included in the category of other chemical control options. Although growth retardants allow manipulation of competitive interactions among turfgrass species, use of these chemical compounds does not necessarily constitute an alternate control option.

Alternate Nontoxic Compounds. The use of nontoxic compounds has recently received renewed attention for alternate control of turfgrass pests and diseases (Klein 1982). Van Leeuwen and Van der Muelen (1928) observed that china clay, chalk, and slaked lime effectively repelled Japanese beetles. A relationship between higher soil pH levels and lower Japanese beetle populations was observed in Ohio (Polinka 1960a, 1960b; Wessel and Polinka 1952). This relationship was established on sites with naturally occurring high pH values and sites treated with lime. However, recent laboratory studies failed to demonstrate reduced hatching and survival of grubs in soil at pH ranging from 5.5 to 7.5, which is the general range for growth of turfgrass (Vittum and Tashiro 1980). Additional research is needed to clarify the potential relationship of soil pH and disease infestations.

Environmental Stress, Water and Nutrient Management, and Cultural Control. Environmental stress, especially the extremes of temperature and water, have a direct and indirect impact on turfgrass health and resistance to pest infestation and disease (Beard 1973, 1982; Chapman 1979; Colbaugh and Elmore 1985; Nus and Hodges 1985; Smiley 1983). Many of the routine cultural practices on golf course turfgrass, including irrigation, fertilization, and mowing have a direct effect on the incidence of pest and disease damage (Beard 1973, 1982). Understanding the relationship of environmental, soil moisture and nutrient conditions, and cultural impacts to pest and disease control is essential in development of TMS (Potter and Braman 1991; Villani and Wright 1981, 1989). The following are examples of research regarding the relationship of nutrient and water management to pest and disease control.

Winter and low temperature related stress results in increased susceptibility of turfgrass to snow molds, dead spot, and snow scald (Smiley 1983). Low light conditions, especially under shade trees, combined with high humidity and moderate temperatures make succulent grass shoot tissue especially susceptible to fungal infection (Beard 1982; Britton 1969; Nilsen and Hodges 1980). Seasonal changes in photoperiod, quality of light, and age of turfgrass affects the ability of turfgrass to tolerate pathogenesis of leaf spot disease (Drechslera sorokiniana) (Nilsen et al. 1979a, 1979b). Longer photoperiods (14 hr) and balanced light conditions during the summer inhibits infection of Kentucky bluegrass by leaf spot disease. Depending on leaf age, shorter

photoperiods (10 hr) with changed color-biased light quality (blue-biased) increases expression of the fungal disease.

Climatic conditions and water management also influence weed infestations on golf courses (Beard 1982; Colbaugh and Elmore 1985). Climate in part dictates the particular set of weed species in a specific region (e.g. Holt 1969; Juska et al. 1969; Keen 1969). However, annual bluegrass, crabgrass, and similar species are exceptions and have become widespread across North America (Beard 1982). Seasonal fluctuations in temperature and moisture conditions will influence germination, survival, and competitive adaptation to the turfgrass environment. Crabgrass and goosegrass are favored by high temperature conditions, while shepherds purse is favored by cool temperatures in the spring and fall. Many weed species are favored by frequent irrigation and overwatering (Beard 1982). Overwatering of golf courses is a major factor encouraging invasion of turfgrass by annual bluegrass (Colbaugh and Elmore 1985). A combination of wet soil and excessive irrigation is also associated with invasions of crabgrass, chickweed, and nutsedge. Quackgrass, goosegrass, dandelions, plantain, yarrow, and white clover are very tolerant of low soil moisture conditions.

The frequency and duration of precipitation and irrigation often determine the suitability of turfgrass as a habitat for fungal pathogens (Colbaugh and Elmore 1985; Dernoeden 1989; Smiley 1983). Continuously wet conditions favor development of gray leaf spot, Pythium blight, brown patch, and various seedling diseases. Diseases favored by wetting-drying cycles or low moisture conditions include dollar spot, fairy ring diseases, Fusarium diseases, Bipolaris and Drechslera diseases, and rusts. Frequent light irrigation reduces the susceptibility of turfgrass to damage by these diseases. Reduction in excessive accumulation of thatch decreases habitat for survival of pathogenic saprophytic fungi (Beard 1973; Smiley 1983).

Water management practices and temperature influence insect and nematode infestations in golf course turfgrass and lawns (Colbaugh and Elmore 1985). Insect life cycles, patterns of dispersal, and survival are closely connected with seasonal variation in precipitation and temperature (Davidson and Roberts 1968; Davidson et al. 1972; Gaylor and Frankie 1979; Potter 1981, 1983; Potter and Gordon 1984; Regniere et al. 1981). Egg deposition and survival of white grubs are reduced in very wet or dry soils (Ladd and Buriff 1979). Dry conditions and low soil fertility was associated with increased damage of pasture Kentucky bluegrass by white grubs (Graber et al. 1931). Drought and heat stress also reduces the viability of grubs of the southern masked chafer (Potter 1981, 1983; Potter and Gordon 1984). Continually moist soils are more conducive to grub feeding and mole cricket activity than drier soils (Colbaugh and Elmore 1985). Frequent application of water increases the survival of sod webworm and fall army worms in turfgrass. However, drier turfgrass conditions and high temperatures are conducive to damage by scale insects, chinch bugs, leaf hoppers, and eriophyid mites (Colbaugh and Elmore 1985).

Water management influences nematode related diseases on golf courses. Soil nematodes are dependent on free water in soil for mobility, parasitic activity, and reproduction. Moist and porous sandy soils receiving heavy irrigation are susceptible to nematode infestation and damage. In the absence of free water, nematode damage is limited. Water conservation practices will restrict the movement and activity of nematodes (Colbaugh and Elmore 1985).

Effectiveness of soil pesticides also is influenced by soil moisture conditions, water management practices, and life-stage of the pest population (Ahmadi et al. 1980; Colbaugh and Elmore 1985, Harris 1972, 1982). Infiltration of insecticides is required for effective control of several insect and nematode species (e. g. Colbaugh and Elmore 1985; Reinert 1974; Reinert 1979; Shetlar et al. 1988; Vittum 1985). However, infiltration of insecticides past the thatch layer or surface soil layers may result in increased and undesirable leaching losses of pesticides. In addition to turfgrass growth and maintenance requirements, irrigation schedules should be designed to reduce site specific infestations of weeds, insects, and disease. Consideration of site specific soil, climate, irrigation, and cultural practices need to be integrated into pest management programs (Engel and Ilnicki 1969; Schmidt and Blaser 1969; Short et al. 1982). In general, the duration and timing of irrigation cycles should be scheduled to limit current pest pressures. Frequent and light irrigation is often necessary on severely compacted soils to ensure infiltration; however this practice 1) favors germination and survival of weed seedlings; 2) ensures a humid environment that favors many insect pests; and 3) enhances production of fungal spores and infection of drought stressed plants.

Cultural and fertility practices also affect pest and disease resistance of turfgrass. Mowing practices has been shown to affect disease resistance. The potential for the occurrence of disease in turfgrass is enhanced when 1) the mowing height is shorter than the optimum for a species, and 2) increased mowing frequency causes excessive damage to leaf tips (Beard 1982). Fertilization practices also influence disease control in turfgrass culture (Beard 1982; Dernoeden 1987; Smiley 1983). High potassium levels usually decrease the severity of fungal diseases. Except for dollar spot, red thread, and rust, most turfgrass diseases are promoted by excessive nitrogen fertilization (Beard 1982; Chapman 1979). Adequate nitrogen fertilization of turfgrass, however, is necessary to maintain turfgrass vigor and density and to reduce the invasion by weeds. Using appropriate nitrogen fertilization practices will reduce turfgrass diseases and their symptoms. Application of nitrogen to chewings fescue sod significantly reduced the intensity of yellow tuft disease (Sclerophthora macrospora) (Dernoeden and Jackson 1980). Despite masking of the disease symptoms, the investigators observed that fertilization did increase the sporulation capacity of this downy mildew fungus. Use of ammonium chloride alone and phenyl mercury acetate plus ammonium sulfate has been used to control take-all patch disease (Gaeumannomyces graminis var. avenae) in creeping bentgrass (Dernoeden 1987). Granular sulfur and pH control were not effective for control of this disease in bentgrass.

The relationship of fertility and pH to insect and weed infestation is complex. Reduced fertility levels will slow development of succulent tissue preferred as insect and fungal food sources. Lower fertility levels will favor low fertility weeds and also decrease the nutrient levels available for high fertility weeds. However, nutrient deficiencies will weaken turfgrass resistance to disease and limit the ability of turfgrasses to compete with weeds for limited nutrient and water

resources (Beard 1982; Murray and Powell 1979).

High levels of soil phosphorus have been found to be conducive for encroachment of annual bluegrass to turfgrass, increasing annual bluegrass density, and increasing the survival and growth of bluegrass in monoculture (Dest and Allinson 1981; Varco and Sartain 1986; Waddington et al. 1978). Waddington et al. (1978) also observed that increased levels of potassium increased the growth of annual bluegrass and its invasion of turfgrass. Application of sulfur and reduction of soil pH has been used to reduce invasion of turfgrass by annual bluegrass and to reduce its growth in monoculture (Goss 1974; Varco and Sartain 1986). Varco and Sartain (1986) observed an interaction between added phosphorus, calcium hydroxide, and sulfur on the growth of annual bluegrass. Establishment and growth of annual bluegrass was enhanced overall by additions of phosphorus and calcium. However, this positive influence on growth was modified by the acidifying effect of sulfur in the root zone. Annual bluegrass infestations of turfgrass could be reduced by limiting additions of phosphorus and acidifying the soil pH to the range of 5. However, turfgrass infested with annual bluegrass must be able to tolerate these conditions (Varco and Sartain 1986).

The effect of pH on white grub survival in turfgrass has been considered as a control option (Klein 1982, 1989). As previously mentioned, Polivka (1960a, 1960b) observed that Japanese beetle oviposition and subsequent grub survival was adversely affected by high soil pH levels. However, Vittum (1984) and Vittum and Tashiro (1980) found that changes in soil pH levels had little effect on either Japanese beetles or European chafer grubs. The preferred pH range for growth of turfgrass is 5.5 to 6.5 for bentgrasses and fine-leafed fescues; 6.0 to 6.5 for ryegrasses; 6.0 to 7.0 for bermudagrass, Kentucky bluegrass, and zoyiagrass; and 6.2 to 7.2 for annual bluegrass (Beard 1973, 1982; Madison 1982). Changing soil pH outside of the optimum range for growth of good quality turfgrass is not a practical approach for control of pests.

Effective long-term control of disease and pests on golf courses requires cultural practices that encourage vigorous growth of turfgrass. Use of pesticides without appropriate cultural practices provides only short-term control of disease and pests in turfgrass (Murray and Powell 1979; Short et al. 1982). Manipulation of cultural practices to promote high quality turfgrass, control undesirable growth conditions, and reduce pest and disease damage is a significant component of TMS.

3.4.6 Monitoring

Another important component of the TMS will be the development of a comprehensive monitoring network that will be used to quickly and accurately assess any deterioration to onsite or offsite water ways. Components of the monitoring system should include the following:

1. Water quality evaluation prior to site construction and development in order to establish existing (baseline) conditions and to assess the extent to which present agricultural practices have impacted both surface and groundwater. This should be conducted by collection of groundwater samples from various site locations, especially areas where shallow ground water aquifers may exist. In addition, surface water runoff during storm conditions should be collected and analyzed. All routes of water loss from the site should be sampled. The choice of analytes to be measured should be constructed around recommendations from the State of Hawaii's 12 conditions for golf course development.

2. Water quality and air quality data should be collected during construction phases to monitor loss of potentially harmful chemicals from the site. This will be conducted at an interval recommended by the State of Hawaii. Groundwater and surface water quality should be assessed to insure that construction activities are having a minimal influence on water quality.

3. After course construction, a permanent monitoring network should be constructed. Sample collection devices should include groundwater observation wells, surface water catchments or weirs, drainage samplers (especially from greens), soil lysimeters, and several high volume air samplers. The number and placement of the devices should be determined from climatic and hydrologic information and with consultation from the State of Hawaii.

4. The golf course superintendent should select a laboratory to perform the analyses based on results of blind samples sent to a number of potential laboratories. Those performing best on the samples should be considered for contracts based on cost, sample turn around, and over all reliability.

5. Data should be analyzed quickly and then integrated into other TMS information. Based on results, cultural or chemical practices at the site can be altered to remedy the situation.

6. Appropriate data documentation, chain of custody, and other Contract Laboratory Practices (CLP) should be employed such that data collected will be of known accuracy and precision.

7. Monitoring frequency should be established after consultation with representatives of the State of Hawaii based on specific site information.

3.4.7 TMS and Construction Activities

Sediment and Runoff Control with Turfgrass: Processes and Control for Established Turfgrass

Use of turfgrass and forage grasses in pastures and crop rotations, reduced tillage systems, construction sites, highway right-of-way, stabilization of mine spoils, and agricultural buffer strips have mitigated serious erosion and sediment loss in both rural and urban environments (Barfield and Albrecht 1982; Barnett 1965; Barnhisel et al. 1990; Bennett 1979; Dillaha et al. 1988; Hafenrichter et al. 1968; Koehler et al. 1982a, 1982b; Moldenhauer 1979; Richards and Middleton 1978; Schwab et al. 1981; Stewart et al. 1975, 1976). Use of pasture and forage grasses also reduces sediment and nutrient loading of surface water through reduction of sediment transport and movement of soluble chemicals in runoff water (Khaleel et al. 1980; Sweeten and Reddel 1978). However, under certain conditions, overloading of conservation turfgrass systems with nutrients (e.g., vegetative filter strips) potentially may increase the content of soluble nutrients in surface runoff (Balogh and Madison 1985; Reddy et al. 1980).

The process of surface runoff and channeled drainage links turfgrass systems with streams, rivers, and lakes. Runoff water is the medium of transport for eroded soil and dissolved chemicals (Daniel and Schneider 1979; Watson 1985). Improvement of infiltration, soil stability, and reduction of runoff losses of water are factors associated with improved soil and water conservation under turfgrass and forage grasses (Bennett 1979; Watson 1985). Numerous studies have demonstrated that loss of water, sediment, and entrained chemicals in surface runoff is effectively reduced by established turfgrass plots and grass buffer strips (Barfield et al. 1979; EPA 1983; Gross et al. 1990, 1991; Hayes et al. 1978; Schuler 1987; Tollner et al. 1977; Welterlen et al. 1989; Young et al. 1980). Reduction in the amount of water lost at runoff increases the amount of water available for plant intake and infiltration through the soil.

Turfgrass is especially effective in reducing runoff and sediment losses in comparison to bare soil and conventional systems (Gross et al. 1987, 1990, 1991; Koehler et al. 1982a). Factors controlling the extent of erosion and runoff from turfgrass are:

1. Rainfall intensity and timing of initiation of runoff,
2. Antecedent soil moisture conditions,
3. Sod vs seeded turfgrass,
4. Soil texture and structure, and
5. Site topography and landscape design.

Tall fescue, Kentucky bluegrass, Bermudagrass, orchardgrass, bromegrass, perennial rygrass, and bahiagrass all have been used as conservation turfgrasses (Barnhise et al. 1990; Bennett 1979; Hafenrichter et al. 1968; Jean and Juang 1979).

Gross et al. (1990) conducted a study of sediment and runoff losses from fertilized and unfertilized plots of sodded tall fescue and Kentucky bluegrass. Event and annual losses of runoff water and sediment were extremely low for the rainfall events that produced runoff. Total annual runoff from the sodded treatment plots ranged from 0.97 to 14.1 mm ha^{-1}. Runoff was significantly greater from the plots receiving a granular vs a liquid urea treatment during the first year of the experiment. However, runoff from the fertilized plots was not significantly different from the sodded control plots. Total annual loss of suspended sediment from the turfgrass plots ranged from 2.01 to 24.87 kg ha^{-1} (0.001 to 0.01 tons ac^{-1}). Fertilizer treatment did not affect the level of suspended sediment in the surface runoff. This experiment site was previously used to examine runoff losses related to different tobacco management practices (Angle 1985). During this agronomic study, Angle estimated that annual runoff averaged 33.4 mm ha^{-1}. Reported runoff and sediment losses from other row crops also are much higher that from turfgrass plots (see Alberts et al. 1978; Andraski et al. 1985a; Klausner et al. 1974 McDonnell and McGregor 1980; Romkens et al. 1973; Sharpley 1985).

In a simulated rainfall study of tall fescue turfgrass plots with variable seeding and tiller density, Gross et al. (1991) also observed low rates of runoff and sediment losses. The mean density of the turfgrass plots ranged from 0 to 5692 tillers m^{-2}. Increasing intensity of simulated rainfall did increase the runoff and sediment load from all of the turfgrass plots. The plots with turfgrass cover (867-5692 tillers m^{-2}) significantly reduced runoff and sediment losses compared to the plots with a bare soil surface for the high-intensity rainfall treatment. There was no significant difference in runoff or sediment transport between the 867, 2056, 3080, and 5692 tillers m^{-1} density plots at the medium- and low-intensity rainfall treatments. Even at relatively low density, turfgrass plots significantly reduce runoff and sediment losses compared to bare soil surfaces. Gross et al. (1991) attributed the reduction in runoff and sediment movement to an increase in infiltration, hydraulic resistance, and surface storage capacity. Runoff and sediment losses reported for row crops using simulated rainfall techniques are significantly greater than those reported for this turfgrass study (see Andraski et al. 1985b; Baker and Laflen 1982; Baker et al. 1978; Sauer and Daniel 1987).

The favorable results of studies demonstrating reduced surface runoff, sediment, and chemical losses from turfgrass plots (e.g., Gross et al. 1990, 1991; Harrison 1989) should be extrapolated to the field, golf course, or watershed level with care. Many of the hydraulic and transport processes operating at the field scale are difficult to predict compared to relatively small (20-150 m^2) and well-tended plots (Anderson et al. 1989; Leonard 1988, 1990). Although runoff and sediment losses from turfgrass plots studies indicate surface losses are in general very low, none the less, runoff and some sediment losses still can occur from turfgrass systems. The reduced volume and velocity of runoff from turfgrass conservation systems will selectively erode small soil particles. Compared to the bulk soil, the smaller eroded soil particles have a higher capacity per unit area to absorb nutrients and organic chemicals. (Caro 1976; Frere 1976; Sharpley 1985; Wauchope 1978). Also in well-drained turfgrass soils, rapid filtration and leaching reduces surface runoff, but increases the potential for subsurface transport (Carrow 1985). This drainage water will eventually (1) migrate to tile drains and emerge as translocated surface runoff or (2)

percolate past the root zone. Displacement of drainage water with entrained chemicals or sediment is not necessarily the intention of conservation and environmental quality practices. During intense rainfall events or antecedent soil saturation with irrigation water, sufficient runoff could occur to transport sediment or relatively mobile chemicals (Balogh and Anderson 1992; Hall et al. 1987). Movement of water and chemical partitioning at the field scale should be considered when evaluating the potential edge of golf course losses of water, sediment, and applied chemicals (Balogh and Anderson 1992; Walker and Branham 1992).

Runoff and Sediment Control During Site Construction and Turfgrass Establishment

Land disturbance during residential construction or construction of new golf course facilities exposes bare soil to water and wind erosion, surface crusting, and loss of soil physical structure (Richards and Middleton 1978). These conditions may result in significant surface loss of water, sediment, and nutrients (Beard 1973, 1982; Daniel et al. 1982)

Daniel et al. (1979) observed that annual sediment losses from residential construction sites ranged from 13.4 to 26.9 Mg ha^{-1} (6 to 12 tons ac^{-1}). On average, sediment yield from the construction sites was 20 times higher compared to adjacent agricultural watersheds. Wolman and Schick (1967) determined that annual sediment yield from construction sites varies from 38 to 251 Mg ha^{-1} (17 to 112 tons ac^{-1}) of sediment annually. The amount of sediment lost from disturbed construction sites depends primarily on: (1) the duration and extent of disturbance, (2) The volume and rate of surface runoff, (3) the configuration and topography of the exposed site, and (4) the use of mitigating soil conservation practices.

After turfgrass has been established, the level of runoff water, sediment, and chemical transport by surface processes is significantly reduced. Reduction in sediment losses during construction, sediment losses from altered drainage systems, and thermal pollution of waterways is needed for protection of aquatic environments (Klein 1990).

Design Considerations to Reduce Runoff and Erosion

Management practices designed to reduce erosion and loss of runoff water during and after construction projects have been reviewed by Forrest (1988), Klein (1990), Richards and Middleton (1978), Schwab et al. (1981), and Schuler (1987). Guidelines for soil and runoff control measures and water conservation practices are summarized from these sources. Immediate coverage of bare soil surfaces by seeding with turfgrass or placement of sod reduces the risk of erosion. Surface coverage provides important protection against wind erosion. Restoration of turfgrass, wooded areas along streambanks, and adapted natural vegetation are some of the best means for long-term control of erosion.

Potential adverse environmental impacts, including surface runoff, flooding, and erosion, should be an *essential consideration in golf course design. Design criteria should minimize the need for site disturbance and reshaping of natural landscape elements.* The intensity of site disturbance and reshaping with heavy equipment is directly related to serious short- and long-term erosion and runoff problems. Loss of topsoil and compaction, resulting from construction and equipment traffic, will significantly increase sediment transport from the construction site. Avoiding design elements that encourage development of gullies, reroute streams, or change the natural surface and subsurface drainage is critical for long-term site stability. Long steep slopes with smooth surfaces and compaction of surface soils are conditions especially conducive to erosion problems.

During construction, temporary erosion control devices will mitigate offsite transport of eroded sediment. These practices include: (1) constructing of temporary silt fences to stop particle transport; (2) construction of small check dams or weirs to flatten upstream slopes and decrease the velocity of runoff; and (3) use of temporary mulches, matting, or blankets to reduce erosive forces until vegetation or long-term measures are in place.

Long-term erosion and runoff control techniques should be used on sites with highly erosive soils, steep banks, or design elements conducive to rapid runoff and sediment transport. A wide range of techniques include the following:

1. Planting of native vegetation with soil stabilizing canopies and root systems.
2. Placement of short (6 in.) silt fences on steep slopes to trap sediment, reduce runoff velocity, and allow development of vegetation.
3. Use wattling on sites with highly erosive soils.
4. Construction of terraces on steep slopes with drainage swales that collect and divert runoff water.
5. Construction of detention ponds within drainage channels which reduce runoff velocity and provides temporary storage for eroded sediment.
6. Avoid irrigation rates or duration which may cause runoff of water, resulting from irrigation of turfgrass at rates greater that soil infiltration rates and soil storage capacity.
7. Repair leaking irrigation systems to reduce potential erosion problems on steep or unstable slopes.

Golf courses also should be constructed to minimize disturbance of vegetation in the vicinity of drainage ditches or stream banks. Disturbed embankments will be susceptible to erosion from stream scour and slumping. On areas with concentrated flow velocities, permanent stream bank and shoreline stabilization should be practices. Long-term stabilization structures include interlocking block walls, riprap, gabion walls, and planting trees with stabilizing root systems.

3.4.8 Additional Water Quality Issues Related to TMS

Water Conservation and Cultural Practices: Mowing, Fertilization, and Irrigation

Mowing, fertilization, and irrigation are the primary cultural practices used to minimize water losses and increase water conservation on golf courses (Carrow et al. 1990; Shearman 1985). *Mowing* height, frequency of cutting, and mowing equipment affect water use on golf courses. Increased water use has been observed for both warm-season and cool-season grasses with increased mowing height (Biran et al. 1981; Feldhake et al. 1983; Madison and Hagan 1962; Mitchell and Kerr 1966; Parr et al. 1984; Shearman and Beard 1973; Sprague and Graber 1938). High cut turfgrass with an open canopy, lower shoot density, and greater leaf area has lower canopy resistance to ET and increased water consumption. Although the effects of mowing frequency are not always consistent, reducing the leaf area, shoot size, and rooting depth by more frequent mowing decreases water consumption (Shearman 1985). Several other studies indicate that increased mowing frequency will increase shoot density and leaf succulence (Hart and Burton 1966; Madison 1960; Madison and Hagen 1962; Prine and Burton 1956). Manipulation of mowing height and frequency for specific turfgrass species and cultivars to enhance depth of rooting, decrease leaf area, and increase canopy resistance can be used to enhance water use efficiency.

Sharpness of the mowing blade also influences water use efficiency of turfgrass (Beard 1973; Shearman et al. 1980a). It has been speculated that water loss will increase, resulting from mutilation of grass leaves with a dull blade. However, in field studies comparing sharp and dull blades, mowing with a dull blade decreases long-term water use by decreasing leaf area, turfgrass quality, and verdure (Shearman et al. 1980a; Steinegger et al. 1983).

Fertilization influences water use indirectly through changes in growth processes. Research has demonstrated that turfgrass growth and water use rates increase with increased mineral, especially nitrogen, nutrition (Carroll 1943; Feldhake et al. 1983; Krogman 1967; Mantell 1966; Power 1985; Shearman and Beard 1973). Feldhake et al. (1983) observed a 13% increase in water use when 0.4 kg 100 m^2 of nitrogen was applied monthly to Kentucky bluegrass during the spring and summer compared to a single spring application. Shearman and Beard (1973) observed the direct relationship of increased water use of "Penncross" creeping bentgrass and nitrogen fertility levels in a controlled environment study. They observed an increase in the water use rate as nitrogen application increased from 0 to 2 lb. of nitrogen per 1000 ft^2. Water use declined as fertilization rates increased from 2 to 6 lb. of nitrogen per 1000 ft^2. Changes in leaf width, shoot growth, and shoot density, resulting from nitrogen fertility levels, were positively correlated with changes in the water use pattern. Increased root and shoot growth occurs as nitrogen nutrition is raised from the deficiency level, but continues after the growth optimum is achieved (Beard 1973). Root growth is suppressed or ceases entirely for turfgrass fertilized at rates beyond growth requirements. With diminished root capacity, turfgrass grown under excessive nitrogen fertilization regimes are more susceptible to wilt and drought injury when exposed to high evaporative demand (Juska and Hanson 1967).

Kneebone and Pepper (1982) compared the water use efficiency of several warm-season and cool-season turfgrasses grown under low- and high-maintenance conditions. Low-maintenance grasses receive 5 g of nitrogen m^2 bimonthly and high-maintenance grasses receive 5 g of nitrogen m^2 monthly. Although the quality of the high-maintenance turfgrass was much better than the low-maintenance turfgrass, consumptive water use was approximately 334 mm less with a low-maintenance system. This research indicates there is considerable potential for water conservation by manipulating fertility levels within specified quality criteria (Shearman 1985).

Several studies on timing of application and interaction of nitrogen, phosphorus, and potassium suggest that fall application of nitrogen and phosphorus compared to spring application results in enhanced ability of turfgrass to recover from moisture stress (Powell et al. 1967; Schmidt and Breuninger 1981; Snyder and Schmidt 1974). Sufficient application of potassium benefitted turfgrass recovery from moisture stress regardless of nitrogen and phosphorus practices (Schmidt and Breuninger 1981). However, application of nitrogen after the onset of dormancy may result in excess leaching losses of nitrogen.

Research on water use in relation to potassium and phosphorus fertilization is limited (Carrow et al. 1990; Shearman 1985). Increased rooting density and depth, resulting from potassium fertilization (Monroe et al. 1969), may be associated with increased drought resistance in turfgrass (Schmidt and Breuninger 1981; Shearman 1985).

The relationship of mineral nutrition and water use is complicated, yet very important. Turfgrass managers should consider fertility programs that meet the needs of turfgrass, but also avoid excessive growth and unnecessary water stress. Water use efficiency of turfgrass should be considered in relation to turfgrass quality, the ability of turfgrass to recuperate from stress, and reduced water use. Production of dry matter should not be a water use issue for turfgrass on golf courses, residential lawns, and conservation turfgrass systems. Additional research on the relationship of (1) rate of potassium application, (2) nitrogen carrier, (3) timing of application, and (4) drought resistance is needed.

Irrigation, in many parts of the United States, is required to supplement precipitation for maintenance of high-quality turfgrass (Carrow et al. 1990; Watson 1985). Irrigation practices alone and their interaction with other practices affect water use and drought resistance of turfgrass (Power 1971; Shearman 1985; Tovey et al. 1969). Although an accepted practice for turfgrass irrigation is deep and infrequent watering (Shearman 1985), this recommendation does not provide specific information on the amount needed or the timing of application.

Adjustment in the frequency of irrigation will affect water use requirements. Several studies have shown that irrigation on the basis of observed need rather than calendar scheduling results in adequate maintenance of turfgrass quality and reduction of water use. Delays in irrigation scheduling on the basis of visual need reduced water use in several studies (Biran et al. 1981;

Peacock and Dudeck 1984; Shearman and Beard 1973; Tovey et al. 1969). Use of visual observation resulted in a 33% reduction of water use on "Penncross" creeping bentgrass (Shearman and Beard, 1973). However, use of visual indicators of wilt alone to reduce irrigation frequency may result in a decline of vegetative cover and turfgrass quality (Shearman and Beard 1973; Tovey et al. 1969).

Using visual indicators as a control and with tensiometers and pan evaporation as the guide to irrigation scheduling, Marsh et al. (1980) and Younger et al. (1981) used 55% less water on warm-season grasses without loss of turfgrass quality. However, on the cool-season grasses, reduced irrigation frequency resulted in decreased quality of tall fescue and Kentucky bluegrass. In the year after full root development, irrigation scheduling by soil moisture deficit did not reduce the quality of the tall fescue grown as turfgrass. Using neutron probe techniques, Gerst and Wendt (1983) assessed the interaction of irrigation frequency and rate on a mature Bermudagrass lawn. Irrigation was scheduled when total soil water content was 41-42 cm in the upper 1.83 m of the soil profile. The best sustained turfgrass growth, with lower frequency and poor quality, was observed at the most frequent and lowest rate of application (2.3 cm). Intermediate (6.1 cm) and high (11.9 cm) rates of irrigation with less frequent application resulted in deeper movement of water in the profile, and good turfgrass quality. The high application rate also required greater frequency of mowing and resulted in water losses by leaching. The intermediate irrigation treatment resulted in the highest water use rate. In addition to water use considerations, irrigation strategies should be designed to reduce the potential for the negative impacts of moisture leaching losses.

Depth of soil wetting affects water use and drought avoidance by turfgrass. Light applications of water encourage shallow rooting, while deep wetting encourages deep root growth (Madison and Hagan 1962). With deeper and more extensive root systems, turfgrass are able to use moisture from a greater portion of the soil profile. Deep rooting enhances the ability of turfgrass to avoid stress, wilt, and the need for increased supplemental irrigation as compared to shallow rooted turfgrass (Shearman 1985).

Several studies using pan evaporation, electronic soil moisture monitoring systems, tensiometers, canopy temperature indices, and soil moisture-controlled irrigation systems have all resulted in significant reductions in water use without reduction of Kentucky bluegrass quality (Carrow et al. 1990; Kneebone and Pepper 1982; Marsh et al. 1980; O'Neil and Carrow 1982; Throssell et al. 1987). Adjustment of irrigation frequency using electronic soil moisture sensing devices, tensiometers, canopy temperature indices, and pan evaporation reduces unnecessary applications of water. Turfgrass managers utilizing this approach to water conservation should consult local data on acceptable levels of soil moisture deficits in relation to maintenance of turfgrass quality. Onsite experimentation may be required to program the equipment for microclimate variations (Shearman 1985). Manipulation of irrigation rates and schedules has high potential as a water conservation practice.

Irrigation systems and design methods which are state-of-the-art irrigation systems that when properly designed, programmed correctly, and installed within design criteria, conserve water and apply it in accordance with the actual needs of the turfgrass plant (Carrow et al 1990). Further, systems equipped with single-head controls and a recycling capacity apply water commensurate with infiltration and percolation capacity of the soil. Appropriate integration of sprinkler heads, valves, and controllers are important criteria for conserving irrigation water (Meyer and Camenga 1985).

Controllers are the key to water conservation in irrigation systems (Carrow et al. 1990). Controllers are electrical timing devices used to open or close valves that regulate the flow of water to the sprinkler heads. They usually are of two types: (1) solid state and (2) electromechanical. Electronic (solid state) controllers are usually accurate within 1 min, an obvious saving of water over the 1-4 min accuracy range of electromechanical types. Computer-controlled systems may be operated from ET rates calculated from on-site weather stations or other programs based on regional ET values. The California Irrigation and Management Information System (CIMIS) is an example of a program that supplies regional ET values for computer-controlled irrigation systems. These generalized ET values are based on generalized average solar radiation and historical data (Anonymous 1987; Sasso 1988). Annual savings of up to 40% water use and 40% energy cost have been speculated when using low pressure sprinkler heads with a computerized controller (Anonymous, 1987).

Use of soil moisture sensing devices to determine the frequency of operation for controllers is another means of effective conservation of water for irrigation of turfgrass (Carrow et al. 1990; Meyer and Camenga 1985). These devices may be used to cancel preselected start and stop times of irrigation systems when soil moisture levels reach a preselected level. Soil moisture sensors are subject to soil variability. However, when properly programmed, the combination of sensors and controllers have been shown to conserve 25-40% of the water recommended for home lawns (Carrow et al. 1990).

Soil manipulation and other cultural practices also influence the need for irrigation of turfgrass. In turfgrass systems, soil compaction reduces bulk density, aeration, and water retention capacity, as well as turfgrass shoot/root growth and development (O'Neil and Carrow 1982; Thurman and Pkorny 1969). Changes in soil physical properties will affect soil hydraulic processes and irrigation requirements (Carrow 1985; Carrow et al. 1990). In two field studies, soil compaction reduced the rate of evaporation by 20% in old Kentucky bluegrass turfgrass (O'Neil and Carrow 1982) and 21-40\9% in perennial rygrass turfgrass (O'Neil and Carrow 1983). Similar results were obtained in a greenhouse study using perennial ryegrass (Stills and Carrow 1983). Cultivation and aeration practices are designed to reduce the negative effects of soil compaction (Carrow 1985). Although limited data is available regarding the effects of turfgrass cultivation on water use, increased hydraulic capacity, water retention, and turfgrass growth may increase water use on cultivated soils (Sherman 1985).

Other practices and soil conditions will influence irrigation scheduling and water use patterns. Syringing may influence the water use efficiency of turfgrass. However no data is currently

available to document speculation on enhanced water use efficiency (Dipaola 1982; Shearman 1985) associated with syringing. Maintaining irrigation equipment to insure proper rates of application and minimizing leakage also reduces unnecessary loss of water during turfgrass irrigation (Marsh 1969).

Use of antitranspirants, wetting agents, and plant growth regulators have all been suggested as potential chemical strategies for increased water use efficiency and water conservation. Antitranspirants have been used to decrease evapotranspiration in several nongrass species (Shearman 1985). Testing of five potential antitranspirants on "Penncross" creeping bentgrass and "Tifway" Bermudagrass demonstrated significant reductions in ET using a mixture of phenylmecuric acetate, Aqua-Gro (a commercial wetting agent), and beta-naphthoxy-acetic acid caused browning of the grass shoots and eventual death of the turfgrass. Several pesticides, including siduron and benefin, also have indirect antitranspirant effects (Shearman 1985; Shearman et al. 1980b). The observed decline in water use was associated with other detrimental effects of the pesticide on shoot and root growth, turfgrass density, and reduction in drought tolerance.

Use of wetting agents and surfactants has been found to increase infiltration rates and irrigation use efficiency on turfgrass systems with hydrophobic thatch, sand, or black layers (Carrow 1985; Letey et al. 1963; Moore 1979; Pelishek et al. 1962; Templeton and Rodriguez 1988; Templeton et al.1989; Wilkenson and Miller 1978). Improved soil water retention and reduced ET also have been attributed to the application of soil wetting agents (Law 1964; Madison 1966). Shearman (1985) suggested that use of wetting agents has only a limited and indirect role in water conservation on turfgrass systems.

Use of plant growth regulators (PGRs) or turfgrass growth retardants for suppression of growth and reduction of water use has also been suggested by several investigators. Research has shown that PGRs will reduce transpiration rates in warm-season and cool-season turfgrasses (Johns and Beard 1982; Shearman 1985). Use of PGRs has shown promise for reduction of turfgrass growth rates and enhancement of water conservation. However, development of chemical management strategies for water conservation has limited potential considering their current social and environmental disadvantages.

Use of alternate sources of water is another water conservation strategy practiced on golf courses (Butler et al 1985; Watson 1985). Use of nonpotable water and wastewater reduces the pressure on potable drinking water sources, reduces depletion of groundwater, and potentially enhances the quality of water emerging from turfgrass systems. However, alternate sources of water, especially saline water, must be used with care. High salt content, contamination with toxic levels of micronutrients, reduction in available oxygen, silting of water storage areas, and increased damage to irrigation equipment caused by heavy loads of suspended solids are all potential problems associated with use of nonpotable water resources (Bulter et al 1985). Use of pH amendments, appropriate irrigation and drainage line spacing, periodic leaching of accumulated salts, and selection of salt-tolerant grasses are strategies to avoid problems associated with saline water and wastewater sources (Butler et al. 1985; Devitt and Miller 1988; Harivandi 1982; Lunt et al. 1961; Younger et al 1967).

3.4.9 Conclusions

The concepts developed for ICM in agriculture are certainly suitable for development of ecologically sound management of turfgrass. The use of TMS would be very effective for growing of high quality turfgrass and for reducing potentially adverse environmental quality effects. TMS practices would coordinate all factors required for long-term sustained productivity and quality of turfgrass, golf course profitability, and ecological soundness of selected management options. The critical components for planning and implementing TMS must include:

1. Proper design and construction of golf courses.
2. Selection of appropriate turfgrass species and cultivars.
3. Selection of timely soil and cultural practices.
4. Integrated planning of water, nutrient, and pest management in relation to other management goals.
5. Consideration of alternate chemical, biological, and cultural pest, nutrient and water management practices when possible.
6. Conservation of soil, water, energy, and natural resources during construction and maintenance of golf courses.

Although IPM programs are critical components of an entire integrated management system, pest management alone is insufficient for overall planning of an economically and environmentally sound turfgrass program. The goal of the TMS approach is to balance turfgrass quality, costs, benefits, public health, and environmental quality. Use of integrated water, pest, and nutrient management strategies will ultimately resolve the issue of maintaining high quality turfgrass with a minimum of environmental disturbance.

Providing consistent information on specifications and practices to mitigate adverse environmental impacts is essential for implementation of TMS. There is no single source of summarized information available to golf course managers regarding management options for TMS and environmental protection. A systematic approach and formulation of guidelines for environmentally sound turfgrass management would provide regulatory and environmental protection agencies with an understanding that turfgrass managers are using consistent practices to mitigate potential environmental hazards. The series of papers on IPM developed by the U.S. EPA (Leslie and Metcalf 1989) could serve as an initial model for documenting a systems perspective. However, an integrated water, nutrient, pest, and water resources perspective should be maintained rather than an alternate pest control perspective.

Compilation of information on a systems approach to turfgrass management requires a direct link

to environmental and water quality protection in addition to issues on maintenance of high quality turfgrass. This type of information should be modified for different climatic regions, soils, irrigation and drainage systems, and golf course management requirements. A single site specific management handbook may not be possible. However, the combined resources of the turfgrass industry, environmental regulatory agencies, university and private sector information services, would be capable of producing a guidance system of principles on TMS.

The general principles for TMS need to be included in development of any environmentally sound guidance system. These principles should include consideration of nutrient and pesticide sources, rates and timing of application to meet turfgrass and environmental goals, chemical and alternate control formulations, use of alternate practices for nutrient and pest management, irrigation scheduling, proximity of surface water and groundwater sources, proper equipment calibration, impacts of other cultural practices, and assessment for offsite movement of applied chemicals.

Prior to implementing local TMS programs, regional IPM and TMS approaches will require additional information from applied research projects. Determining economic thresholds and scouting programs for implementing nutrient and pest management strategies should be a high research priority. Development of commercially viable alternate control technologies requires additional research on pest and disease monitoring, improved application technology for chemical and biological control agents, selection or development of insect and disease resistant cultivars, and expansion of current research techniques to a wide range of climatic conditions and turfgrass management conditions. Research on timing, method, and rate of nutrients and pest control agents in relation to climatic and soil conditions ultimately controls their efficacy and environmental impacts. Development or selection of disease and pest resistant turfgrass cultivars also will have a significant impact on reducing pesticide use on turfgrass systems. Education of turfgrass managers in appropriate integrated systems technology is required before changes can be made in current management strategies.

Several transport and environmental fate models could be used to evaluate pesticide and nutrient movement on turfgrass systems. Simulation approaches provide an opportunity to evaluate the environmental effects of different management plans prior to their implementation. These models need to be calibrated and modified for simulation of water and chemical movement in turfgrass systems. Research is required to improve simulation of water transport, volatilization, adsorption, and degradation. Accurate projections of these processes is needed before chemical fate models will be capable of realistic predictions. Current simulation technology for turfgrass is not adequate to produce appropriate results for site specific management, research, or regulatory decisions. However regulatory agencies will use current simulation strategies to establish management guidelines, unless efforts are made to provide more suitable predictive approaches. Development of modeling and risk assessment approaches is an essential component of TMS.

3.5 Offsite Wind-Drift Potential

After reviewing the literature and examining other studies aimed at assessing the potential for determining offsite wind-drift, we have concluded that no reasonable modeling approach can be used to yield estimates with any certainty. Rather, we suggest that a monitoring system be employed at the site that is capable of determining air transport of pesticide drift from the site.

We also note that if the TMS plan is implemented within the guidelines suggested here, that wind-drift can be minimized in most cases and eliminated in others. Implementation of the TMS will reduce the potential for pesticide loss from the site especially compared to present land use management.

3.6 Effluent Water Use and Recycling/Solid Waste Disposal

A water source now being used for irrigating golf courses and which will be of considerable interest in the future is effluent water. Turfs can accept effluent water containing moderate levels of heavy metals and other elements which cannot be used in crop production because of potential problems entering the human food chain or restricting crop yield. Thus, turf irrigation offers one of the best approaches to disposing of certain types of effluent water. In addition, many golf courses are in reasonable delivery distance of treatment plants. The proposed course should make use of this type of water if available in order to minimize pressure on limited groundwater supplies.

Sewage treatment plants have three levels of possible treatment. The primary level is concerned with solids removal. The secondary level removes many dissolved impurities, while the tertiary level removes even more impurities. Each level is more expensive. In contrast, soils function as very efficient water filters and offer an economical means of advanced water treatment. Soils have a great capacity to handle organic wastes.

The reliability of an effluent water is a positive factor. In addition, the cost can be fairly attractive compared with that of other alternatives. In some areas, effluent water is available at no cost or at only the pumping charge involved. In other areas, effluent water is being sold for from 25 to 35 percent of the price of domestic water. The cost of effluent water will probably rise in the future but still remains an economically compared with that of other sources.

Chemical analyses of typical effluent have shown that nitrogen, chiefly on the form of ammonia, is present in an amount of 60 to 100 pounds per acre foot of water, while potassium is in the 200 pound range and phosphates between 60 and 100 pounds. Thus, each effluent water source may serve as a bonus source of N,P and K. Obviously, if effluent is used, it should be consistently monitored for these nutrients and figured in to the total nutrient requirement of the turf in order to avoid application of excess N and P.

Use of effluent water at the site will have to take into consideration the following factors related to safe use of effluent:

- Some chemicals present in effluent may be injurious to turfgrass growth, and for this reason the water used for irrigation should be continually monitored as suggested EPA regulations. The main chemical problems arise from industrial contaminants such as brine, heavy metals, and stable organic compounds.

- Five elements are of particular concern and should be frequently determined in the effluent water. These are cadmium (Cd), copper (Cu), nickel (Ni), zinc (Zn) and boron (B). Current guidelines suggest the following maximum levels for turfgrass:
  Cd: 5 ppb
  Cu: 200 ppb
  Ni: 500 ppb
  Zn: 5 ppm
  B: 1 ppm

- The site managers may want to consider complying with California regulations for Waster Water Reclamation Plants with Direct Filtration. This regulation will require a very high degree of effluent such that the water would be unrestricted in use.

In addition to effluent water use and reuse it is recommended that the proposed golf course development plan include appropriate protocols for solid-waste storage and disposal. The solid-waste at the site is likely to include both pesticide containers and remnants and turfgrass clippings.

All pesticides at the site should be handled and stored according to manufacturers instructions and in compliance with all local, state and federal regulations. Pesticide should be stored in an adequate sized structure (200-400 square feet) with adequate ventilation and containing a cement containment floor in case of accidental spills. The floor should contain a drain line connected by pump to an independent storage tank outside such that all residues washed from the floor can be easily pumped to a holding tank. Storage materials inside the building should be located on sturdy shelves, have appropriate labels clearly visible, and should be contained within separate plastic buckets with lids to avoid accidental spills. Disposal of all residue solutions and containers must comply with label instructions, local, state and federal regulations. All pertinent safety equipment should be installed as deemed by law.

Turfgrass clippings from mowing operations can, in many cases, be directly returned to rough areas adjacent to the green or fairway from which they were removed. Clippings that cannot be returned immediately to the playing surface will be composted in a site remote from the playing area. This designated composting area will provide a useful means of accelerating the degradation of any pesticide residues in the clippings and allowing the composted clippings to be mixed with soil for use as a topdressing for rough or low spots on greens and fairways. All clippings therefore should be recyclable on-site.

3.7 Simulating the Impacts of Candidate Pesticides and Nutrients

3.7.1 Modeling Pesticide and Nutrient Fate and Transport: An Environmental Quality Perspective

Golf course turfgrass is a cultural, economic, and environmental benefit to the State of Hawaii and the United States. The benefits of turfgrass management have been reviewed extensively by Balogh et al. (1992a) and Roberts et al. (1992). Golf course managers, developers, and the public also recognize the need to minimize any potential adverse effects of intensive turfgrass management (Balogh et al. 1992a). Assessment of potential impacts of golf course construction and management must consider the critical need to protect surface water, groundwater, and soil resources.

The public remains intensely concerned about water and environmental quality issues. The total extent of surface water and especially groundwater use and contamination has not been well characterized in Hawaii and the rest of the United States (Anderson et al. 1989). However, it is currently apparent that water resources are increasingly under threat of depletion and contamination from a variety of sources (Balogh and Watson 1992). A complex array of compounds have been identified in surface and groundwater throughout the United States including; fertilizers, pesticides, and petroleum products (Balogh and Anderson 1992, Balogh and Watson 1992; Walker and Branham 1992). The benefits of golf course management must be balanced against public health concerns including; adverse affects on non-target organisms; and potential contamination of surface water and groundwater resources. The challenge is to develop management strategies that optimize the benefit of turfgrass management practices and minimize the risk of nonpoint source pollution.

Computer simulation of water resources and chemical fate has been shown to be very valuable for planning and management of environmentally sound turfgrass management systems (Balogh et al. 1992b). Computer models combine site specific soils and climate data with chemical and management factors to estimate potential movement of chemicals in runoff water, sediment, and subsurface movement of water. Assessment of water use (e.g. irrigation), pesticide application, and nutrient practices prior golf course construction provides an excellent opportunity for cost and environmentally effective management of turfgrass. Computer simulation models are a logical tool used to combine the complex factors that potentially effect water quality, fate and persistence of chemicals, and the impact of different management practices (Anderson et al. 1989; Balogh et al. 1992b; Donigian and Rao 1986a; Jury et al. 1987). Computer models predict with varying degrees of sophistication runoff, leaching, sediment transport, offsite movement of nutrients, and offsite movement of pesticides. The accuracy of predictions from simulation models is contingent on the availability of reliable soils, climate, and irrigation data (Balogh and Gordon 1987).

Simulation models can be used to identify turfgrass management practices with potentially favorable or adverse effects on the environment. Computer simulation is used to (1) evaluate alternate management practices; (2) select alternate compounds for pest and nutrient control; (3) design optimum water, cultural, and chemical management strategies to meet turfgrass and environmental quality goals.

Several computer models capable of simulating chemical movement in the turfgrass environment have been reviewed by Balogh et al. (1992a). The primary factors and processes controlling the fate or pesticides, nutrients, and other contaminants in turfgrass systems were reviewed extensively by Balogh and Anderson (1992), Balogh and Watson (1992), Balogh et al. (1992b), and Walker and Branham (1992). Briefly, the critical factors required for conceptual understanding and assessment or water and chemical fate in turfgrass systems are:

1. The timing and amount of precipitation and irrigation in relationship to the amount and extent of pesticide and nutrient application.
2. Biological and chemical transformations in the soil.
3. Sorption and desorption by the organic and mineral phases of soil, which controls chemical mobility in soil.
4. Uptake of the compounds and water by plants.
5. Volatilization or loss of compounds by evaporation from the soil.
6. Dilution of compounds in surface and subsurface water flow during transport to surface water or groundwater.
7. Soil (including thatch) properties and climate data.
8. Turfgrass cultural practices, especially pest and nutrient management practices in relationship to potential sediment movement, runoff of surface water, and subsurface flow of percolating water.

Computer simulation integrates these processes with chemical properties, site characteristics, management options, and climatic conditions over space and time. There is a wide range of computer models and assessment techniques that address water, sediment, and chemical pollutant transport on agricultural and forest land. Currently reliable computer models and simulation strategies for assessment of water, pesticide, and nutrient fate in the environment have been reviewed extensively by Balogh and Gordon (1987), Balogh et al. (1992b), Leonard (1990), and Wagenet and Rao (1990). Construction of simulation databases, including climate, soils, and chemicals, screening model, and management models described in these articles were all used for this project.

The objective of this portion of the environmental assessment project is to report the results of the computer simulation and evaluation of the fate and movement of chemicals used in management of a proposed golf course on the Galbraith Trust Estate, Wahiawa, Hawaii. In this section of the report *Spectrum Research, Inc.* describes (1) background information on computer assessment for turfgrass; (2) previous work on computer screening of chemical fate and transport in turfgrass systems; and (3) the simulation results for assessment of chemical movement on the Galbraith Trust Estate, Wahiawa, Hawaii. This portion of the project was conducted by Dr. James C. Balogh, CPSS and Sheila R. Murphy of Spectrum Research, Inc., Duluth, MN at the request of Dr. William J. Walker of Environmental Chemistry, Sacramento California.

3.7.2 Computer Modeling: Methods and Strategy

Model Selection Criteria

Model selection criteria for this project included: (1) the spatial and temporal scale of application; (2) intended use and interpretation of model output; (3) availability and resolution of model input data (soils, climate, chemical properties), (4) appropriate calibration of model input parameters, and (5) confidence in the output. Selecting a model compatible with the goals of this simulation project, the availability of software or ability to modify program code to meet the project needs, and the availability of input climate and soil data were three crucial criteria.

Several studies have recommended the use of computer simulation models for assessment of environmental impacts on golf courses (e.g. Horsley and Moser 1990; Klein 1990; Cohen et al. 1990). However, modification of computer models to adequately simulate the hydrology, transport processes, and environmental conditions for golf course turfgrass has not been published or field validated. Incorporation of thatch and irrigation into the simulation strategy for this project was critical for accurate evaluation of sediment, pesticide, and nutrient movement (Balogh and Watson 1992; Balogh et al. 1992b).

The models selected for this project were configured for the unique conditions of turfgrass systems. Balogh and Gordon (1987) revised the original input/output (I/O) strategy and database compilation methods for the Pesticide Root Zone Model (PRZM). This unique configuration meets the need for continuous simulation of contaminant transport for agricultural, silvicultural, and turfgrass systems. PRZM was originally developed by the Environmental Protection Agency (Carsel et al. 1984, 1985). The Leaching Estimation and Chemistry Model (LEACHM), developed at Cornell University (Hutson and Wagenet 1992), can be used to simulate nitrogen leaching for agricultural and turfgrass systems despite certain model limitations. LEACHM does not simulate surface runoff or simulate the daily variation in evapotranspiration. Despite these restrictions, LEACHM provides a heuristic perspective on potential leaching of nitrogen from golf course greens and fairways.

Quantitative and qualitative methods evaluating the movement of water and chemicals using empirical or simulation approaches have several limitations. Limitations encountered in extrapolation of model results to turfgrass systems include:

1. Validity of model assumptions concerning interaction of sorption, microbial transformations, and plant uptake.
2. Over-simplification of processes in construction of management level models.
3. Failings in numerical solution of the solute/solvent transport functions.
4. Problems in describing stochastic, preferential, and macropore flow phenomena.
5. Inability to determine model parameters and lack of readily available spatially derived input data.
6. Lack of software that is sufficiently free of program errors and developed for use on computer hardware generally available to natural resource and turfgrass managers.
7. Lack of field testing.

8. Failure to incorporate spatial variation of physical, chemical, and biological processes in assessment strategies.
9. Need to incorporate a thatch layer for turfgrass soils and a perched water table for putting greens into deterministic and screening model approaches.

Use of research, deterministic, stochastic, or screening models all have specific advantages and limitations. William J. Walker of Environmental Chemistry and his clients agree to recognize these limitations and recognize the risk of making management decisions based solely on deterministic computer simulations. Appropriate interpretation of model results in relation to the intended scale and use of the model requires a sophisticated understanding of the model on the part of the golf course developers and managers. Despite many limitations in modeling of chemical and environmental effects, simulation remains a viable management strategy for assessment of the impacts of agricultural, forestry, and turfgrass management practices.

Selection of specific models to be used to evaluate the fate and transport of specific pesticides and nutrients were based on discussions of the project investigators, ability to convert models for use on turfgrass systems, resolution of the acquired soils and climate data, and the suitability of simulation models under the soil and climate conditions of Hawaii. Simple environmental partitioning models developed and utilized by Spectrum Research, Inc. in previous research projects (Balogh et al. 1992b) were used to identify candidate compounds for simulation by management level models.

Description of Selected Management Level Models

Qualitative screening models are available for initial evaluation of pesticide runoff, sediment, and leaching potential (e.g. Gustafson 1989; Mackay and Stiver 1991). The initial screening of turfgrass pesticides was conducted by Balogh et al. (1992b) using software developed by Spectrum Research, Inc. Chemical fate and transport models selected for the impacts assessment are PRZM (Carsel et al. 1984, 1985) and LEACHM (Hutson and Wagenet 1992; Wagenet and Hutson 1986). Runoff and sediment transport were evaluated using PRZM. These management level models have been described in detail by Balogh et al. (1992b) and Wagenet and Rao (1990).

The simple environmental partitioning models and management level models used in this project were developed, compiled, and owned by Spectrum Research, Inc. prior to this project. These models have been successfully executed for many environmental impacts assessment projects in agricultural and turfgrass systems (e.g. Balogh and Gordon 1987; Balogh et al. 1992b; Murphy and Balogh 1992). The following is a brief review of the essential characteristics of models used in assessment of potential fate and transport of candidate compounds on the proposed golf course at the Galbraith Trust Estate, Wahiawa, Hawaii.

PRZM. Several management level models incorporate both subsurface leaching and surface transport of nutrients and pesticides used in agricultural and turfgrass systems. PRZM, developed by the U. S. Environmental Protection Agency (Carsel et al. 1984, 1985), is a functional level model used for evaluation of surface and subsurface transport of pesticides. PRZM uses a moderately sophisticated simulation strategy for continuous daily simulations.

PRZM simulates surface runoff, erosion, leaching, and related movement of pesticides and other organic compounds in agricultural and turfgrass systems. Data inputs and model outputs are relatively easy to understand, although often difficult to obtain (Balogh and Gordon 1987). PRZM uses a simplified advective-dispersive water balance method for water and solute movement within a multiple layered profile (Carsel et al. 1985). PRZM bases surface runoff and erosion on the USDA Soil Conservation Service (SCS) runoff curve number and the Modified Universal Soil Loss Equation (MUSLE) (USDA SCS 1972a; Wischmeier and Smith 1978). PRZM uses a simplified approach to plant uptake of pesticides, linear sorption partitioning strategy, and lumped first order biological and chemical transformations.

PRZM has undergone limited validation by comparison to field data (Carsel et al. 1986; Donigian and Rao 1986b; Hedden 1986). PRZM also has been used to evaluate the nonpoint source pollution effects of agricultural management and to a limited extent turfgrass practices (e.g. Donigian and Carsel 1987; Horslyy and Moser 1990; Sauer et al. 1990). Although a recent release of PRZM is linked to a generalized vadose zone model (VADOFT), use of this model system is not appropriate for simulation of systems with highly fractured bedrock, which is a characteristic of the Hawaiian Islands (Robert Carsel, Personal Communication, ERL-Athens, U. S. Environmental Protection Agency, 1992).

In previous research and development projects PRZM, and LEACHM, have been enhanced through I/O modification and input parametrization to simulate runoff, leaching, sediment, and organic compound transport from both agricultural and turfgrass systems by Spectrum Research, Inc. (Balogh and Gordon 1987; Murphy and Balogh 1992). This version of the model was used to simulate pesticide transport for this assessment project.

LEACHM. LEACHM, developed at Cornell University, is a theoretically and processed based research model used for deterministic evaluation of pesticide and nitrogen leaching through agricultural soils (Hutson and Wagenet 1992; Wagenet and Hutson 1986). Using a finite differencing technique to simulate water and solute movement, LEACHM is intended for use in a single growing season with surface applied chemicals. LEACHM currently has sophisticated components to simulate nitrogen transformations in the soil. An important feature of LEACHM is its ability to simulate transport of the parent compounds and transformation products. This is essential for modeling the behavior of both organic and inorganic nitrogen fertilizers.

LEACHM does provides accurate predictions of nitrogen fate and movement at the expense of large microcomputer time and extensive field data requirements. This model also has several other features that limit its utility as a management level model. LEACHM incorporates a variable depth and multilayer soil profile under transient moisture conditions into the simulation strategy. However, LEACHM does not incorporate variations in surface management techniques such as turfgrass management conditions, slope, or surface hydrology. LEACHM also has a very simplistic approach to simulating the variability of potential evapotranspiration, which is a critical component of surface and subsurface soil hydrology (Balogh and Gordon 1987; Balogh and Watson 1992). Also, LEACHM currently lacks a surface runoff and sediment transport component which compromises its practical utility. Despite these limitations, LEACHM is a potentially effective simulation model for site specific assessment of potential nitrogen leaching losses.

Screening Models. Several modeling approaches have been used for qualitative assessment of the environmental impacts of water and chemical management on turfgrass systems (Balogh et al. 1992b). Screening models are very useful for categorization of chemicals, especially pesticides, into broad behavioral classes. Screening models focus on chemical properties related to surface and subsurface transport processes (Mackay and Stiver 1991; Wagenet and Rao 1990). These models combine sorption, degradation, and volatilization into relative mobility classes based on index scores or environmental partitioning potential.

Mackay and Stiver (1991) developed an environmental partitioning or fugacity model for classification and screening pesticides on the basis of environmental fate. The fugacity or partitioning approach uses linear sorption and volatilization functions, first order lumped degradation, and linear moisture flux in a surface soil horizon. Using simplified boundary conditions for volatilization, water transport, degradation, and sorption processes (Table 3.7-1), this pesticide partitioning model evaluates potential distribution and initial distribution of pesticides in the environment (Table 3.7-2). The Pesticide Partitioning Model (PPM) computes the distribution of a pesticide between environmental compartments, volatile losses, leaching losses, and degradation losses (Table 3.7-2). The rate of water movement, rates of application, and organic matter content were modified to reflect site specific conditions generally found on golf courses.

The pesticide partitioning approach provides a preliminary assessment of rates and pathways of pesticide loss. As a screening approach the pesticide partitioning model provides an overall profile of potential chemical behavior in the environment. Use of the overall pesticide persistence calculated in the partitioning model (Table 3.7-2) can be used for initial assessment of the potential for exposure of non-target organisms (e.g. Table 3.7-3).

Use of basic pesticide properties as an index of leaching potential is another screening approach for management and regulatory assessments. The basic premise in this approach is to combine essential information influencing pesticide transport into a single rating score. Sorption and degradation are two of the most critical processes controlling potential pesticide leaching (Balogh and Anderson 1992). Gustafson (1989) combined the organic carbon partition coefficient (K_{oc}) and degradation half-life ($t_{0.5}$) into a Groundwater Ubiquity Score (GUS). This score is based on a weighted equation such that

$$GUS = \log_{10}(t_{0.5}) * (4 - \log_{10}(K_{oc})) \qquad [1]$$

where $t_{0.5}$ is the soil degradation half-life of a pesticide in days and K_{oc} organic matter partition coefficient. The GUS provides a consistent index of leachability based on pesticide mobility and persistence (Table 3.7-4). Gustafson (1989) classified chemicals with a GUS greater than 2.8 as "leachers" and chemicals with a GUS less than 1.8 as "nonleachers." Transition compounds have intermediate scores between 1.8 and 2.8. Results of the GUS classification are consistent with the leaching potential criteria developed by Cohen et al. (1984) and the U. S. Environmental Protection Agency (EPA) (1988). The EPA has developed a suggested list of pesticide characteristics and soil conditions conducive to chemical leaching conditions (Table 3.7-5). Based on established soil and pesticide characteristics, these EPA guidelines characteristics can also be used to establish preliminary estimates of pesticide leaching potential.

Using GLEAMS and CREAMS, Goss (1991) developed a tabular hazard rating for both surface and subsurface losses of pesticides for the USDA Soil Conservation Service (SCS) (Table 3.7-4). This hazard rating can be used for initial screening of turfgrass pesticide runoff and leaching losses (Table 3.7-4). Pesticides are ranked in the SCS system by extra small, small, medium, or large probability classes for loss in surface runoff or subsurface leaching. The rating for potential leaching losses of pesticides in the Goss (1991) method is similar to the hazard score system developed by Gustafson (1989). The SCS index and GUS hazard score index can be used to rank potential exposure of aquatic organisms to turfgrass pesticides applied in the vicinity of sensitive aquatic systems (Table 3.7-6).

Table 3.7-2. Results of pesticide partitioning ranking procedure for major use turfgrass pesticides (Balogh et al. 1992b)[1].

Chemical Name	Percent Distribution of Chemicals			Percent Loss			Field Dissipation[3] half-life (days)
	Air	Water	Soil	Volatilization	Leaching	Degradation[2]	
Insecticides and Nematicides							
Bendiocarb	<0.0	0.6	99.4	<0.1	4.3	95.7	5
Carbaryl	<0.0	1.1	98.9	<0.1	14.6	85.4	9
Chlorpyrifos	<0.0	0.1	99.9	0.7	2.5	96.8	29
Diazinon	<0.0	1.5	98.5	2.6	46.9	50.5	20
Ethoprop	<0.0	2.7	97.3	0.7	50.9	48.4	12
Fenamiphos	<0.0	1.9	98.1	0.1	59.9	40.0	20
Isazofos	<0.0	3.2	96.8	2.4	61.6	36.0	12
Isofenphos	<0.0	0.5	99.5	0.3	56.2	43.5	65
Trichlorfon	<0.0	24.6	75.4	<0.0	79.6	20.3	2

[1]Initial boundary conditions for soil, air, water movement, and pesticide application are defined in Table 3.7-1.

[2]Degradation includes biological and chemical reactions.

[3]Overall half-life indicates persistence of the chemical in the upper 2 cm of soil with loss mechanisms including degradation, volatilization, and leaching losses.

Table 3.7-1. Initial boundary conditions for the surface of a field moist sandy soil for qualitative partitioning of selected pesticides used on turfgrass (Balogh et al. 1992)

Soil and Air Properties	Dimension
Area	1 m^2
Depth	0.02 m
Volume	0.02 m^3
Volumetric water content	10 %
Porosity of dry soil	50 %
Fraction organic matter content	0.025 kg kg^{-1} soil
Water leaching rate	0.0022 m^3 m^{-2} h^{-1}
Water diffusivity	4.3E-5 m^2 d^{-1}
Air diffusivity	0.43 m^2 d^{-1}
Equivalent air mass transfer coefficient	90.5 m d^{-1}
Air boundary layer thickness	0.00475 m
Pesticide Properties	
Rate of pesticide application	1 kg a.i. ha^{-1}
Vapor density (Pa)	Balogh and Anderson (1992)
Organic carbon partition coefficient (K_{oc})	
Water Solubility (g m^3)	Balogh and Anderson (1992)
Degradation Half-life (d)	Balogh and Anderson (1992)

Table 3.7-2. Results of pesticide partitioning ranking procedure for major use turfgrass pesticides (Balogh et al. 1992b)[1].

Chemical Name	Percent Distribution of Chemicals Air	Water	Soil	Percent Loss Volatilization	Leaching	Degradation[2]	Field Dissipation[3] half-life (days)
				Fungicides			
Anilazine	<0.0	0.3	99.7	<0.0	0.5	99.5	1
Benomyl	<0.0	0.2	99.8	<0.0	38.3	61.7	148
Chloroneb	<0.0	0.3	99.7	73.0	9.9	17.1	22
Chlorothalonil	<0.1	0.2	99.8	81.0	1.9	17.1	5
Etridiozole	<0.0	0.3	99.7	0.4	9.3	90.2	18
Fenarimol	<0.0	0.3	99.7	0.1	65.0	34.9	126
Fosetyl Al	<0.0	14.1	85.9	<0.0	18.2	81.8	1
Iprodione	<0.0	0.5	99.5	<0.1	9.4	90.6	13
Mancozeb	<0.0	0.3	99.7	0.3	15.3	84.4	30
Maneb	<0.0	0.3	99.7	0.1	15.3	84.6	30
Metalaxyl	<0.0	8.5	91.5	<0.1	77.2	22.8	6
PCNB	<0.0	0.1	99.9	13.0	1.9	85.1	18
Propamocarb HCl	<0.0	<0.0	100.0	<0.0	0.2	99.8	30

Table 3.7-2. Results of pesticide partitioning ranking procedure for major use turfgrass pesticides (Balogh et al. 1992b)[1].

Chemical Name	Percent Distribution of Chemicals Air	Water	Soil	Percent Loss Volatilization	Leaching	Degradation[2]	Field Dissipation[3] half-life (days)
				Fungicides			
Propiconazole	<0.0	0.3	99.7	<0.1	34.1	65.9	66
Thiophanate-methyl	<0.0	0.2	99.8	<0.1	2.8	97.2	10
Thiram	<0.0	0.5	99.5	0.1	10.4	89.5	13
Triadimefon	<0.0	1.1	98.9	<0.0	30.8	69.2	18
				Herbicides			
Atrazine	<0.0	2.1	97.9	0.1	66.9	33.0	20
Benefin	<0.0	<0.1	100.0	1.8	1.9	96.3	39
Bensulide	<0.0	0.3	99.7	0.2	38.2	61.6	74
2,4-D, acid	<0.0	14.1	85.9	0.1	69.0	30.9	3
2,4-D, amine	<0.0	3.2	96.8	0.9	33.1	66.0	7
DCPA	<0.0	0.1	99.9	1.8	11.3	86.9	87
Dicamba	<0.0	62.0	38.0	<0.0	93.2	6.8	1

Table 3.7-2. Results of pesticide partitioning ranking procedure for major use turfgrass pesticides (Balogh et al. 1992b)[1].

Chemical Name	Percent Distribution of Chemicals: Air	Water	Soil	Percent Loss: Volatilization	Leaching	Degradation[2]	Field Dissipation[3] half-life (days)
				Herbicides			
DSMA	<0.0	0.4	99.6	<0.0	40.2	59.8	60
Endothall	<0.0	14.1	85.9	<0.0	60.9	39.1	3
Ethofumesate	<0.0	1.0	99.0	0.1	31.2	65.7	21
Glyphosate	<0.0	<0.1	100.0	<0.0	2.4	97.6	46
MCPA Amine Salt	<0.0	14.1	85.9	<0.0	84.8	15.2	4
MCPA Ester	<0.0	0.3	99.7	0.1	11.4	88.5	22
MCPP	<0.0	14.0	86.0	<0.0	82.4	17.6	4
MSMA	<0.0	<0.1	100.0	<0.0	34.2	65.8	658
Oxadiazon	<0.0	0.1	99.9	0.4	8.8	90.8	54
Pendimethalin	<0.0	0.1	99.9	19.9	6.8	73.2	66
Siduron	<0.0	0.8	99.2	<0.1	52.5	47.5	43
Simazine	<0.0	2.4	97.6	0.1	70.0	30.0	18
Triclopyr -							
Amine	<0.0	14.0	86.0	<0.0	91.1	8.9	4
Ester	<0.0	0.4	99.6	0.1	23.3	76.6	35
Trifluralin	<0.0	0.4	99.6	18.3	3.1	78.6	47

Table 3.7-3. Relative ranking for risk of pesticide exposure to terrestrial organisms on turfgrass based on estimates of field dissipation[1] (Balogh et al. 1992b).

Level of Potential Exposure	Range of Field Dissipation
Low	Half-life < 5
Moderate	5 < Half-life < 20
Moderately High	20 < Half-life < 45
High	Half-life > 45

[1]Ranking is for purposes of preliminary assessment and comparison only. Field dissipation includes all forms of loss from the soil surface as calculated in Table 3.7-2.

Table 3.7-4. Qualitative assessment of potential surface and subsurface losses of pesticides.

Chemical Name	Potential Surface Losses: SCS Runoff Rating[1] Sediment	Soluble	Potential Subsurface Losses: GUS[2]	GUS Ranking	SCS Leaching[1] Rating
	Insecticides and Nematicides				
Bendiocarb	Small	Large	0.87	Non-leacher	Small
Carbaryl	Small	Medium	1.52	Non-leacher	Small
Chlorpyrifos	Medium	Small	0.32	Non-leacher	Small
Diazinon	Large	Large	2.65	Intermediate	Small
Ethoprop	Small	Medium	2.68	Intermediate	Large
Fenamiphos	Medium	Large	3.01	Leacher	Large
Isazofos	Small	Large	3.06	Leacher	Large
Isofenphos	Medium	Large	2.65	Intermediate	Medium
Trichlorfon	Small	Medium	3.00	Leacher	Large

[1]USDA SCS water quality ratings developed by Goss (1991) and reported in USDA SCS pesticide database (Wauchope et al. 1991).

[2]GUS core and leaching potential rating based on pesticide degradation and organic matter partitioning was developed by Gustafson (1989). Potential difference in GUS rating and SCS rating is due to selection of different partition coefficients for development of ratings (Wauchope et al. 1991).

Table 3.7-4. Qualitative assessment of potential surface and subsurface losses of pesticides.

Chemical Name	Potential Surface Losses: SCS Runoff Rating[2] Sediment	Potential Surface Losses: SCS Runoff Rating[2] Soluble	Potential Subsurface Losses: GUS[3]	Potential Subsurface Losses: GUS Ranking	Potential Subsurface Losses: SCS Leaching[2] Rating
Fungicides					
Anilazine	Small	Small	0.00	Non-leacher	Small
Benomyl	Large	Large	2.01	Intermediate	Small
Chloroneb	Large	Large	1.98	Intermediate	Small
Chlorothalonil	Medium	Medium	1.27	Non-leacher	Small
Etridiozole	Medium	Medium	1.30	Non-leacher	Small
Fenarimol	Medium	Large	2.55	Intermediate	Large
Fosetyl Al	Small	Medium	0.00	Non-leacher	Small
Iprodione	Small	Large	1.32	Non-leacher	Small
Mancozeb	Large	Large	1.54	Non-leacher	Small
Maneb	Large	Large	1.54	Non-leacher	Small
Metalaxyl	Medium	Large	3.43	Leacher	Large
PCNB	Medium	Small	0.39	Non-leacher	Small
Propamocarb HCl	Medium	Small	-1.48	Non-leacher	Extra-small
Propiconazole	Large	Large	2.00	Intermediate	Medium
Thiophanate-methyl	Medium	Medium	0.74	Non-leacher	Small
Thiram	Small	Large	1.38	Non-leacher	Small
Triadimefon	Small	Large	2.15	Intermediate	Medium

Table 3.7-4. Qualitative assessment of potential surface and subsurface losses of pesticides.

Chemical Name	Potential Surface Losses: SCS Runoff Rating[2] Sediment	Potential Surface Losses: SCS Runoff Rating[2] Soluble	Potential Subsurface Losses: GUS[3]	Potential Subsurface Losses: GUS Ranking	Potential Subsurface Losses: SCS Leaching[2] Rating
Herbicides					
Atrazine	Medium	Large	3.24	Leacher	Large
Benefin	Large	Medium	-0.05	Non-leacher	Small
Bensulide	Large	Large	2.08	Intermediate	Medium
2,4-D, acid	Small	Medium	2.69	Intermediate	Medium
2,4-D, amine	Small	Medium	2.00	Intermediate	Medium
DCPA	Large	Medium	0.80	Non-leacher	Small
Dicamba	Small	Medium	4.24	Leacher	Large
DSMA	Large	Small	2.31	Intermediate	Extra-small
Endothall	Small	Medium	2.28	Intermediate	Medium
Ethofumesate	Small	Medium	2.17	Intermediate	Medium
Glyphosate	Large	Large	0.00	Non-leacher	Extra-small
MCPA Amine Salt	Small	Medium	3.77	Leacher	Large
MCPA Ester	Medium	Medium	1.39	Non-leacher	Small
MCPP	Small	Medium	3.51	Leacher	Large
MSMA	Large	Small	0.00	Non-leacher	Extra-small
Oxadiazon	Large	Medium	0.88	Non-leacher	Small
Pendimethalin	Large	Medium	0.59	Non-leacher	Small
Pronamide	Medium	Large	3.02	Leacher	Large
Siduron	Medium	Large	2.69	Intermediate	Medium
Simazine	Medium	Large	3.35	Leacher	Large
Triclopyr Amine	Medium	Large	4.49	Leacher	Large
Triclopyr Ester	Medium	Large	1.84	Intermediate	Medium
Trifluralin	Large	Medium	0.17	Non-leacher	Small

Table 3.7-5. Chemical/physical properties of pesticides: Values which indicate potential for groundwater contamination (EPA 1988).

Pesticide Characteristic	Parameter value or range indicating potential for groundwater contamination
Water solubility	Greater than 30 ppm
K_d	Less than 5, usually less than 1
K_{oc}	Less than 300 - 500
Henry's Law Constant	Less than 10^{-2} atm m^{-3} mol
Speciation	Negatively charged, fully or partially at ambient pH
Hydrolysis half-life	Greater than 175 days
Photolysis half-life	Greater than 7 days
Field dissipation half-life	Greater than 21 days

Table 3.7-6. Relative ranking for risk of pesticide exposure to aquatic organisms in the vicinity of turfgrass based on potential soluble losses in runoff and subsurface drainage.

Level of Potential Exposure	Potential for loss in runoff		Potential for loss in[2] subsurface drainage
Low	Small	and	GUS < 1.8
Moderate	Small	and	GUS > 1.8
	Medium	and	GUS < 1.8
Moderately High	Medium	and	GUS > 1.8
	Large	and	GUS < 1.8
High	Large	and	GUS > 1.8

[1]Ranking is for purposes of preliminary assessment and comparison only.

[2]Loss in runoff based on SCS Soluble Runoff Ranking (Table 4). Risk of subsurface drainage losses are based on GUS (Table 4).

Simulation Strategy and Model Input Parameters

Simulation Regimes. Surface water runoff, sediment transport, subsurface percolation of water, pesticide fate and movement, and nitrogen leaching were simulated for the proposed golf course. Simulations were conducted for an established USGA Green and fairways with Wahiawa and Kolekole soil mapping units. The soil mapping units were described in previous sections. A thirty year simulation was conducted for each green and fairway soil unit using eleven different pesticides. A similar simulation was conducted for a soluble inorganic nitrogen fertilizer (NH_4NO_3) and urea fertilizer.

Availability of long-term daily climatic data, physical and chemical information for pesticides, and simulation of realistic management strategies have compromised recent attempts to use simulation models in many ecosystems (Balogh and Gordon 1987; Balogh et al. 1992b). Recently released databases on soil and chemical properties were developed specifically for use with simulation models (e.g. Balogh and Anderson 1992; Murphy and Balogh 1992; Walker and Branham 1992; Wauchope et al. 1991). All of these sources were used to compile the databases required for the current simulation.

Climate and Irrigation Data. A thirty year continuous climate database was compiled for the proposed golf course (Table 3.7-7). The original source of data is the Opaeula Cooperative Weather Station. This station is located within the same climatic zone on Oahu as the proposed golf course (Elv. 1060 ft., Lat. 21° 31', Long. 158° 02'). The climate data was obtained from the Western Regional Climate Center, Desert Research Institute, Reno, Nevada. The database contained nearly continuous records for thirty climate years. The daily climate data included daily precipitation totals, maximum temperature, and minimum temperature. Missing values and construction of a continuous climate record was developed using concatenation and relabeling procedures as described by Balogh and Gordon (1987).

Potential evapotranspiration (PET) for this project was estimated using a simplified version of the Penman Formula. This method was described in detail by Linacre (1977). The Linacre version of the Penman formula was developed for grassy conditions in warm environments. The Linacre PET equation requires only elevation, latitude, and daily minimum and maximum temperature as surrogate information for the complex Penman Equation. The estimated PET value was used in both simulation models. Irrigation scheduling was based on meeting 60 percent of the evaporative demand with a combination of irrigation and precipitation. Several reviews suggest meeting at least 60 percent of consumptive water demand is a minimum acceptable level for warm season turfgrasses (Balogh and Watson 1992; Kneebone et al. 1992).

Soil, Site Hydrology Data, and Turfgrass Data. Soil and site hydrologic data were estimated from (1) the USDA Soil Conservation Service soil survey report for the Island of Oahu (USDA SCS 1972); (2) the SCS Soil Interpretation Records (S5) for the dominant mapping units on the proposed golf course; (3) the USGS 7.5 minute series topographic map for the Halewia Quadrangle; and (4) the Helber Hastert & Fee base map of the proposed golf course. Wahiawa and Kolekole are the dominant mapping units which were discussed earlier in this report by Dr. Walker. Properties of the USGA Green were estimated from the USGA "Specifications for a Method of Putting Green Construction" (USGA 1989). Development of soil parameter files for PRZM and LEACHM were constructed specifically for golf course soils with a moderately developed thatch from information compiled by Spectrum Research, Inc. and other literature sources (e.g. Balogh and Walker 1992; Hurto et al. 1980; White and Dickens 1984; Meinhold et al. 1973; Waddington 1992; Waddington et al. 1992).

Table 3.7-7. Structure of synthetic meteorological time series used as climate input for the PRZM and LEACHM impacts assessment.

Station Location	Climate Year	Simulation Year
Opaeula	1950	1950
Opaeula	1951	1951
Opaeula	1952	1952
Opaeula	1953	1953
Opaeula	1954	1954
Opaeula	1955	1955
Opaeula	1956	1956
Opaeula	1957	1957
Opaeula	1958	1958
Opaeula	1959	1959
Opaeula	1960	1960
Opaeula	1961	1961
Opaeula	1962	1962
Opaeula	1963	1963
Opaeula	1964	1964
Opaeula	1965	1965
Opaeula	1966	1966
Opaeula	1967	1967
Opaeula	1968	1968
Opaeula	1969	1969
Opaeula	1970	1970
Opaeula	1971	1971
Opaeula	1972	1972
Opaeula	1973	1973
Opaeula	1974	1974
Opaeula	1975	1975
Opaeula	1976	1976
Opaeula	1977	1977
Opaeula	1978	1978
Opaeula	1991	1979

Critical soil data required for each soil horizon includes: (1) depth or thickness; (2) bulk density; (3) water retention data, water content at field capacity and wilting point, or soil texture; and (4) organic carbon content (Table 3.7-8). Important additional information required for estimation of actual evapotranspiration (AET), runoff, sediment movement, and leaching are (1) maximum turfgrass rooting depth; (2) soil runoff curve number; (3) simulated area of application; and (4) modified universal soil loss equation factors (Table 3.7-9). These factors reflect the critical soil and site factors controlling the fate and movement of chemicals applied to turfgrass (Balogh and Anderson 1992; Walker and Branham 1992).

Table 3.7-8. Summary of soil horizon parameters for simulation of chemical movement from a USGA Green, Wahiawa Fairway, and Kolekole Fairway.

Soil Property	Horizon							
	Thatch(1)	2	3	4	5	6	7	8
Horizon Designation								
Green	Oe/i	RZH[2]	RZH	C				
Wahiawa	Oe/i	Ap1	Ap2	Bw1	Bw2	Bw3	Bw4	
Kolekole	Oe/i	Ap1	Ap2	Bw1	Bw2	Bw3	Bw4	Bbt
Thickness (cm)								
Green	1.0	20.0	11.0	5.0				
Wahiawa	1.5	15.0	15.0	10.0	43.0	30.0	35.5	
Kolekole	1.5	10.0	20.0	20.0	13.0	18.0	15.0	52.5
Bulk Density (Mg m^{-3})								
Green	0.37	1.45	1.45	1.45				
Wahiawa	0.37	1.20	1.30	1.40	1.40	1.40	1.40	
Kolekole	0.37	1.10	1.15	1.20	1.30	1.30	1.40	1.50
Water Content (cm cm^{-1})								
Field Capacity								
Green	0.36	0.18	0.18	0.09				
Wahiawa	0.36	0.36	0.36	0.38	0.38	0.38	0.38	
Kolekole	0.36	0.32	0.32	0.34	0.34	0.34	0.34	0.34
Wilting Point								
Green	0.05	0.03	0.03	0.02				
Wahiawa	0.05	0.25	0.25	0.25	0.25	0.25	0.25	
Kolekole	0.05	0.22	0.22	0.23	0.23	0.23	0.23	0.21
Texture								
Green	---	sand	sand	coarse sand				
Wahiawa	---	sic[3]	sic	sic	sic	sic	sic	
Kolekole	---	sicl[4]	sicl	sicl	sicl	sicl	sic	sicl
Organic Carbon (%)[1]								
Green	40	2.00	2.00	0.55				
Wahiawa	40	3.62	3.05	3.00	2.22	1.20	0.55	
Kolekole	40	3.62	3.10	2.70	2.20	1.20	0.55	0.55

[1]Subsurface horizons estimated from USDA SCS Soil Interpretation Records.

[2]RZM=USGA Putting Green Root Zone Mix (USGA 1989).

[3]sic = silty clay. [4]sicl = silty clay loam.

Table 3.7-9. Summary of site and hydrological parameters for simulation of chemical movement from a USGA Green, Wahiawa Fairway, and Kolekole Fairway.

Soil and Site Properties	Simulated Green or Fairway		
	Green	Wahiawa	Kolekole
Duration of Simulation (yr)	30	30	30
Depth of Soil Core (cm)	37	150	150
Maximum Rooting Depth (cm)	31	30	30
Runoff Curve Number	39	58	58
Simulated Area of Application (ha)	0.14	1.15	1.15
Modified Universal Soil Loss Equation Factors			
Erodibility (K)	0.02	0.17	0.17
Slope/Length (LS)	0.24	0.47	0.47
Practice (P)	1.00	1.00	1.00
Crop Mgmt. (C)	0.01	0.02	0.02

Pesticide Data. The critical chemical properties influencing potential losses of pesticides in surface runoff water, sediment, and subsurface leaching are: (1) rate and extent of pesticide application; (2) timing of application in relation to runoff and leaching events; (3) rate of pesticide degradation; (4) pesticide sorption properties; and (5) rates of volatilization for volatile compounds. All of these factors have been discussed in detail by Balogh and Anderson (1992).

Important pesticide and turfgrass specific parameters include (1) the organic carbon normalized soil adsorption partition coefficient (K_{oc}) and (2) pesticide degradation rate (Table 3.7-10). Pesticide property data used in PRZM were obtained from databases of chemical properties developed by Spectrum Research, Inc. (PESTFATE™; Murphy and Balogh 1992) and other literature sources summarized by Balogh and Anderson (1992). Rates and timing of application were estimated from the *Turf & Ornamental Chemicals Reference* (T&OCR 1991), *Crop Protection Chemicals Reference* (CPCR 1992), and *Farm Chemicals Handbook* (1992). Pesticides were applied on April 15 of all climate years at label specified rates of application (Table 3.7-11). On alternate years a second application of pesticide was applied on September 15 at label specified rates (Table 3.7-11). Pesticides were applied on the same dates for consistent evaluation of responses to timing of precipitation and irrigation at variable levels of labeled pesticide rates.

Several candidate insecticides, fungicides, and herbicides were selected for simulation. These compounds represent a wide range of chemical properties and management conditions (Table 3.7-10; Table 3.7-11). These major use chemicals are likely candidates for selection for initial control of weeds, diseases, and insect pests (Balogh and Anderson 1992; Bruneau et al. 1992). Insecticides and nematicides used in the simulation include bendiocarb, chlorpyrifos, fenamiphos, and trichlorfon. Fungicides used in the simulation are benomyl, chlorothalonil, and metalaxyl. Selected herbicides are bensulide, 2,4-D, DCPA, and dicamba.

Table 3.7-10. Pesticide properties used in PRZM simulation of pesticide movement in surface runoff, sediment, and leaching.

Pesticide	Soil Adsorption Coefficient, K_{oc}	Rate of Degradation (days^{-1})		
		Foliar	Surface Horizons	Subsurface Horizons
Insecticides and Nematicides				
Bendiocarb	570	0.10	0.132	0.050
Chlorpyrifos	13600	0.25	0.023	0.017
Fenamiphos	120	0.25	0.120	0.060
Trichlorfon	6	0.25	0.128	0.077
Fungicides				
Benomyl	162	0.08	0.006	0.004
Chlorothalonil	3590	0.08	0.029	0.019
Metalaxyl	158	0.08	0.052	0.028
Herbicides				
Bensulide	740	0.20	0.014	0.009
2,4-D	20	0.08	0.093	0.069
DCPA	4000	0.10	0.012	0.007
Dicamba	4	0.08	0.055	0.037

Table 3.7-11. Pesticide application strategies used in PRZM simulation of pesticide movement in surface runoff, sediment, and leaching.

Pesticide	Rate of Application (kg active ingred. ha^{-1})	Date of Application	
	Insecticides and Nematicides		
Bendiocarb	2.24	April 15	September 15[1]
Chlorpyrifos	1.12	April 15	September 15[1]
Fenamiphos	1.76	April 15	September 15[1]
Trichlorfon	9.07	April 15	September 15[1]
	Fungicides		
Benomyl	3.00	April 15	September 15[1]
Chlorothalonil	8.96	April 15	September 15[1]
Metalaxyl	1.53	April 15	September 15[1]
	Herbicides		
Bensulide	13.44	April 15	September 15[1]
2,4-D	1.25	April 15	September 15[1]
DCPA	3.22	April 15	September 15[1]
Dicamba	0.11	April 15	September 15[1]

[1]A single April application was simulated in all years. A second application of a pesticide in September was applied in simulation years 1950, 1952, 1954, 1956, 1958, 1960, 1962, 1964, 1966, 1968, 1970, 1972, 1974, 1976, 1978, 1979. In these years the total pesticide load is doubled compared to single application years: (1) to avoid development of pest and disease resistance; (2) to reduce potential carryover problems during overseeding of different sensitive turfgrass species; or (3) to reduce overall chemical loading of the same pesticide to certain areas. Changing the number of applications is an important component of integrated management systems for turfgrass.

Nutrient Data. The critical chemical properties influencing potential subsurface losses of nitrogen are: (1) rate and extent of fertilizer application; (2) timing of application in relation to runoff and leaching events; (3) rates of nitrogen transformations; (4) nutrient sorption properties; and (5) rates of volatilization or denitrification (Anderson et al. 1989; Walker and Branham 1992) (Table 3.7-12). Important nitrogen and turfgrass specific parameters include (1) the soil adsorption partition coefficient (K_d); (2) urea hydrolysis rates; (3) nitrification and denitrification rates; (4) rate of ammonia volatilization; and (5) rates and timing of application. Nitrogen fate and management data used in LEACHM were obtained from suggestions by the authors of LEACHM (Hutson and Wagenet 1992) and other literature sources summarized by Anderson et al. (1989), Walker and Branham (1992), and Turner and Hummel (1992).

Table 3.7-12. Nitrogen adsorption and hydrolysis rates used in LEACHM.

Nitrogen Source	Soil Adsorption Coefficient, K_d	Rates of Transformation ($days^{-1}$)[1] Urea Hydrolysis	Nitrification	Denitrification
		Surface Layers		
Urea-N	2.00	0.36	0.24	0.24
Ammonium-N	5.00			
Nitrate-N	0.05			
		Subsurface Root Zone		
Urea-N	2.00	0.18-0.24	0.06-0.12	0.12-0.24
Ammonium-N	5.00			
Nitrate-N	0.05			
		Subsurface Vadose Zone		
Urea-N	2.00	0.16	0.06	0.01-0.12
Ammonium-N	5.00			
Nitrate-N	0.05			

Table 3.7-13. Nutrient application strategies used in LEACHM simulation of nitrate leaching.

Nitrogen Source	Rate of Application (kg N ha^{-1} $application^{-1}$)	Date of Application
		Green
Urea-N	20.0	4/15, 5/15, 6/15, 7/15, 9/15, 11/15
Ammonium-N	10.0	4/15, 5/15, 6/15, 7/15, 9/15, 11/15
Nitrate-N	10.0	4/15, 5/15, 6/15, 7/15, 9/15, 11/15
Total-N	40.0	4/15, 5/15, 6/15, 7/15, 9/15, 11/15
		Fairway: Wahiawa and Kolekole Soils
Urea-N	15.0	4/15, 6/15, 9/15, 11/15
Ammonium-N	7.5	4/15, 6/15, 9/15, 11/15
Nitrate-N	7.5	4/15, 6/15, 9/15, 11/15
Total-N	30.0	4/15, 6/15, 9/15, 11/15

Nitrogen fertilizer sources include a combination of urea and ammonium nitrate applied four times a year on fairways (April 15, June 15, and September 15, November 15) and applied six times a year on putting greens and other high intensity area (April 15, May 15, June 15, July 15, September 15, November 15) (Table 3.7-13).

Turfgrass Management Factors. Bermudagrass was the primary turfgrass species used for simulation of both pesticide and nitrogen transport. Rooting depth, root growth, emergence and dormancy, interception capacity, and other cultural influences were used to create the turfgrass maintenance input files. Information on turfgrass management practices was obtained from several literature review sources (e.g. Balogh and Walker 1992; Beard 1982; Gibeault and Cockerham 1985; Waddington et al. 1992).

Model Output: Summarization and Analysis

Daily simulation results from PRZM and LEACHM were summarized as annual and mean monthly mass movement of water, pesticides, and nitrogen compounds. Soil hydrology variables include surface runoff, sediment loss, and movement of water past the root zone. Pesticide movement was summarized for losses in runoff water, bound to sediment, and leaching of past the active root depth. Average monthly pesticide concentrations in water leaching beneath the active root zone also were summarized. Monthly and annual summaries, statistics, and graphs were computed from the daily simulation output files using SYSTAT (Wilkinson 1990) and output summary routines developed and solely owned by Spectrum Research, Inc.

The distribution of annual runoff, sediment and subsurface leaching of water beneath the root zone is somewhat skewed (e.g. Appendix B: Figure B-1a, b; Figure B-2a, b; Figure B-3a, b; Figure B-7; Figure B-8; Figure B-9). The median may represent a better data "centroid or average" than the mean values for the chemical and hydrologic model summaries. The mean of these distributions is often influenced by a single large precipitation event that occurred on 4/19/74. This single large monthly and annual event significantly influences the parametric summary statistics. However, this event does represent a realistic although rare large scale transport event (e.g. Appendix B: Figure B-1b, Figure B-2b, Figure B-3b, Figure B-4; Figure B-5; Figure B-6) and should be considered as a potential maximum pesticide and nutrient transport condition.

Pesticides leached past the biologically active surface soil, the active root zone, are at increased risk for long term subsurface leaching (Anderson et al. 1989). The subsurface soil has fewer microorganisms capable of degrading pesticides. With reduced organic matter content, the subsurface soil horizons have diminished sorption capacity to attenuate the mass movement of organic compounds (Balogh and Anderson 1992). An important issue in determining the risk of surface loss and subsurface leaching of a specific pesticide is the frequency or probability of annual mass surface loss and subsurface leaching past the root zone (Anderson et al. 1989; Carsel et al. 1984).

Based on the 30 year climatic record a cumulative frequency distribution (CFD) was constructed for the annual mass movement of pesticides by surface movement (runoff and erosion) and leaching past the active root zone. This frequency distribution provides a probability statement regarding the potential for offsite movement of pesticides by surface and subsurface routes. Each percent level in the CFD represents the probability that a certain pesticide mass will be lost in surface movement or leaching below the root zone. The value at a given frequency level represents the proportion of the time less than a given amount of chemical will be lost in runoff, sediment, or leached below the root zone. The 50 percent level means that half the time less than the given amount of pesticide will move in surface transport or leached below the root zone. A return interval (RT) is calculated using the equation:

$$RT = 1 * [1 - P(X \leq x)]^{-1} \qquad [2]$$

where

RT = return interval or simple frequency (years)

$P(X \leq x)$ = probability of an event equal to or less than x occurring once in RT years.

At a risk level of 50 percent, the return period is 2 years. At the 80 percent risk level, the return interval is 5 years. At the 90 percent risk level, the return interval is 10 years. This formulation of risk is similar to the calculation of return periods for rain or flooding events. The 5 year and 10 year return intervals are useful benchmarks to compare the potential loss of pesticides from soils. This represents the 80 percent and 90 percent probability level for annual mass movement of a compound in surface runoff or movement beneath the root zone. *Pesticides with a higher mass loss at a given probability of occurrence are at greater risk of movement to surface water or subsurface movement to groundwater.* The CFD and RT level for each pesticide and soil simulated by PRZM were calculated using SYSTAT (Wilkinson 1990).

Nitrogen leached past the biologically active surface root zone also are at increased risk for long term subsurface leaching (Anderson et al. 1989; Walker and Branham 1992). The subsurface soil has fewer roots and microorganisms capable of immobilizing, transforming, and using the applied nitrogen. LEACHM has limited continuous simulation capabilities for long term risk assessment and evaluation of management practices (Balogh et al. 1992b). LEACHM requires massive climatic and soil data input with severe limitations on continuous simulation (Hutson and Wagenet 1992). Although suitable for a research environment, the current model limits continuous simulation available with PRZM. Simulation of nitrate and ammonium leaching was conducted using an averaged annual climatic year and two years with significant amounts of subsurface movement of water. An "average climatic and irrigation year" was selected from the 30 year climatic and irrigation record. Climate year 1950 was selected as the "average climate year" with median levels of runoff and leaching compared to the hydrologic distribution of the 30 year record (Appendix B: Figure B-1a, B-1b; Figure B-2a, B-2b; Figure 3a, 3b; Figure B-7; Figure B-8; Figure B-9). Two worst case leaching years are (1) 1974 with a single worst case rain event occurring on 4/19/74 which is within 4 days of the first fertilizer application; and (2) 1965 with the highest annual subsurface leaching of water beneath the root zone (124 cm yr^{-1}) (Appendix B: Figure B-7).

3.7.3 Results and Discussion of Pesticide and Nutrient Fate and Transport Simulation

Water and chemical management are critical components of high quality turfgrass systems (Balogh et al. 1992a, 1992b; Carrow et al. 1990; Turner and Hummel 1992; Bruneau et al. 1992). However, concern over potential nonpoint source pollution resulting from intensive turfgrass management stimulates the need to assess site suitability prior to golf course construction. On a regional scale nonpoint source pollution of water resources from turfgrass, in general, is significantly less than pollution from agricultural and many urban environments (Balogh et al. 1992a). However under certain conditions such as golf course construction or inappropriate chemical application in relation to rain or irrigation, contamination of water resources with applied chemicals and sediment can be a problem in local turfgrass systems (Balogh and Anderson 1992; Walker and Branham 1992).

The issue of water and sediment movement is a critical component for environmental assessment and planning regarding pesticide and nutrient fate in turfgrass systems. Use of computer simulation allows the developers of the proposed golf course to integrate and visualize the many climate, soil, chemical, and management factors that influences the potential efficacy and offsite movement of pesticides and nutrients. Evaluation of the impacts of the proposed golf course are categorized by effects on (1) the hydrologic cycle: runoff, sediment movement, and subsurface leaching; (2) surface and subsurface losses of pesticides; and (3) leaching losses of nitrogen.

Runoff, Sediment, Subsurface Flow

Precipitation, irrigation, water movement, and water storage in turfgrass and soils determines the availability of water for (1) turfgrass growth; (2) nutrient cycling; (3) surface runoff; (4) recharge and quality of groundwater; and (5) potential transport of sediment and applied chemicals (Balogh and Anderson 1992; Balogh and Watson 1992; Walker and Branham 1992).

The annual cycle of simulated water and sediment movement on the putting green and two fairway soils reflects the integrated process of soil water movement, climate and energy inputs, evapotranspiration, turfgrass dynamics, and characteristics of the soils. Compared to cropping systems (Anderson et al. 1989), the annual range of sediment loss and runoff from all of the turfgrass soils on the proposed site is significantly reduced (Table 3.7-14; Table 3.7-15; Table 3.7-16; Appendix B: Figure B-1a, b; Figure B-2a, b; Figure B-3a, b; Figure B-4; Figure B-5; Figure B-6). Turfgrass management reduces sediment transport by three orders of magnitude compared to agricultural soils and urban construction sites (Balogh and Watson 1992). However, the golf course developers should be aware that during construction phase of the golf course, the site will be subject to considerably higher levels of surface runoff and sediment loss.

On a unit area basis runoff and sediment losses were higher on both fairway soils in comparison to the putting greens (Table 3.7-14; Table 3.7-15; Table 3.7-16; Appendix B: Figure B-1a, b; Figure B-2a, b; Figure B-3a, b). With a coarser texture and better drainage, surface movement of water and sediment on greens is reduced. On the fairways runoff and sediment transport is greater and leaching of water is reduced compared to the greens (Table 3.7-14; Table 3.7-15; Table 3.7-16; Appendix B: Figure B-1a, b; Figure B-2a, b; Figure B-3a, b).

Median annual runoff and sediment from the simulated USGA green is 3.9 cm yr^{-1} and 1.8 kg ha^{-1} yr^{-1}, respectively. Given similar surface soil characteristics (Table 3.7-8; Table 3.7-9), runoff, sediment, and leaching losses were almost identical for both the simulated Wahiawa and Kolekole fairways (Appendix B: Figure B-2a, b; Figure B-3a, b; Figure B-8; Figure B-9). Median annual runoff and sediment from the simulated fairways is 9.3 cm yr^{-1} and 85 kg ha^{-1} yr^{-1}, respectively. During the wet season (October through April) average monthly runoff and sediment transport are elevated on all simulated soils (Figure B-4; Figure B-5; Figure B-6). On average runoff and sediment losses are greatest from February through April. Runoff and sediment transport is significantly reduced between May and September. Higher rates of evapotranspiration increase water consumption by the turfgrass and reduce excess water available for surface and subsurface movement.

The range or variability of annual subsurface leaching of water is somewhat greater on the simulated putting green compared to the fairways. However, median annual movement of water beneath the root zone is similar for the green and fairways (Table 3.7-14; Table 3.7-15; Table 3.7-16; Appendix B: Figure B-7; Figure B-8; Figure B-9). Median annual recharge or leaching of water past the root zone was 55 cm yr^{-1} for the simulated green (range is 7 to 128 cm yr^{-1}), 58 cm yr^{-1} for the simulated Wahiawa fairway (range is 13 to 124 cm yr^{-1}), and 58 cm yr^{-1} for the simulated Kolekole fairway (range is 13 to 124 cm yr^{-1}).

The volume of subsurface movement of water is comparable the amounts of recharge beneath other undisturbed soils such as pastures, meadows, and reduced tillage agricultural systems (Anderson et al. 1989; Balogh and Watson 1992; Logan et al. 1987). During the wet season (October through April) average monthly subsurface movement of water are elevated on all simulated soils (Appendix B: Figure B-10; Figure B-11; Figure B-12). Leaching is significantly reduced from May through September. The monthly cycle observed for drainage of water beneath the root zone was similar to the runoff patterns.

As previously mentioned a single large precipitation event occurred on 4/19/74 which produced exceptionally large surface and subsurface transport during April of 1974. The massive loss of runoff water during this single event reduced the total annual movement of water beneath the root zone. Despite reduced movement of leaching water during 1974, the single large transport event contributed to the majority of both runoff and leaching losses of applied chemicals. Application of pesticides four days prior to such an event represents a "catastrophic" loss for this system. Simulation year 1974 should be considered a potential maximum pesticide and nutrient transport condition. However, sediment and chemical losses from this type of event would be several orders of magnitude larger for agricultural systems when compared to turfgrass (e.g. Anderson et al. 1989; Balogh and Anderson 1992; Wauchope et al. 1978). This event demonstrates that timing of chemical application in relation to rain is a critical component for managing potential offsite chemical transport. Applying chemicals in relation to weather forecasts will significantly decrease the risk of catastrophic chemical losses. This condition applies to all chemicals regardless of the route of offsite movement.

Table 3.7-14. Mean Annual Flux of Water and Sediment from a 30 Year Simulation of an Established USGA Green on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Runoff[a] (cm yr^{-1})	Sediment Loss (kg ha^{-1} yr^{-1})	Recharge Past the Maximum Root Zone (cm yr^{-1})
Minimum	0.00	0.00	7.46
Maximum	23.37	10.94	128.49
Mean	5.31	2.37	58.90
SD	5.34	2.43	28.54
Median	3.93	1.76	55.38

[a]Median Area of Greens is 0.14 ha. SD = Standard Deviation.

Table 3.7-15. Mean Annual Flux of Water and Sediment from a 30 Year Simulation of an Established Wahiawa Soil Fairway on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Runoff[a] (cm yr^{-1})	Sediment Loss (kg ha^{-1} yr^{-1})	Recharge Past the Maximum Root Zone (cm yr^{-1})
Minimum	0.10	1.10	13.17
Maximum	29.50	293.09	124.43
Mean	9.66	89.25	59.38
SD	7.54	71.54	26.06
Median	9.35	84.88	57.59

[a]Median Area of Fairways is 1.15 ha. SD = Standard Deviation.

Table 3.7-16. Mean Annual Flux of Water and Sediment from a 30 Year Simulation of an Established Kolekole Soil Fairway on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Runoff[a] (cm yr^{-1})	Sediment Loss (kg ha^{-1} yr^{-1})	Recharge Past the Maximum Root Zone (cm yr^{-1})
Minimum	0.10	1.10	13.17
Maximum	29.50	293.09	124.43
Mean	9.66	89.25	59.38
SD	7.54	71.54	26.06
Median	9.35	84.88	57.59

Pesticide Fate and Transport

The potential for surface and subsurface movement of pesticides applied to turfgrass is determined by a complex interaction of chemical, soil, climatic, and management factors. All of the critical components affecting these relationships are discussed in detail by Balogh and Anderson (1992). The principal factors controlling fate and movement of pesticides in turfgrass systems are (1) rate and extent of application; (2) pesticide adsorption and rates of degradation; (3) application of a pesticide in relation to the occurrence of precipitation and irrigation; and (4) control of water movement by soil hydrologic and plant uptake characteristics.

Computer simulation of pesticide fate and transport on golf courses using PRZM integrates the essential processes and properties that determine whether a pesticide is subject to leaching or runoff losses (Balogh et al. 1992b). The annual cycle of simulated climate and pesticide application on the putting green and two fairway soils reflects the interaction of climate, soil characteristics and hydrology, management practices, and turfgrass dynamics. In general, the results of the computer simulation demonstrate that pesticide losses in surface runoff, water and sediment, and in leaching beneath the root zone rarely exceed the levels observed in agricultural systems (Anderson et al. 1989; Leonard 1990). The following discussion outlines the results of the simulation of insecticides, fungicides, and herbicides. The selected compounds have a wide range of chemical characteristics and rates of application (Table 3.7-10; Table 3.7-11).

Insecticides

Bendiocarb is a major use turfgrass insecticide with moderate application rates. As a relatively short-lived and moderately soluble compound (Table 3.7-10), bendiocarb is qualitatively considered at low risk to leaching and surface transport on sediment but at high risk to losses in surface runoff water (Table 3.7-2; Table 3.7-4).

Annual mass movement of bendiocarb in runoff and on sediment from the simulated putting green and two fairway soils is low to moderate (Table 3.7-17; Table 3.7-18; Table 3.7-19; Appendix B: Figure B-13a, B-13b; Figure B-14a, B-14b; Figure B-15a, B-15b; Figure B-16; Figure B-17; Figure B-18). The risk of bendiocarb loss in runoff water is much higher than on sediment. Median annual loss of bendiocarb in runoff water and sediment from the simulated green, Wahiawa soil, and Kolekole soil is 1.74 mg ha^{-1} yr^{-1}, 57.52 mg ha^{-1} yr^{-1}, and 61.33 mg ha^{-1} yr^{-1}, respectively. Maximum or worst case annual surface losses of bendiocarb as the percent of total application from the simulated green, Wahiawa soil, and Kolekole soil is 4.5 percent, 2.1 percent, and 2.2 percent, respectively. Although these quantities are detectable, the simulated worst case losses of bendiocarb from the turfgrass soils are comparable to the usual annual losses of short-lived, moderately soluble pesticides from agricultural systems (Anderson et al. 1989; Balogh and Anderson 1992; Leonard 1990).

On average surface losses of bendiocarb is greatest in the months during and immediately after application (Appendix B: Figure B-16; Figure B-17; Figure B-18). During the spring application of bendiocarb, surface losses are greatest during April. With relatively low surface runoff of water and sediment during the September pesticide application, peak fall surface losses are delayed until October which has higher levels of surface runoff (Appendix B: Figure B-4; Figure B-5; Figure B-6; Figure B-16; Figure B-17; Figure B-18). On average surface movement of bendiocarb is greater following the spring application than the fall application. However, this loss is biased by a single massive runoff event occurring in April of 1974.

Table 3.7-17. Mean Annual Flux of Bendiocarb from a 30 Year Simulation of an Established USGA Green on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	0.00	0.00	0.000
Maximum	200682.97	1003.70	0.008
Mean	7252.71	39.96	2.683E-04
SD	36553.74	182.60	0.001
Median	1.72	0.02	2.405E-09

Table 3.7-18. Mean Annual Flux of Bendiocarb from a 30 Year Simulation of an Established Wahiawa Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	4.69E-08	1.23E-07	7.64E-09
Maximum	89020.60	2766.20	1.135
Mean	3629.60	129.67	0.042
SD	16182.05	503.48	0.207
Median	52.86	4.66	2.40E-05

Table 3.7-19. Mean Annual Flux of Bendiocarb from a 30 Year Simulation of an Established Kolekole Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	5.00E-08	1.31E-08	2.14E-09
Maximum	94280.70	2929.60	2.95
Mean	3848.15	137.57	0.11
SD	17138.17	533.25	0.54
Median	56.36	4.97	6.84E-05

Table 3.7-20. Risk Level of Annual Bendiocarb Transport from an Established USGA Green at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Bendiocarb Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff (g ha^{-1} yr^{-1})	1.15	2.46
Sediment (g ha^{-1} yr^{-1})	0.02	0.02
Leachate (ug ha^{-1} yr^{-1})	6.96E-8	1.81E-5

Table 3.21. Risk Level of Annual Bendiocarb Transport from an Established Wahiawa Fairway Soil at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Bendiocarb Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff (g ha^{-1} yr^{-1})	1.32	2.63
Sediment (g ha^{-1} yr^{-1})	0.05	0.16
Leachate (ug ha^{-1} yr^{-1})	0.002	0.008

Table 3.7-22. Risk Level of Annual Bendiocarb Transport from an Established Kolekole Fairway Soil at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Bendiocarb Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff (g ha^{-1} yr^{-1})	1.40	2.80
Sediment (g ha^{-1} yr^{-1})	0.06	0.17
Leachate (ug ha^{-1} yr^{-1})	0.006	0.023

Based on an evaluation of the return period for surface movement of bendiocarb at the 80 percent and 90 percent (5 and 10 year return periods), there is some risk of detectable amounts of bendiocarb lost in surface runoff (soluble and sediment-bound) (Table 3.7-20; Table 3.7-21; Table 3.7-22). The risk of surface movement of bendiocarb in the three soils increases in the following order: USGA Green < Wahiawa < Kolekole. However, the single largest surface loss of bendiocarb from a simulated soil occurs on the USGA Green (Table 3.7-17).

Annual mass movement or leaching of bendiocarb beneath the turfgrass root zone is very low on the simulated putting green and fairway soils (Table 3.7-17; Table 3.7-18; Table 3.7-19; Appendix B: Figure B-19; Figure B-20; Figure B-21; Figure B-22; Figure B-23; Figure B-24). Maximum or worst case annual leaching loss of bendiocarb beneath the root zone of the simulated green, Wahiawa soil, and Kolekole soil is 0.008 ug ha^{-1} yr^{-1}, 1.135 ug ha^{-1} yr^{-1}, and 2.95 ug ha^{-1} yr^{-1}, respectively. Concentration in leachate from all three simulated soils is always less than the analytical detection limit (Appendix B; Table B-1; Table B-2; Table B-3).

On average subsurface losses of bendiocarb is greatest in the months during spring application and lags one month after the fall application (Appendix B: Figure B-22; Figure B-23; Figure B-24). During the spring application of bendiocarb, subsurface losses are greatest during April. The lowest subsurface flux of water occurs during the September pesticide application. Therefore, peak fall leaching losses are attenuated into October and November which have higher levels of water movement past the root zone (Appendix B: Figure B-10; Figure B-11; Figure B-12; Figure B-22; Figure B-23; Figure B-24). On average subsurface movement of bendiocarb is greater following the spring application than the fall application. However, this loss is biased by a single large leaching event occurring in April of 1974.

Evaluation of the return period for leaching of bendiocarb at the 80 percent and 90 percent shows very low risk of detectable amounts of bendiocarb leaching past the root zone (Table 3.7-20; Table 3.7-21; Table 3.7-22). The risk of subsurface movement of bendiocarb in the three soils increases in the following order: USGA Green < Wahiawa < Kolekole. The largest maximum loss of bendiocarb past the root zone is from the simulated Kolekole soil. This maximum loss, 2.95 ug ha^{-1} yr^{-1}, is extremely low.

Chlorpyrifos is a major use turfgrass insecticide with moderate label rates of application. As a moderately persistent to moderately short-lived compound with a high degree of adsorption to soil and organic matter (Table 3.7-10), chlorpyrifos is qualitatively considered at low risk to leaching and surface transport in runoff water but medium risk to losses on eroded sediment (Table 3.7-2; Table 3.7-4).

Annual mass movement of chlorpyrifos in runoff and on sediment from the simulated putting green and two fairway soils is low with the exception of moderate losses during 1974 (Table 3.7-23; Table 3.7-24; Table 3.7-25; Appendix B: Figure B-25a, B-25b; Figure B-26a, B-26b; Figure B-27a, B-27b; Figure B-28; Figure B-29; Figure B-30). With low sediment losses on the putting green, the risk of chlorpyrifos loss in runoff water is higher than on sediment. On the two fairway soils, the risk of chlorpyrifos loss in runoff water and sediment is nearly equivalent. Median annual loss of chlorpyrifos in runoff water and sediment from the simulated green, Wahiawa soil, and Kolekole soil is 23.05 mg ha^{-1} yr^{-1}, 25.70 mg ha^{-1} yr^{-1}, and 27.43 mg ha^{-1} yr^{-1}, respectively. Maximum or worst case annual surface losses of chlorpyrifos as the percent of total application from the simulated green, Wahiawa soil, and Kolekole soil is 0.3 percent, 0.16 percent, and 0.18 percent, respectively. Although these quantities are detectable, the simulated worst case losses of chlorpyrifos from the turfgrass soils are lower than the usual annual surface losses of moderately persistent, insoluble pesticides from agricultural systems (Anderson et al. 1989; Balogh and Anderson 1992; Leonard 1990).

On average surface losses of chlorpyrifos is greatest in the months during spring application and lags one month after the fall application (Appendix B: Figure B-28; Figure B-29; Figure B-30). During the spring application of chlorpyrifos, surface losses are greatest during April. With relatively low surface runoff of water and sediment during the September pesticide application, peak fall surface losses are delayed until October and November which have higher levels of surface runoff and erosion (Appendix B: Figure B-4; Figure B-5; Figure B-6; Figure B-28; Figure B-29; Figure B-30). On average surface movement of chlorpyrifos is greater following the spring application than the fall application. However, this loss is biased by a single massive runoff event occurring in April of 1974.

Based on an evaluation of the return period for surface movement of chlorpyrifos at the 80 percent and 90 percent (5 and 10 year return periods), there is relatively low risk of detectable amounts of chlorpyrifos lost in surface runoff (soluble and sediment-bound) (Table 3.7-26; Table 3.7-27; Table 3.7-28). The risk of surface movement of chlorpyrifos in the three soils increases in the following order: USGA Green < Wahiawa < Kolekole. However, the single largest surface loss of chlorpyrifos from a simulated soil occurs on the USGA Green (Table 3.7-23).

Annual mass movement or leaching of chlorpyrifos beneath the turfgrass root zone is undetectable on the simulated putting green and extremely low on the fairway soils (Table 3.7-23; Table 3.7-24; Table 3.7-25; Appendix B: Figure B-31; Figure B-32; Figure B-33; Figure B-34; Figure B-35; Figure B-36). Maximum or worst case annual leaching loss of chlorpyrifos beneath the root zone of the simulated green, Wahiawa soil, and Kolekole soil is negligible. Concentration in leachate from all three simulated soils is always less than the analytical detection limit (Appendix B; Table B-4; Table B-5; Table B-6).

On average subsurface losses of chlorpyrifos on the fairway soils is greatest in the months during spring application and is attenuated into the winter following the fall application (Appendix B: Figure B-35; Figure B-36). During the spring application of chlorpyrifos, subsurface losses are greatest during April. Chlorpyrifos is tightly adsorbed to the organic matter on the turfgrass soils. Therefore, fall leaching losses are attenuated into the six months after application which have higher levels of water movement past the root zone (Appendix B: Figure B-10; Figure B-11; Figure B-12; Figure B-35; Figure B-36). On average subsurface movement of chlorpyrifos is greater following the spring application than the fall application. However, this loss is biased by a single large leaching event occurring in April of 1974.

Table 3.7-23. Mean Annual Flux of Chlorpyrifos from a 30 Year Simulation of an Established USGA Green on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	0.00	0.00	0.00
Maximum	6030.40	722.17	0.00
Mean	242.12	32.59	0.00
SD	1095.48	130.99	0.00
Median	18.99	4.06	0.00

Table 3.7-24. Mean Annual Flux of Chlorpyrifos from a 30 Year Simulation of an Established Wahiawa Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	0.02	0.06	0.00
Maximum	2103.77	1578.29	5.78E-12
Mean	99.51	87.66	3.67E-13
SD	381.20	286.83	1.06E-12
Median	12.34	13.36	6.68E-14

Table 3.7-25. Mean Annual Flux of Chlorpyrifos from a 30 Year Simulation of an Established Kolekole Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	0.02	0.06	0.00
Maximum	2245.52	1684.63	1.76E-11
Mean	106.23	93.57	1.12E-12
SD	406.89	306.15	3.22E-12
Median	13.17	14.26	2.06E-13

Table 3.7-26. Risk Level of Annual Chlorpyrifos Transport from an Established USGA Green at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Chlorpyrifos Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff (g ha^{-1} yr^{-1})	0.08	0.15
Sediment (g ha^{-1} yr^{-1})	0.02	0.03
Leachate (ug ha^{-1} yr^{-1})	0.00	0.00

Table 3.7-27. Risk Level of Annual Chlorpyrifos Transport from an Established Wahiawa Fairway Soil at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Chlorpyrifos Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff (g ha^{-1} yr^{-1})	0.06	0.13
Sediment (g ha^{-1} yr^{-1})	0.07	0.13
Leachate (ug ha^{-1} yr^{-1})	3.00E-13	8.48E-13

Table 3.7-28. Risk Level of Annual Chlorpyrifos Transport from an Established Kolekole Fairway Soil at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Chlorpyrifos Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff ($g\ ha^{-1}\ yr^{-1}$)	0.07	0.14
Sediment ($g\ ha^{-1}\ yr^{-1}$)	0.08	0.14
Leachate ($ug\ ha^{-1}\ yr^{-1}$)	9.14E-13	2.58E-12

Evaluation of the return period for leaching of chlorpyrifos at the 80 percent and 90 percent shows extremely low risk of detectable amounts of chlorpyrifos leaching past the root zone (Table 3.7-26; Table 3.7-27; Table 3.7-28). The risk of subsurface movement of chlorpyrifos in the three soils increases in the following order: USGA Green < Wahiawa < Kolekole. However, all losses are below the analytical detection limits.

Fenamiphos is a major use turfgrass insecticide and nematicide with moderate rates of application. As a moderately short-lived and soluble compound (Table 3.7-10), fenamiphos is qualitatively considered at (1) high risk to surface transport in runoff water; (2) medium risk to surface loss on sediment; and (3) high risk to losses by leaching (Table 3.7-2; Table 3.7-4). The degradation products of fenamiphos (e.g. Fenamiphos sulfoxide) are very soluble and moderately persistent in the soil environment. Although this compound was not modeled, the risk of subsurface leaching of these compounds could be higher than the parent compound (Balogh and Anderson 1992).

Annual mass movement of fenamiphos in runoff and on sediment from the simulated putting green and two fairway soils is low to moderate (Table 3.7-29; Table 3.7-30; Table 3.7-31; Appendix B: Figure B-37a, B-37b; Figure B-38a, B-38b; Figure B-39a, B-39b; Figure B-40; Figure B-41; Figure B-42). The risk of fenamiphos loss in runoff water is much higher than on sediment. Median annual loss of fenamiphos in runoff water and sediment from the simulated green, Wahiawa soil, and Kolekole soil is 0.28 mg $ha^{-1}\ yr^{-1}$, 52.51 mg $ha^{-1}\ yr^{-1}$, and 55.58 mg $ha^{-1}\ yr^{-1}$, respectively. Maximum or worst case annual surface losses of fenamiphos as the percent of total application from the simulated green, Wahiawa soil, and Kolekole soil is 5.9 percent, 4.5 percent, and 4.6 percent, respectively. The simulated worst case surface losses of fenamiphos from the turfgrass soils are comparable to annual losses of moderately short-lived, soluble pesticides from agricultural systems (Anderson et al. 1989; Balogh and Anderson 1992; Leonard 1990).

On average surface losses of fenamiphos is greatest in the months during and immediately after application (Appendix B: Figure B-40; Figure B-41; Figure B-42). During the spring application of fenamiphos, surface losses are greatest during April. With relatively low surface runoff of water and sediment during the September pesticide application, peak fall surface losses are delayed until October (Appendix B: Figure B-4; Figure B-5; Figure B-6; Figure B-40; Figure B-41; Figure B-42). On average surface movement of fenamiphos is greater following the spring application than the fall application. However, this high differential of loss is biased by a single massive runoff event occurring in April of 1974.

Based on an evaluation of the return period for surface movement of fenamiphos at the 80 percent and 90 percent (5 and 10 year return periods), there is some risk of detectable amounts of fenamiphos lost in surface runoff (soluble and sediment-bound) (Table 3.7-32; Table 3.7-33; Table 3.7-34). The risk of surface movement of fenamiphos in the three soils increases in the following order: USGA Green < Wahiawa < Kolekole. However, the single largest surface loss of fenamiphos from a simulated soil occurs on the USGA Green (Table 3.7-29).

Annual mass movement or leaching of fenamiphos beneath the turfgrass root zone is low to moderate on the simulated putting green and fairway soils (Table 3.7-29; Table 3.7-30; Table 3.7-31; Appendix B: Figure B-43; Figure B-44; Figure B-45; Figure B-46; Figure B-47; Figure B-48). Median annual loss of fenamiphos in subsurface leaching from the simulated green, Wahiawa soil, and Kolekole soil is 0.88 ug $ha^{-1}\ yr^{-1}$, 3.16 ug $ha^{-1}\ yr^{-1}$, and 7.01 ug $ha^{-1}\ yr^{-1}$, respectively. Although these levels are low, potential worst case losses are significant. Maximum or worst case annual leaching loss of fenamiphos beneath the root zone of the simulated green, Wahiawa soil, and Kolekole soil is 0.31 g $ha^{-1}\ yr^{-1}$, 0.07 g $ha^{-1}\ yr^{-1}$, and 0.12 g $ha^{-1}\ yr^{-1}$, respectively. Concentration in leachate from all three simulated soils is within analytical detection limits in large level leaching events following application (Appendix B; Table B-7; Table B-8; Table B-9).

On average subsurface losses of fenamiphos is greatest in the months during spring application and lags one month after the fall application (Appendix B: Figure B-46; Figure B-47; Figure B-48). During the spring application of fenamiphos, subsurface losses are greatest during April. The lowest subsurface flux of water occurs during the September pesticide application. Therefore, peak fall leaching losses are attenuated into October and November which have higher levels of water movement past the root zone (Appendix B: Figure B-10; Figure B-11; Figure B-12; Figure B-46; Figure B-47; Figure B-48). On average subsurface movement of fenamiphos is greater following the spring application than the fall application. However, this loss is biased by a single large leaching event occurring in April of 1974.

Evaluation of the return period for leaching of fenamiphos at the 80 percent and 90 percent shows moderate risk of detectable amounts of fenamiphos leaching past the root zone (Table 3.7-20; Table 3.7-21; Table 3.7-22). The risk of subsurface movement of fenamiphos in the three soils increases in the following order: USGA Green < Wahiawa < Kolekole. The largest maximum loss of fenamiphos past the root zone is from the simulated USGA Green. This maximum loss, 0.31 g $ha^{-1}\ yr^{-1}$, is high. Use of fenamiphos on greens should be carefully considered. Restricting application prior to anticipated storm events will reduce potential surface and subsurface losses of fenamiphos and its degradation products.

Table 3.7-29. Mean Annual Flux of Fenamiphos from a 30 Year Simulation of an Established USGA Green on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	0.00	0.00	1.40E-06
Maximum	203268.56	217.60	310036.33
Mean	7727.78	9.81	10923.13
SD	37049.04	40.03	56523.59
Median	0.28	5.04E-04	0.88

Table 3.7-30. Mean Annual Flux of Fenamiphos from a 30 Year Simulation of an Established Wahiawa Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	7.85E-08	3.72E-09	2.43E-04
Maximum	156662.62	1024.17	67194.75
Mean	6723.38	52.24	2577.47
SD	28610.71	189.78	12228.74
Median	51.49	1.02	3.16

Table 3.7-31. Mean Annual Flux of Fenamiphos from a 30 Year Simulation of an Established Kolekole Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	8.11E-08	3.84E-09	5.20E-04
Maximum	162353.88	1061.29	124108.45
Mean	6999.20	54.52	4828.66
SD	29657.10	196.86	22583.54
Median	54.50	1.08	7.01

Table 3.7-32. Risk Level of Annual Fenamiphos Transport from an Established USGA Green at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Fenamiphos Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff (g ha^{-1} yr^{-1})	0.63	2.13
Sediment (g ha^{-1} yr^{-1})	0.001	0.006
Leachate (ug ha^{-1} yr^{-1})	231.19	1624.88

Table 3.7-33. Risk Level of Annual Fenamiphos Transport from an Established Wahiawa Fairway Soil at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Fenamiphos Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff (g ha^{-1} yr^{-1})	1.06	4.73
Sediment (g ha^{-1} yr^{-1})	0.02	0.06
Leachate (ug ha^{-1} yr^{-1})	545.93	1919.01

Table 3.7-34. Risk Level of Annual Fenamiphos Transport from an Established Kolekole Fairway Soil at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Fenamiphos Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff ($g\ ha^{-1}\ yr^{-1}$)	1.12	5.00
Sediment ($g\ ha^{-1}\ yr^{-1}$)	0.02	0.06
Leachate ($ug\ ha^{-1}\ yr^{-1}$)	1179.72	4092.58

Trichclorfon is a major use turfgrass insecticide with high label rates of application. As a moderately short-lived but very soluble compound (low K_{oc}) (Table 3.7-10), trichlorfon is qualitatively considered at (1) high risk to leaching losses; (2) medium losses in runoff water; and (3) low risk of offsite movement on eroded sediment (Table 3.7-2; Table 3.7-4). The high rate of application (9.1 kg ha^{-1}) increases the risk of leaching and surface losses.

Typical annual mass movement of trichlorfon in runoff and on sediment from the simulated putting green and two fairway soils is low to moderate with potential for very high losses immediately after large storm events (Table 3.7-35; Table 3.7-36; Table 3.7-37; Appendix B: Figure B-49a, B-49b; Figure B-50a, B-50b; Figure B-51a, B-51b; Figure B-52; Figure B-53; Figure B-54). The risk of trichlorfon loss in runoff water is much higher than losses on sediment. The risk of surface losses of trichlorfon is much greater on the two fairway soils than the USGA green. Median annual loss of trichlorfon in runoff water and sediment from the simulated green, Wahiawa soil, and Kolekole soil is 0.0002 mg ha^{-1} yr^{-1}, 586.83 mg ha^{-1} yr^{-1}, and 562.94 mg ha^{-1} yr^{-1}, respectively. Maximum or worst case annual surface losses of trichlorfon as the percent of total application from the simulated green, Wahiawa soil, and Kolekole soil is 2.8 percent, 5.3 percent, and 5.2 percent, respectively. The percentages of the total pesticide applied to turfgrass for the simulated worst case surface losses are comparable to annual losses of moderately short-lived, very soluble pesticides from agricultural systems. However on an area basis, the total worst case mass losses of trichlorfon in surface runoff from turfgrass are equivalent to the worst case mass losses observed in agricultural systems (Anderson et al. 1989; Balogh and Anderson 1992; Leonard 1990).

On average surface losses of trichlorfon is greatest in the months during and immediately after application (Appendix B: Figure B-52; Figure B-53; Figure B-54). During the spring application of trichlorfon, surface losses are greatest during April. With relatively low surface runoff of water and sediment during the September pesticide application, peak fall surface losses are delayed until October (Appendix B: Figure B-4; Figure B-5; Figure B-6; Figure B-52; Figure B-53; Figure B-54). On average surface movement of trichlorfon is greater following the spring application than the fall application.

Based on an evaluation of the return period for surface movement of trichlorfon at the 80 percent and 90 percent (5 and 10 year return periods), there is moderate risk of trichlorfon surface movement in runoff from both greens and fairway soils (Table 3.7-38; Table 3.7-39; Table 3.7-40). The risk of surface movement of trichlorfon in the three soils increases in the following order: USGA Green < Wahiawa < Kolekole. However, the single largest event and median surface loss of trichlorfon from a simulated soil occurs on the Wahiawa soil (Table 3.7-36).

Annual mass movement or leaching of trichlorfon beneath the turfgrass root zone is extremely high on the simulated putting green and fairway soils (Table 3.7-29; Table 3.7-30; Table 3.7-31; Appendix B: Figure B-43; Figure B-44; Figure B-45; Figure B-46; Figure B-47; Figure B-48). Median annual loss of trichlorfon in subsurface leaching from the simulated green, Wahiawa soil, and Kolekole soil is 19.1 g ha^{-1} yr^{-1}, 9.14 g ha^{-1} yr^{-1}, and 10.4 g ha^{-1} yr^{-1}, respectively. These levels indicate a significant potential for leaching losses. Maximum or worst case annual leaching loss of trichlorfon beneath the root zone as the percent of total application from the simulated green, Wahiawa soil, and Kolekole soil is 10.3 percent, 4.6 percent, and 4.9 percent, respectively.

Simulated annual mass loss of trichlorfon beneath the root zone is very high. Concentration in leachate from all three simulated soils often is very detectable from April through December (Appendix B; Table B-10; Table B-11; Table B-12). The greatest annual mass loss of trichlorfon from the putting green occurs in 1963 which is year with relatively high overall leaching (Appendix B: Figure B-7, Figure B-55). Extremely large surface losses of trichlorfon from the simulated green during the large storm event in April of 1974 significantly reduced the level of compound available for loss by leaching after the storm. However, the maximum subsurface loss from the fairway soils occurs in 1974 which is the result of a single extremely large leaching event (Appendix B: Figure B-8; Figure B-9; Figure B-56; Figure B-57).

On average subsurface losses of trichlorfon is greatest in the months during spring application and the two months after the fall application (Appendix B: Figure B-58; Figure B-59; Figure B-60). During the spring application of trichlorfon, subsurface losses are greatest during April. After the September pesticide application, fall leaching losses are evenly spread between September and October (Appendix B: Figure B-58; Figure B-59; Figure B-60). On average subsurface movement of trichlorfon is greater following the spring application than the fall application.

Evaluation of the return period for leaching of trichlorfon at the 80 percent and 90 percent shows a significant risk of detectable amounts of trichlorfon leaching past the root zone (Table 3.7-38; Table 3.7-39; Table 3.7-40). The risk of subsurface movement of trichlorfon in the three soils increases in the following order: Wahiawa < Kolekole < USGA Green. The largest maximum loss of trichlorfon past the root zone is from the simulated USGA Green. However, simulated subsurface losses from all soils is high.

There is a high risk of surface and subsurface losses of trichlorfon from all of the simulated soils. Use of trichlorfon on greens and fairway soils should be carefully considered. If this pesticide is considered for use, the following management practices should be considered: (1) application should be limited to once a year; (2) restriction of use prior to anticipated storm events; and (3) only allowing application in June, July, and August.

Table 3.7-35. Mean Annual Flux of Trichlorfon from a 30 Year Simulation of an Established USGA Green on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	0.00	0.00	0.90
Maximum	516249.92	27.18	1.86E+09
Mean	28852.28	2.45	2.29E+08
SD	100096.38	6.96	4.75E+08
Median	1.63E-04	1.60E-08	1.91E+07

Table 3.7-36. Mean Annual Flux of Trichlorfon from a 30 Year Simulation of an Established Wahiawa Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	5.78E-09	1.32E-11	3.46
Maximum	951863.24	308.37	8.41E+08
Mean	71001.76	34.07	9.64E+07
SD	202391.76	84.89	2.12E+08
Median	586.35	0.48	9.14E+06

Table 3.7-37. Mean Annual Flux of Trichlorfon from a 30 Year Simulation of an Established Kolekole Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	4.66E-09	9.86E-12	3.42
Maximum	933930.36	302.49	8.89E+08
Mean	70916.08	34.18	1.06E+08
SD	200621.63	84.98	2.29E+08
Median	562.47	0.47	1.04E+07

Table 3.7-38. Risk Level of Annual Trichlorfon Transport from an Established USGA Green at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Trichlorfon Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff (g ha^{-1} yr^{-1})	1.24	30.13
Sediment (g ha^{-1} yr^{-1})	0.0002	0.004
Leachate (g ha^{-1} yr^{-1})	147.68	794.81

Table 3.7-39. Risk Level of Annual Trichlorfon Transport from an Established Wahiawa Fairway Soil at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Trichlorfon Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff (g ha^{-1} yr^{-1})	15.02	95.20
Sediment (g ha^{-1} yr^{-1})	0.01	0.07
Leachate (g ha^{-1} yr^{-1})	60.18	282.87

Table 3.7-40. Risk Level of Annual Trichlorfon Transport from an Established Kolekole Fairway Soil at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Trichlorfon Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff ($g\ ha^{-1}\ yr^{-1}$)	14.88	95.48
Sediment ($g\ ha^{-1}\ yr^{-1}$)	0.01	0.07
Leachate ($g\ ha^{-1}\ yr^{-1}$)	64.97	317.16

General Discussion on Insecticides. The candidate insecticides demonstrate a wide range of physical and chemical characteristics. Combined with the variable climatic conditions and management strategies (e.g. rate of application), the insecticides have a wide range of potential losses in surface runoff and by leaching. Overall, chlorpyrifos has the lowest potential for surface and subsurface losses. Bendiocarb has moderate potential for losses in surface runoff and low potential for movement beneath the root zone.

Fenamiphos has a moderate level of risk for loss in surface and subsurface water flow. Fenamiphos should be selected and used with caution. Trichlorfon has moderate to high potential for loss in surface runoff and very high potential for subsurface leaching. Trichlorfon only should be used in June, July, and August; months with low occurrence of runoff and leaching.

Fungicides

Benomyl is a major use turfgrass fungicide with moderate label rates of application. As a highly persistent and moderately soluble compound (K_{oc} = 162)) (Table 3.7-10), benomyl is qualitatively considered at intermediate risk for leaching losses and for runoff losses in water and on eroded sediment (Table 3.7-2; Table 3.7-4).

Typical annual mass movement of benomyl in runoff and on sediment from the simulated putting green and two fairway soils is moderate to high with potential for relatively high losses after large storm events (Table 3.7-41; Table 3.7-42; Table 3.7-43; Appendix B: Figure B-61a, B-61b; Figure B-62a, B-62b; Figure B-63a, B-63b; Figure B-64; Figure B-65; Figure B-66). The risk of benomyl loss in runoff water is much higher than losses on sediment. The risk of surface losses of benomyl is much greater on the two fairway soils than on the USGA green. Median annual loss of benomyl in runoff water and sediment from the simulated green, Wahiawa fairway soil, and Kolekole soil is 5.98 $g\ ha^{-1}\ yr^{-1}$, 25.81 $g\ ha^{-1}\ yr^{-1}$, and 21.69 $g\ ha^{-1}\ yr^{-1}$, respectively. Maximum or worst case annual surface losses of benomyl as the percent of total application from the simulated green, Wahiawa fairway soil, and Kolekole soil is 11.1 percent, 8.1 percent, and 7.9 percent, respectively. The percentages of the total pesticide applied to turfgrass for the simulated worst case surface losses are comparable to worst case losses of persistent and moderately soluble pesticides from agricultural systems (Anderson et al. 1989; Balogh and Anderson 1992; Leonard 1990).

On average surface losses of benomyl is greatest in the month during spring application and several months after fall application (Appendix B: Figure B-52; Figure B-53; Figure B-54). During the spring application of benomyl, surface losses are greatest during April. With relatively low surface runoff during September and considering the resistance of benomyl to degradation, fall losses of benomyl in runoff are attenuated from October through March (Appendix B: Figure B-4; Figure B-5; Figure B-6; Figure B-64; Figure B-65; Figure B-66). On average surface movement of benomyl is greater following the spring application than the fall application.

Based on an evaluation of the return period for surface movement of benomyl at the 80 percent and 90 percent, there is moderate risk of benomyl surface movement off of both greens and fairway soils runoff (Table 3.7-44; Table 3.7-45; Table 3.7-46). The risk of surface movement of benomyl in the three soils increases in the following order: USGA Green < Wahiawa < Kolekole. However, the single largest event and median surface loss of benomyl from a simulated soil occurred on the USGA Green (Table 3.7-41).

Annual mass movement or leaching of benomyl beneath the turfgrass root zone is very high on the simulated putting green and fairway soils (Table 3.7-41; Table 3.7-42; Table 3.7-43; Appendix B: Figure B-67; Figure B-68; Figure B-69; Figure B-70; Figure B-71; Figure B-72). Median annual loss of benomyl in subsurface leaching from the simulated green, Wahiawa soil, and Kolekole soil is 14.1 $g\ ha^{-1}\ yr^{-1}$, 6.9 $g\ ha^{-1}\ yr^{-1}$, and 8.4 $g\ ha^{-1}\ yr^{-1}$, respectively. These levels indicate a significant potential for leaching losses. Maximum or worst case annual leaching loss of benomyl beneath the root zone as the percent of total application from the simulated green, Wahiawa soil, and Kolekole soil is 1.7 percent, 0.7 percent, and 0.9 percent, respectively. Leaching of benomyl, a moderately soluble compound, results from its persistence in the soil and long term availability for movement in percolating water. This contrasts the rapid short-term, high leaching rates of trichlorfon, which is a moderately short-lived but very soluble compound.

Simulated mass loss of benomyl beneath the root zone is very high. Concentration in leachate from all three simulated soils can be detected throughout the management year (Appendix B; Table B-13; Table B-14; Table B-15). The greatest annual mass loss of benomyl from the putting green and fairway soils occurs in 1965 followed by 1971, which are years with high overall leaching (Appendix B: Figure B-7, Figure B-8; Figure B-9; Figure B-67; Figure 68; Figure 69). Extremely large surface losses of benomyl from the simulated soil during the large storm event in April of 1974 significantly reduced the level of compound available for loss by leaching after the storm.

Table 3.7-41. Mean Annual Flux of Benomyl from a 30 Year Simulation of an Established USGA Green on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	0.00	0.00	10182.54
Maximum	667566.70	952.96	1.02E+08
Mean	34826.34	62.66	2.26E+07
SD	121108.74	173.23	2.37E+07
Median	5966.12	16.91	1.41E+07

Table 3.7-42. Mean Annual Flux of Benomyl from a 30 Year Simulation of an Established Wahiawa Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	254.86	8.22	3300.79
Maximum	479050.29	4339.30	4.16E+07
Mean	43454.47	512.90	1.07E+07
SD	86450.07	792.66	1.06E+07
Median	25481.35	328.57	6859672.14

Table 3.7-43. Mean Annual Flux of Benomyl from a 30 Year Simulation of an Established Kolekole Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	228.07	7.36	65763.64
Maximum	472375.77	4272.85	5.08E+07
Mean	40031.85	470.17	1.35E+07
SD	84952.70	776.33	1.33E+07
Median	21408.82	282.46	8414949.36

Table 3.7-59. Risk Level of Annual Benomyl Transport from an Established USGA Green at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Benomyl Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff (g ha^{-1} yr^{-1})	23.42	35.05
Sediment (g ha^{-1} yr^{-1})	0.06	0.12
Leachate (g ha^{-1} yr^{-1})	38.77	48.55

Table 3.7-60. Risk Level of Annual Benomyl Transport from an Established Wahiawa Fairway Soil at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Benomyl Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff (g ha^{-1} yr^{-1})	47.45	64.53
Sediment (g ha^{-1} yr^{-1})	0.63	0.97
Leachate (g ha^{-1} yr^{-1})	17.59	21.98

Table 3.7-61. Risk Level of Annual Benomyl Transport from an Established Kolekole Fairway Soil at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Benomyl Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff ($g\ ha^{-1}\ yr^{-1}$)	42.88	60.03
Sediment ($g\ ha^{-1}\ yr^{-1}$)	0.64	0.83
Leachate ($g\ ha^{-1}\ yr^{-1}$)	21.65	28.79

On average subsurface losses of benomyl is greatest in the months during spring application and throughout the months following the September application (Appendix B: Figure B-70; Figure B-71; Figure B-72). During the spring application of benomyl, subsurface losses are greatest during April, yet significant during May. After the September application of this persistent compound, leaching losses are attenuated at a high level from October through March (Appendix B: Figure B-70; Figure B-71; Figure B-72). Average peak benomyl leaching occurs in February, the month with the highest average level of subsurface water movement. Attenuation of leaching losses throughout the year is typical of highly persistent and mobile compounds (Balogh and Gordon 1987).

Evaluation of the return period for leaching of benomyl at the 80 percent and 90 percent shows a significant risk of detectable amounts of benomyl leaching past the root zone (Table 3.7-44; Table 3.7-45; Table 3.7-46). The risk of subsurface movement of benomyl in the three soils increases in the following order: USGA Green < Kolekole < Wahiawa. The largest maximum loss of benomyl past the root zone is from the simulated USGA Green. However, simulated subsurface losses from all soils is high.

There is a significant level of risk for surface and subsurface losses of benomyl from all of the simulated soils. Use of benomyl on greens and fairway soils should be carefully considered. If this pesticide is considered for use, the following management practices should be considered: (1) application should be limited to once a year; (2) restricting use prior to anticipated storm events; and (3) only allowing application in June, July, and August.

Chlorothalonil is a major use turfgrass fungicide with high label rates of application. As a moderately persistent to moderately short-lived compound with a high degree of adsorption to soil and organic matter (Table 3.7-10), chlorothalonil is qualitatively considered at low risk to leaching and medium risk to loss in runoff water and on eroded sediment (Table 3.7-2; Table 3.7-4).

Annual mass movement of chlorothalonil in runoff and on sediment from the simulated putting green and two fairway soils is relatively low with the exception of heavy losses during 1974 (Table 3.7-47; Table 3.7-48; Table 3.7-49; Appendix B: Figure B-73a, B-73b; Figure B-74a, B-74b; Figure B-75a, B-75b; Figure B-76; Figure B-77; Figure B-78). With low sediment losses on the putting green, the risk of chlorothalonil loss in runoff water is higher than on sediment. On the two fairway soils, the risk of chlorothalonil loss in runoff water also is higher than sediment losses. Median annual loss of chlorothalonil in runoff water and sediment from the simulated green, Wahiawa soil, and Kolekole soil is 779.99 mg $ha^{-1}\ yr^{-1}$, 571.41 mg $ha^{-1}\ yr^{-1}$, and 609.22 mg $ha^{-1}\ yr^{-1}$, respectively. Although, chlorothalonil and chlorpyrifos have similar physical and chemical properties, chlorothalonil is applied at 8 times the rate of chlorpyrifos (Table 3.7-11). Therefore, chlorothalonil is at greater risk of surface transport than chlorpyrifos.

Maximum or worst case annual surface losses of chlorothalonil as the percent of total application from the simulated green, Wahiawa soil, and Kolekole soil is 1.4 percent, 0.6 percent, and 0.6 percent, respectively. Although the total mass loss in surface run off is relatively high, the simulated worst case losses of chlorothalonil from the turfgrass soils are comparable to annual losses of moderately persistent, insoluble pesticides from many agricultural systems (Anderson et al. 1989; Balogh and Anderson 1992; Leonard 1990).

On average surface losses of chlorothalonil is greatest in the months during spring application and lags two to three months after the fall application (Appendix B: Figure B-76; Figure B-77; Figure B-78). During the spring application of chlorothalonil, surface losses are greatest during April. With relatively low surface runoff of water and sediment during the September pesticide application, peak fall surface losses are delayed until October and November which have higher levels of surface runoff and erosion (Appendix B: Figure B-4; Figure B-5; Figure B-6; Figure B-76; Figure B-77; Figure B-78). As a persistent compound, simulated movement of chlorothalonil can be detected in surface runoff between October and February after the fall application. On average surface movement of chlorothalonil is greater following the spring application than the fall application. However, this loss is biased by a single massive runoff event occurring in April of 1974.

Based on an evaluation of the return period for surface movement of chlorothalonil at the 80 percent and 90 percent (5 and 10 year return periods), there is moderate risk of detectable amounts of chlorothalonil lost in surface runoff (soluble and sediment-bound) (Table 3.7-50; Table 3.7-51; Table 3.7-52). The risk of surface movement of chlorothalonil is greater in runoff water than sediment. At the 90 percent level the risk of surface movement of chlorothalonil in the three soils increases in the following order: USGA Green < Wahiawa < Kolekole. However, the single largest event and largest median surface loss of chlorothalonil from a simulated soil occurs on the USGA Green (Table 3.7-47).

Annual mass movement or leaching of chlorothalonil beneath the turfgrass root zone is undetectable on the simulated putting green and extremely low on the fairway soils (Table 3.7-47; Table 3.7-48; Table 3.7-49; Appendix B: Figure B-79; Figure B-80; Figure B-81; Figure B-82; Figure B-83; Figure B-84). Maximum or worst case annual leaching loss of chlorothalonil beneath the root zone of the simulated green, Wahiawa soil, and Kolekole soil is negligible. Concentration in leachate from all three simulated soils is always less than the analytical detection limit (Appendix B; Table B-16; Table B-17; Table B-18).

On average subsurface losses of chlorothalonil on the fairway soils is greatest in the months during spring application and is attenuated well into the winter following the fall application (Appendix B: Figure B-83; Figure B-84). During the spring application of chlorothalonil, subsurface losses are greatest during April. Chlorothalonil is tightly adsorbed to the organic matter on the turfgrass soils. Therefore, fall leaching losses are attenuated into the six months after application which have higher levels of water movement past the root zone (Appendix B: Figure B-10; Figure B-11; Figure B-12; Figure B-83; Figure B-84). On average, subsurface movement of chlorothalonil is greater following the spring application than the fall application. However, the accumulated loss of chlorothalonil in the months following the fall application is much greater than the spring and summer leaching losses.

Table 3.7-47. Mean Annual Flux of Chlorothalinol from a 30 Year Simulation of an Established USGA Green on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	0.00	0.00	0.00
Maximum	246357.44	7776.65	0.00
Mean	10429.19	374.88	0.00
SD	44800.42	1413.03	0.00
Median	744.02	35.97	0.00

Table 3.7-48. Mean Annual Flux of Chlorothalinol from a 30 Year Simulation of an Established Wahiawa Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	0.41	0.33	6.20E-11
Maximum	89283.50	17644.88	1.62E-05
Mean	4516.17	1060.66	1.02E-06
SD	16190.09	3202.64	2.96E-06
Median	426.44	144.97	1.12E-07

Table 3.7-49. Mean Annual Flux of Chlorothalinol from a 30 Year Simulation of an Established Kolekole Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	0.43	0.35	1.87E-10
Maximum	95188.99	18811.80	4.79E-05
Mean	4815.85	1131.17	3.02E-06
SD	17260.98	3414.49	8.76E-06
Median	454.62	154.60	3.32E-07

Table 3.7-50. Risk Level of Annual Chlorothalinol Transport from an Established USGA Green at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Chlorothalinol Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff (g ha^{-1} yr^{-1})	2.49	5.99
Sediment (g ha^{-1} yr^{-1})	0.20	0.45
Leachate (ug ha^{-1} yr^{-1})	0.00	0.00

Table 3.7-51. Risk Level of Annual Chlorothalinol Transport from an Established Wahiawa Fairway Soil at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Chlorothalinol Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff (g ha^{-1} yr^{-1})	3.02	5.46
Sediment (g ha^{-1} yr^{-1})	0.96	1.88
Leachate (ug ha^{-1} yr^{-1})	1.04E-06	1.86E-06

Table 3.7-52. Risk Level of Annual Chlorothalinol Transport from an Established Kolekole Fairway Soil at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Chlorothalinol Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff ($g\ ha^{-1}\ yr^{-1}$)	3.22	5.83
Sediment ($g\ ha^{-1}\ yr^{-1}$)	1.02	2.00
Leachate ($ug\ ha^{-1}\ yr^{-1}$)	3.10E-06	5.51E-06

Evaluation of the return period for leaching of chlorothalonil at the 80 percent and 90 percent shows extremely low risk of detectable amounts of chlorothalonil leaching past the root zone (Table 3.7-50; Table 3.7-51; Table 3.7-52). The risk of subsurface movement of chlorothalonil in the three soils increases in the following order: USGA Green < Wahiawa < Kolekole. However, all losses are below the analytical detection limits.

Metalaxyl is a major use turfgrass fungicide with moderate rates of application. As a moderately short-lived and soluble compound (Table 3.7-10), metalaxyl is qualitatively considered at (1) medium risk to surface transport in runoff water; (2) low risk to surface loss on sediment; and (3) high risk to losses by leaching (Table 3.7-2; Table 3.7-4).

Annual mass movement of metalaxyl in runoff and on sediment from the simulated putting green and two fairway soils is relatively low with heavy losses in 1974 (Table 3.7-53; Table 3.7-54; Table 3.7-55; Appendix B: Figure B-85a, B-85b; Figure B-86a, B-86b; Figure B-87a, B-87b; Figure B-88; Figure B-89; Figure B-900. The risk of metalaxyl loss in runoff water is much higher than on sediment. Median annual loss of metalaxyl in runoff water and sediment from the simulated green, Wahiawa soil, and Kolekole soil is 94.51 mg ha^{-1} yr^{-1}, 473.75 mg ha^{-1} yr^{-1}, and 498.04 mg ha^{-1} yr^{-1}, respectively. Maximum or worst case annual surface losses of metalaxyl as the percent of total application from the simulated green, Wahiawa soil, and Kolekole soil is 10.1 percent, 7.0 percent, and 7.3 percent, respectively. The simulated worst case surface losses of metalaxyl from the turfgrass soils are comparable to worst case losses of moderately short-lived, soluble pesticides from agricultural systems (Anderson et al. 1989; Balogh and Anderson 1992; Leonard 1990).

On average surface losses of metalaxyl is greatest in the months during and immediately after application (Appendix B: Figure B-88; Figure B-89; Figure B-90). During the spring application of metalaxyl, surface losses are greatest during April. With relatively low surface runoff of water and sediment during the September pesticide application, peak fall surface losses are

delayed until October (Appendix B: Figure B-4; Figure B-5; Figure B-6; Figure B-88; Figure B-89; Figure B-90). On average surface movement of metalaxyl is greater following the spring application than the fall application. However, this high differential of loss is biased by a single massive runoff event occurring in April of 1974.

Based on an evaluation of the return period for surface movement of metalaxyl at the 80 percent and 90 percent (5 and 10 year return periods), there is some risk of detectable amounts of metalaxyl lost in surface runoff (soluble and sediment-bound) (Table 3.7-32; Table 3.7-33; Table 3.7-34). The risk of surface movement of metalaxyl in the three soils increases in the following order: USGA Green < Wahiawa < Kolekole. However, the single largest surface loss of metalaxyl from a simulated soil occurs on the USGA Green (Table 3.7-29).

Annual mass movement or leaching of metalaxyl beneath the turfgrass root zone is low to moderate on the simulated putting green and fairway soils (Table 3.7-53; Table 3.7-54; Table 3.7-55; Appendix B: Figure B-91; Figure B-92; Figure B-93; Figure B-94; Figure B-95; Figure B-96). Median annual loss of metalaxyl in subsurface leaching from the simulated green, Wahiawa soil, and Kolekole soil is 419.39 ug ha^{-1} yr^{-1}, 405.38 ug ha^{-1} yr^{-1}, and 834.59 ug ha^{-1} yr^{-1}, respectively. Although these levels are low, potential worst case losses are significant. Maximum or worst case annual leaching loss of metalaxyl beneath the root zone of the simulated green, Wahiawa soil, and Kolekole soil is 0.11 g ha^{-1} yr^{-1}, 0.03 g ha^{-1} yr^{-1}, and 0.61 g ha^{-1} yr^{-1}, respectively. Concentration in leachate from all three simulated soils is within analytical detection limits in large level leaching events following application (Appendix B; Table B-19; Table B-20; Table B-21).

On average subsurface losses of metalaxyl is greatest in the months during spring application and lags two months after the fall application (Appendix B: Figure B-94; Figure B-95; Figure B-96). During the spring application of metalaxyl, subsurface losses are greatest during April. The lowest subsurface flux of water occurs during the September pesticide application. Therefore, peak fall leaching losses are attenuated into October and November followed by lower level losses throughout the winter. Metalaxyl is more persistent than compounds such as fenamiphos which have similar transport characteristics. With slightly higher persistence in the simulated turfgrass soils, fall leaching losses are attenuated into the six months after application which have higher levels of water movement past the root zone (Appendix B: Figure B-10; Figure B-11; Figure B-12; Figure 94; Figure B-95; Figure B-96). On average, subsurface movement of metalaxyl is greater following the spring application than the fall application. However, the accumulated loss of metalaxyl in the months following the fall application is similar to the spring and summer leaching losses.

Evaluation of the return period for leaching of metalaxyl at the 80 percent and 90 percent shows moderate risk of detectable amounts of metalaxyl leaching past the root zone (Table 3.7-20; Table 3.7-21; Table 3.7-22). The risk of subsurface movement of metalaxyl in the three soils increases in the following order: Wahiawa < USGA Green < Kolekole. The largest maximum loss of metalaxyl past the root zone is from the simulated USGA Green. This maximum loss, 0.11 g ha^{-1} yr^{-1}, is somewhat high. Use of metalaxyl on greens should be carefully considered. Restricting application prior to anticipated storm events will reduce potential surface and subsurface losses.

CORRECTION

THE PRECEDING DOCUMENT(S) HAS BEEN REPHOTOGRAPHED TO ASSURE LEGIBILITY
SEE FRAME(S)
IMMEDIATELY FOLLOWING

Table 3.7-52. Risk Level of Annual Chlorothalinol Transport from an Established Kolekole Fairway Soil at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Chlorothalinol Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff ($g\ ha^{-1}\ yr^{-1}$)	3.22	5.83
Sediment ($g\ ha^{-1}\ yr^{-1}$)	1.02	2.00
Leachate ($ug\ ha^{-1}\ yr^{-1}$)	3.10E-06	5.51E-06

Evaluation of the return period for leaching of chlorothalonil at the 80 percent and 90 percent shows extremely low risk of detectable amounts of chlorothalonil leaching past the root zone (Table 3.7-50; Table 3.7-51; Table 3.7-52). The risk of subsurface movement of chlorothalonil in the three soils increases in the following order: USGA Green < Wahiawa < Kolekole. However, all losses are below the analytical detection limits.

Metalaxyl is a major use turfgrass fungicide with moderate rates of application. As a moderately short-lived and soluble compound (Table 3.7-10), metalaxyl is qualitatively considered at (1) medium risk to surface transport in runoff water; (2) low risk to surface loss on sediment; and (3) high risk to losses by leaching (Table 3.7-2; Table 3.7-4).

Annual mass movement of metalaxyl in runoff and on sediment from the simulated putting green and two fairway soils is relatively low with heavy losses in 1974 (Table 3.7-53; Table 3.7-54; Table 3.7-55; Appendix B: Figure B-85a, B-85b; Figure B-86a, B-86b; Figure B-87a, B-87b; Figure B-88; Figure B-89; Figure B-900. The risk of metalaxyl loss in runoff water is much higher than on sediment. Median annual loss of metalaxyl in runoff water and sediment from the simulated green, Wahiawa soil, and Kolekole soil is 94.51 mg ha^{-1} yr^{-1}, 473.75 mg ha^{-1} yr^{-1}, and 498.04 mg ha^{-1} yr^{-1}, respectively. Maximum or worst case annual surface losses of metalaxyl as the percent of total application from the simulated green, Wahiawa soil, and Kolekole soil is 10.1 percent, 7.0 percent, and 7.3 percent, respectively. The simulated worst case surface losses of metalaxyl from the turfgrass soils are comparable to worst case losses of moderately short-lived, soluble pesticides from agricultural systems (Anderson et al. 1989; Balogh and Anderson 1992; Leonard 1990).

On average surface losses of metalaxyl is greatest in the months during and immediately after application (Appendix B: Figure B-88; Figure B-89; Figure B-90). During the spring application of metalaxyl, surface losses are greatest during April. With relatively low surface runoff of water and sediment during the September pesticide application, peak fall surface losses are

delayed until October (Appendix B: Figure B-4; Figure B-5; Figure B-6; Figure B-88; Figure B-89; Figure B-90). On average surface movement of metalaxyl is greater following the spring application than the fall application. However, this high differential of loss is biased by a single massive runoff event occurring in April of 1974.

Based on an evaluation of the return period for surface movement of metalaxyl at the 80 percent and 90 percent (5 and 10 year return periods), there is some risk of detectable amounts of metalaxyl lost in surface runoff (soluble and sediment-bound) (Table 3.7-32; Table 3.7-33; Table 3.7-34). The risk of surface movement of metalaxyl in the three soils increases in the following order: USGA Green < Wahiawa < Kolekole. However, the single largest surface loss of metalaxyl from a simulated soil occurs on the USGA Green (Table 3.7-29).

Annual mass movement or leaching of metalaxyl beneath the turfgrass root zone is low to moderate on the simulated putting green and fairway soils (Table 3.7-53; Table 3.7-54; Table 3.7-55; Appendix B: Figure B-91; Figure B-92; Figure B-93; Figure B-94; Figure B-95; Figure B-96). Median annual loss of metalaxyl in subsurface leaching from the simulated green, Wahiawa soil, and Kolekole soil is 419.39 ug ha^{-1} yr^{-1}, 405.38 ug ha^{-1} yr^{-1}, and 834.59 ug ha^{-1} yr^{-1}, respectively. Although these levels are low, potential worst case losses are significant. Maximum or worst case annual leaching loss of metalaxyl beneath the root zone of the simulated green, Wahiawa soil, and Kolekole soil is 0.11 g ha^{-1} yr^{-1}, 0.03 g ha^{-1} yr^{-1}, and 0.61 g ha^{-1} yr^{-1}, respectively. Concentration in leachate from all three simulated soils is within analytical detection limits in large level leaching events following application (Appendix B; Table B-19; Table B-20; Table B-21).

On average subsurface losses of metalaxyl is greatest in the months during spring application and lags two months after the fall application (Appendix B: Figure B-94; Figure B-95; Figure B-96). During the spring application of metalaxyl, subsurface losses are greatest during April. The lowest subsurface flux of water occurs during the September pesticide application. Therefore, peak fall leaching losses are attenuated into October and November followed by lower level losses throughout the winter. Metalaxyl is more persistent than compounds such as fenamiphos which have similar transport characteristics. With slightly higher persistence in the simulated turfgrass soils, fall leaching losses are attenuated into the six months after application which have higher levels of water movement past the root zone (Appendix B: Figure B-10; Figure B-11; Figure B-12; Figure 94; Figure B-95; Figure B-96). On average, subsurface movement of metalaxyl is greater following the spring application than the fall application. However, the accumulated loss of metalaxyl in the months following the fall application is similar to the spring and summer leaching losses.

Evaluation of the return period for leaching of metalaxyl at the 80 percent and 90 percent shows moderate risk of detectable amounts of metalaxyl leaching past the root zone (Table 3.7-20; Table 3.7-21; Table 3.7-22). The risk of subsurface movement of metalaxyl in the three soils increases in the following order: Wahiawa < USGA Green < Kolekole. The largest maximum loss of metalaxyl past the root zone is from the simulated USGA Green. This maximum loss, 0.11 g ha^{-1} yr^{-1}, is somewhat high. Use of metalaxyl on greens should be carefully considered. Restricting application prior to anticipated storm events will reduce potential surface and subsurface losses.

Table 3.7-53. Mean Annual Flux of Metalaxyl from a 30 Year Simulation of an Established USGA Green on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	0.00	0.00	6.71E-02
Maximum	310279.32	430.22	106368.61
Mean	12415.94	20.23	8336.35
SD	56406.42	78.19	22964.38
Median	94.11	0.40	419.39

Table 3.7-54. Mean Annual Flux of Metalaxyl from a 30 Year Simulation of an Established Wahiawa Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	0.01	6.60E-04	0.44
Maximum	212107.41	1833.43	31125.03
Mean	9989.58	103.71	3142.98
SD	38479.39	333.50	6774.33
Median	465.56	8.19	405.38

Table 3.7-55. Mean Annual Flux of Metalaxyl from a 30 Year Simulation of an Established Kolekole Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	0.02	6.87E-04	1.01
Maximum	220886.25	1909.16	60987.30
Mean	10437.20	108.56	6096.85
SD	40072.26	347.36	13130.40
Median	489.34	8.70	834.59

Table 3.7-56. Risk Level of Annual Metalaxyl Transport from an Established USGA Green at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Metalaxyl Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff (g ha^{-1} yr^{-1})	3.49	11.50
Sediment (g ha^{-1} yr^{-1})	0.01	0.02
Leachate (ug ha^{-1} yr^{-1})	4015.07	12620.02

Table 3.7-57. Risk Level of Annual Metalaxyl Transport from an Established Wahiawa Fairway Soil at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Metalaxyl Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff (g ha^{-1} yr^{-1})	4.59	13.41
Sediment (g ha^{-1} yr^{-1})	0.07	0.16
Leachate (ug ha^{-1} yr^{-1})	3265.30	11971.53

Table 3.7-58. Risk Level of Annual Metalaxyl Transport from an Established Kolekole Fairway Soil at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Metalaxyl Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff ($g\ ha^{-1}\ yr^{-1}$)	4.88	14.22
Sediment ($g\ ha^{-1}\ yr^{-1}$)	0.08	0.17
Leachate ($ug\ ha^{-1}\ yr^{-1}$)	5962.34	23692.15

General Discussion on Fungicides. The candidate fungicides demonstrate a wide range of physical and chemical characteristics. Combined with the variable climatic conditions and management strategies (e.g. rate of application), the fungicides have a wide range of potential losses in surface runoff and by leaching. Overall, chlorothalinol has the lowest potential for surface and subsurface losses.

There is a significant level of risk for surface and subsurface losses of benomyl from all of the simulated soils. The combination of slightly elevated rates of application and persistence increases the risk of offsite movement of benomyl. Metalaxyl has moderate to high potential for losses in surface runoff with worst case losses comparable to worst case losses in agricultural systems. Leaching losses of metalaxyl are moderate, but still detectable. Use of benomyl and metalaxyl on greens and fairway soils should be carefully considered. If these pesticides are considered for use, the following management practices should be considered: (1) application should be limited to once a year; (2) restriction of use prior to anticipated storm events; and (3) only allowing application in June, July, and August.

Herbicides

Bensulide is a major use turfgrass herbicide with high label rates of application. As a moderately persistent and moderately insoluble (Table 3.7-10), bensulide is qualitatively considered at high risk to losses in surface runoff (water and sediment) and medium losses in subsurface percolation (Table 3.7-2; Table 3.7-4). The potentially high level of mass loading with high label rates of application and resistance to degradation (Table 3.7-10; Table 3.7-11), increases the risk of offsite movement of bensulide.

Annual mass movement of bensulide in runoff and on sediment from the simulated putting green and two fairway soils is high with potentially severe losses after large storm events (Table 3.7-59; Table 3.7-60; Table 3.7-61; Appendix B: Figure B-97a, B-97b; Figure B-98a, B-98b; Figure B-99a, B-99b; Figure B-100; Figure B-101; Figure B-102). With low to sediment losses on the putting green, the risk of bensulide loss in runoff water is higher than on sediment. On the two fairway soils, the risk of bensulide loss in runoff water also is higher than sediment losses. Median annual loss of bensulide in runoff water and sediment from the simulated green, Wahiawa soil, and Kolekole soil is 6031.06 mg $ha^{-1}\ yr^{-1}$, 8504.62 mg $ha^{-1}\ yr^{-1}$, and 8967.17 mg $ha^{-1}\ yr^{-1}$, respectively.

Maximum or worst case annual surface losses of bensulide as the percent of total application from the simulated green, Wahiawa fairway soil, and Kolekole soil is 4.0 percent, 1.8 percent, and 1.9 percent, respectively. Although the total percentage of bensulide lost in worst case runoff from the simulated turfgrass soils is similar to annual agricultural losses, the total mass loss in surface run off is still very high (Balogh and Anderson 1992; Leonard 1990).

On average surface losses of bensulide is greatest in the months during spring application and lags five to six months after the fall application (Appendix B: Figure B-100; Figure B-101; Figure B-102). During the spring application of bensulide, surface losses are greatest during April. With relatively low surface runoff of water and sediment during September and given the environmental persistence of bensulide, surface losses from the fall application are attenuated from October through March (Appendix B: Figure B-4; Figure B-5; Figure B-6; Figure B-76; Figure B-77; Figure B-78). As a persistent and heavily applied compound, the simulated movement of bensulide can be detected in surface runoff between October and February after the fall application. On average surface movement of bensulide is greater following the spring application than the fall application. However, this loss is biased by a single massive runoff event occurring in April of 1974.

Based on an evaluation of the return period for surface movement of bensulide at the 80 percent and 90 percent (5 and 10 year return periods), there is high risk of detectable amounts of bensulide lost in surface runoff water (Table 3.7-62; Table 3.7-63; Table 3.7-64). The risk of surface movement of bensulide is much greater in runoff water than sediment. At the 80 percent level the risk of surface movement of bensulide in the three soils increases in the following order: Kolekole < Wahiawa < USGA Green. At the 90 percent level the risk of surface movement of bensulide in the three soils increases in the following order: USGA Green < Kolekole < Wahiawa. The single largest event surface loss of bensulide from a simulated soil occurs on the USGA Green (Table 3.7-59).

Annual mass movement or leaching of bensulide beneath the turfgrass root zone is low on the simulated putting green and the fairway soils (Table 3.7-59; Table 3.7-60; Table 3.7-61; Appendix B: Figure B-103; Figure B-104; Figure B-105; Figure B-106; Figure B-107; Figure B-108). Large losses of bensulide in surface runoff reduces the amount of the compound available for leaching. Changing the pattern of surface runoff loses for this persistent compound also changes the time series of annual subsurface losses of bensulide (Appendix B: Figure B-103; Figure B-104; Figure B-105). This annual leaching pattern is similar to other persistent compounds with large runoff losses (e.g. benomyl).

Table 3.7-59. Mean Annual Flux of Bensulide from a 30 Year Simulation of an Established USGA Green on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	0.00	0.00	2.17E-08
Maximum	1086510.55	7092.40	6.03
Mean	48604.59	371.77	0.67
SD	196911.61	1283.32	1.39
Median	5941.86	89.20	0.07

Table 3.7-60. Mean Annual Flux of Bensulide from a 30 Year Simulation of an Established Wahiawa Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	31.93	4.85	0.06
Maximum	478705.13	19649.99	535.50
Mean	27050.13	1348.11	60.21
SD	86319.55	3553.01	106.03
Median	7984.25	520.37	24.57

Table 3.7-61. Mean Annual Flux of Bensulide from a 30 Year Simulation of an Established Kolekole Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	33.82	5.14	0.17
Maximum	507332.59	20822.58	1354.36
Mean	28661.58	1428.80	150.03
SD	91486.05	3765.54	266.73
Median	8421.00	546.17	59.94

Table 3.7-62. Risk Level of Annual Bensulide Transport from an Established USGA Green at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Bensulide Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff (g ha^{-1} yr^{-1})	20.63	43.27
Sediment (g ha^{-1} yr^{-1})	0.28	0.42
Leachate (ug ha^{-1} yr^{-1})	0.87	1.50

Table 3.7-63. Risk Level of Annual Bensulide Transport from an Established Wahiawa Fairway Soil at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Bensulide Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff (g ha^{-1} yr^{-1})	23.13	31.22
Sediment (g ha^{-1} yr^{-1})	1.56	2.20
Leachate (ug ha^{-1} yr^{-1})	86.51	127.76

Table 3.7-64. Risk Level of Annual Bensulide Transport from an Established Kolekole Fairway Soil at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Bensulide Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff ($g\ ha^{-1}\ yr^{-1}$)	24.58	33.12
Sediment ($g\ ha^{-1}\ yr^{-1}$)	1.66	2.35
Leachate ($ug\ ha^{-1}\ yr^{-1}$)	221.00	307.74

Median leaching loss of bensulide from the simulated green, Wahiawa soil, and Kolekole soil is 0.07 ug $ha^{-1}\ yr^{-1}$, 24.57 ug $ha^{-1}\ yr^{-1}$, and 59.94 ug $ha^{-1}\ yr^{-1}$, respectively. Although these levels are low, potential worst case losses are slightly higher. Maximum or worst case annual leaching loss of bensulide beneath the root zone of the simulated green, Wahiawa soil, and Kolekole soil is 6.03 ug $ha^{-1}\ yr^{-1}$, 535.50 ug $ha^{-1}\ yr^{-1}$, and 1354.36 ug $ha^{-1}\ yr^{-1}$, respectively. Concentration in leachate from all three simulated soils sometimes approaches analytical detection limits in large level leaching events following application (Appendix B; Table B-22 Table B-23; Table B-24).

On average subsurface losses of bensulide on the simulated soils is distributed throughout the year with significant attenuation of leaching loses well into the months following both spring and fall application (Appendix B: Figure 106; Figure B-107; Figure B-108). During the spring application of bensulide, subsurface losses are greatest during April on the fairway soils and during February on the simulated green. The combination of adsorption to organic matter and resistance to degradation are responsible for the attenuation of the leaching losses into the months following both spring and fall application . are attenuated into the six months after application which have higher levels of water movement past the root zone (Appendix B: Figure 106; Figure B-107; Figure B-108).

Evaluation of the return period for leaching of bensulide at the 80 percent and 90 percent shows low to intermediate risk of detectable amounts of bensulide leaching past the root zone (Table 62; Table 3.7-63; Table 3.7-64). The risk of subsurface movement of bensulide in the three soils increases in the following order: USGA Green < Wahiawa < Kolekole. However, all leachate concentrations are below current analytical detection limits.

There is a high risk of surface losses of bensulide from all of the simulated soils. Use of bensulide on greens and fairway soils should be carefully considered. If this pesticide is considered for use, the following management practices should be considered: (1) application limited to once a year or selection of alternate less persistent herbicide when possible; (2) restriction of use prior to anticipated storm events; and (3) only allowing application in May, June, July, and August.

2,4-D is a major use turfgrass herbicide with moderate label rates of application. As a moderately short-lived but very soluble compound (low K_{oc}) (Table 3.7-10), 2,4-D is qualitatively considered at (1) high risk to leaching losses; (2) medium losses in runoff water; and (3) low risk of offsite movement on eroded sediment (Table 3.7-2; Table 3.7-4).

Typical annual mass movement of 2,4-D in runoff and on sediment from the simulated putting green and two fairway soils is low to moderate with potential for high losses immediately after large storm events (Table 3.7-65; Table 3.7-66; Table 3.7-67; Appendix B: Figure B-109a, B-109b; Figure B-110a, B-110b; Figure B-111a, B-111b; Figure B-112; Figure B-113; Figure B-114). The risk of 2,4-D loss in runoff water is much higher than losses on sediment. The risk of surface losses of 2,4-D is greater on the two fairway soils than the USGA green. Median annual loss of 2,4-D in runoff water and sediment from the simulated green, Wahiawa soil, and Kolekole soil is 5.67 mg $ha^{-1}\ yr^{-1}$, 955.40 mg $ha^{-1}\ yr^{-1}$, and 990.75 mg $ha^{-1}\ yr^{-1}$, respectively.

Maximum or worst case annual surface losses of 2,4-D as the percent of total application from the simulated green, Wahiawa soil, and Kolekole soil is 8.4 percent, 12.1 percent, and 12.1 percent, respectively. The percentages of the total pesticide applied to turfgrass for the simulated worst case surface losses are comparable to worst case losses of moderately short-lived, very soluble pesticides from agricultural systems (Anderson et al. 1989; Balogh and Anderson 1992; Leonard 1990).

On average surface losses of 2,4-D is greatest in the months during and immediately after application (Appendix B: Figure B-112; Figure B-113; Figure B-114). During the spring application of 2,4-D, surface losses are greatest during April. With relatively low surface runoff of water and sediment during the September pesticide application, peak fall surface losses are delayed until October (Appendix B: Figure B-4; Figure B-5; Figure B-6; Figure B-112; Figure B-113; Figure B-114). On average surface movement of 2,4-D is greater following the spring application than the fall application. However, this loss is biased by a single massive runoff event occurring in April of 1974.

Based on an evaluation of the return period for surface movement of 2,4-D at the 80 percent and 90 percent (5 and 10 year return periods), there is moderate risk of 2,4-D surface movement in runoff from both greens and fairway soils (Table 3.7-68; Table 3.7-69; Table 3.7-70). The risk of surface movement of 2,4-D in the three soils increases in the following order: USGA Green < Wahiawa < Kolekole. However, the largest surface loss of 2,4-D from a simulated soil occurs on the Wahiawa soil (Table 3.7-66).

Annual leaching of 2,4-D beneath the turfgrass root zone is very high on the simulated putting green and fairway soils (Table 3.7-65; Table 3.7-66; Table 3.7-67; Appendix B: Figure B-115; Figure B-116; Figure B-117; Figure B-118; Figure B-119; Figure B-120). Median annual loss of 2,4-D in subsurface leaching from the simulated green, Wahiawa soil, and Kolekole soil is 0.80 g $ha^{-1}\ yr^{-1}$, 0.38 g $ha^{-1}\ yr^{-1}$, and 0.57 g $ha^{-1}\ yr^{-1}$, respectively. Maximum or worst case annual leaching loss of 2,4-D beneath the root zone as the percent of total application from the simulated green, Wahiawa soil, and Kolekole soil is 4.5 percent, 2.0 percent, and 2.4 percent, respectively. These levels indicate a significant potential for detectable leaching losses of 2,4-D. Concentration in leachate from all three simulated soils often is very detectable from April through December (Appendix B; Table B-23; Table B-24; Table B-25).

On average subsurface losses of 2,4-D is greatest in the months during spring application and the two months after the fall application (Appendix B: Figure B-118; Figure B-119; Figure B-120). During the spring application of 2,4-D, subsurface losses are greatest during April. After the September pesticide application, fall leaching losses are attenuated into October and November (Appendix B: Figure B-118; Figure B-119; Figure B-120). On average subsurface movement of 2,4-D is greater following the spring application than the fall application.

Table 3.7-65. Mean Annual Flux of 2,4-D from a 30 Year Simulation of an Established USGA Green on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	0.00	0.00	283.96
Maximum	210509.14	36.94	1.12E+08
Mean	9253.10	2.19	12277128.37
SD	38371.98	6.94	24233816.19
Median	5.67	1.74E-03	796333.53

Table 3.7-66. Mean Annual Flux of 2,4-D from a 30 Year Simulation of an Established Wahiawa Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	2.84E-04	1.98E-07	171.86
Maximum	303141.59	329.22	49102579.04
Mean	16550.57	23.95	4383121.32
SD	55501.28	62.51	9635038.86
Median	952.52	2.88	375904.02

Table 3.7-67. Mean Annual Flux of 2,4-D from a 30 Year Simulation of an Established Kolekole Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	2.72E-05	1.89E-07	208.99
Maximum	302822.07	328.80	58990792.08
Mean	16718.06	24.31	5528242.71
SD	55498.78	62.68	11731484.62
Median	987.78	2.97	571681.70

Table 3.7-68. Risk Level of Annual 2,4-D Transport from an Established USGA Green at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual 2,4-D Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff (g ha^{-1} yr^{-1})	2.66	9.12
Sediment (g ha^{-1} yr^{-1})	0.001	0.003
Leachate (g ha^{-1} yr^{-1})	19.00	40.53

Table 3.7-69. Risk Level of Annual 2,4-D Transport from an Established Wahiawa Fairway Soil at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual 2,4-D Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff (g ha^{-1} yr^{-1})	8.94	26.06
Sediment (g ha^{-1} yr^{-1})	0.02	0.05
Leachate (g ha^{-1} yr^{-1})	7.88	10.46

Table 3.7-70. Risk Level of Annual 2,4-D Transport from an Established Kolekole Fairway Soil at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual 2,4-D Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff ($g\ ha^{-1}\ yr^{-1}$)	9.13	26.75
Sediment ($g\ ha^{-1}\ yr^{-1}$)	0.02	0.06
Leachate ($g\ ha^{-1}\ yr^{-1}$)	10.74	13.18

Evaluation of the return period for leaching of 2,4-D at the 80 percent and 90 percent shows a significant risk of detectable amounts of 2,4-D leaching past the root zone (Table 3.7-38; Table 3.7-39; Table 3.7-40). The risk of subsurface movement of 2,4-D in the three soils increases in the following order: USGA Green < Kolekole < Wahiawa. The largest maximum loss of 2,4-D past the root zone is from the simulated USGA Green. However, simulated subsurface losses from all soils is high.

There is a moderate risk of surface and high risk of subsurface loss of 2,4-D from all of the simulated soils. Use of 2,4-D on greens and fairway soils should be carefully considered. If this pesticide is considered for use, the following management practices should be considered: (1) application should be limited to once a year with possible selection of an alternate herbicide; (2) restriction of use prior to anticipated storm events; and (3) only allowing application in May, June, July, and August.

DCPA is a major use turfgrass herbicide with moderate label rates of application. As a moderately persistent compound with a high degree of adsorption to soil and organic matter (Table 3.7-10), DCPA is qualitatively considered at (1) low risk to leaching: (2) medium risk to loss in runoff water; and (3) high risk to loss on eroded sediment (Table 3.7-2; Table 3.7-4).

Annual mass movement of DCPA in runoff and on sediment from the simulated putting green and two fairway soils is moderate with the exception of substantial losses during 1974 (Table 3.7-71; Table 3.7-72; Table 3.7-73; Appendix B: Figure B-121a, B-121b; Figure B-122a, B-122b; Figure B-123a, B-123b; Figure B-124; Figure B-125; Figure B-126). With low sediment losses on the putting green, the risk of DCPA loss in runoff water is higher than on sediment. On the two fairway soils, the risk of DCPA loss in runoff water also is higher than sediment losses. Median annual loss of DCPA in runoff water and sediment from the simulated green, Wahiawa soil, and Kolekole soil is 912.41 mg ha^{-1} yr^{-1}, 1403.51 mg ha^{-1} yr^{-1}, and 3818.99 mg ha^{-1} yr^{-1}, respectively.

Maximum or worst case annual surface losses of DCPA as the percent of total application from the simulated green, Wahiawa soil, and Kolekole soil is 1.3 percent, 0.6 percent, and 0.8 percent, respectively. Although the total mass loss in surface run off is relatively high, the simulated worst case losses of DCPA from the turfgrass soils are comparable to annual losses of moderately persistent, insoluble pesticides from many agricultural systems (Anderson et al. 1989; Balogh and Anderson 1992; Leonard 1990).

On average surface losses of DCPA is greatest in the months during spring application and lags three to five months after the fall application (Appendix B: Figure B-124; Figure B-125; Figure B-126). During the spring application of DCPA, surface losses are greatest during April. With relatively low surface runoff of water and sediment during the September pesticide application, fall surface losses are attenuated from October through February which have higher levels of surface runoff and erosion (Appendix B: Figure B-4; Figure B-5; Figure B-6; Figure B-124; Figure B-125; Figure B-126). As a persistent compound, simulated movement of DCPA can be detected in surface runoff between October and March after the fall application. On average surface movement of DCPA is greater following the spring application than the fall application. However, this loss is biased by a single massive runoff event occurring in April of 1974.

Based on an evaluation of the return period for surface movement of DCPA at the 80 percent and 90 percent (5 and 10 year return periods), there is some risk of detectable amounts of DCPA lost in surface runoff (soluble and sediment-bound) (Table 3.7-74; Table 3.7-75; Table 3.7-76). The risk of surface movement of DCPA is greater in runoff water than sediment. The risk of surface movement of DCPA in the three soils increases in the following order: Wahiawa < USGA Green < Kolekole. However, the largest annual surface loss of DCPA from a simulated soil occurs on the USGA Green (Table 3.7-71).

Annual mass movement or leaching of DCPA beneath the turfgrass root zone is undetectable on the simulated putting green and extremely low on the fairway soils (Table 3.7-71; Table 3.7-72; Table 3.7-73; Appendix B: Figure B-127; Figure B-128; Figure B-129; Figure B-130; Figure B-131; Figure B-132). Maximum or worst case annual leaching loss of DCPA beneath the root zone of the simulated green, Wahiawa soil, and Kolekole soil is negligible. Concentration in leachate from all three simulated soils is always less than the analytical detection limit (Appendix B; Table B-26; Table B-27; Table B-28).

On average subsurface losses of DCPA on the fairway soils is greatest in the months during and after spring application and is attenuated well into the winter following the fall application (Appendix B; Figure B-83; Figure B-84). DCPA is tightly adsorbed to the organic matter on the turfgrass soils. Therefore, both spring and fall leaching losses are attenuated into the six months after application.

Table 3.7-71. Mean Annual Flux of DCPA from a 30 Year Simulation of an Established USGA Green on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	0.00	0.00	0.000
Maximum	81127.78	2875.80	0.000
Mean	4354.87	185.53	0.000
SD	14689.00	520.42	0.000
Median	832.19	80.22	0.000

Table 3.7-72. Mean Annual Flux of DCPA from a 30 Year Simulation of an Established Wahiawa Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	3.90	3.16	2.84E-09
Maximum	29578.92	6593.38	7.04E-05
Mean	2046.35	564.89	1.40E-05
SD	5328.54	1190.94	1.90E-05
Median	1064.64	338.87	7.36E-06

Table 3.7-73. Mean Annual Flux of DCPA from a 30 Year Simulation of an Established Kolekole Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	13.50	10.96	1.53E-08
Maximum	40364.36	9041.96	5.80E-04
Mean	4634.01	1342.64	1.22E-04
SD	7733.72	1792.65	1.68E-04
Median	2813.70	1005.29	4.92E-05

Table 3.7-74. Risk Level of Annual DCPA Transport from an Established USGA Green at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual DCPA Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff (g ha^{-1} yr^{-1})	3.10	4.82
Sediment (g ha^{-1} yr^{-1})	0.15	0.27
Leachate (ug ha^{-1} yr^{-1})	0.00	0.00

Table 3.7-75. Risk Level of Annual DCPA Transport from an Established Wahiawa Fairway Soil at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual DCPA Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff (g ha^{-1} yr^{-1})	1.81	2.89
Sediment (g ha^{-1} yr^{-1})	0.62	0.98
Leachate (ug ha^{-1} yr^{-1})	2.08E-5	4.09E-5

Table 3.7-76. Risk Level of Annual DCPA Transport from an Established Kolekole Fairway Soil at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual DCPA Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff ($g\ ha^{-1}\ yr^{-1}$)	4.89	7.35
Sediment ($g\ ha^{-1}\ yr^{-1}$)	1.60	2.37
Leachate ($ug\ ha^{-1}\ yr^{-1}$)	1.60E-4	4.11E-4

Evaluation of the return period for leaching of DCPA at the 80 percent and 90 percent shows extremely low risk of detectable amounts of DCPA leaching past the root zone (Table 3.7-50; Table 3.7-51; Table 3.7-52). The risk of subsurface movement of DCPA in the three soils increases in the following order: USGA Green < Kolekole < Wahiawa. However, all losses are well below the analytical detection limits.

The U. S. Environmental Protection Agency (EPA) recently completed a 5-year national survey of chemical contamination of drinking water wells (EPA 1990). DCPA metabolites, or degradation products, were the most common contaminant of rural and community well systems. Although DCPA has low risk of subsurface movement, the products of DCPA decomposition may be at elevated risk of subsurface transport.

Dicamba is a major use turfgrass herbicide with low label rates of application. As a moderately short-lived but very soluble compound (low K_{oc}) (Table 3.7-10), dicamba is qualitatively considered at (1) high risk to leaching losses; (2) medium losses in runoff water; and (3) low risk of offsite movement on eroded sediment (Table 3.7-2; Table 3.7-4).

Typical annual mass movement of dicamba in runoff and on sediment from the simulated putting green and two fairway soils is low to moderate (Table 3.7-77; Table 3.7-78; Table 3.7-79; Appendix B: Figure B-133a, B-133b; Figure B-134a, B-134b; Figure B-135a, B-135b; Figure B-136; Figure B-137; Figure B-138). The risk of dicamba loss in runoff water is much higher than losses on sediment. The risk of surface losses of dicamba is much greater on the two fairway soils than the USGA green. Median annual loss of dicamba in runoff water and sediment from the simulated green, Wahiawa soil, and Kolekole soil is 0.53 mg $ha^{-1}\ yr^{-1}$, 172.42 mg $ha^{-1}\ yr^{-1}$, and 168.64 mg $ha^{-1}\ yr^{-1}$, respectively. Maximum or worst case annual surface losses of dicamba as the percent of total application from the simulated green, Wahiawa soil, and Kolekole soil is 6.8 percent, 10.4 percent, and 10.3 percent, respectively. The percentages of the total pesticide applied to turfgrass for the simulated worst case surface losses are comparable to high rates of annual losses of moderately short-lived, very soluble pesticides from agricultural systems (Anderson et al. 1989; Balogh and Anderson 1992; Leonard 1990).

On average surface losses of dicamba is greatest in the months during and immediately after application (Appendix B: Figure B-136; Figure B-137; Figure B-138). During the spring application of dicamba, surface losses are greatest during April. With relatively low surface runoff of water and sediment during the September pesticide application, peak fall surface losses are delayed until October (Appendix B: Figure B-4; Figure B-5; Figure B-6; Figure B-136; Figure B-137; Figure B-138). On average surface movement of dicamba is greater following the spring application than the fall application.

Based on an evaluation of the return period for surface movement of dicamba at the 80 percent and 90 percent (5 and 10 year return periods), there is low to moderate risk of dicamba surface losses from of both greens and fairway soils (Table 3.7-80; Table 3.7-81; Table 3.7-82). The risk of surface movement of dicamba in the three soils increases in the following order: USGA Green < Wahiawa < Kolekole. However, the single largest event and median surface loss of dicamba from a simulated soil occurs on the Wahiawa soil (Table 3.7-78).

Annual mass movement or leaching of dicamba beneath the turfgrass root zone is very high on the simulated putting green and fairway soils (Table 3.7-77; Table 3.7-78; Table 3.7-79; Appendix B: Figure B-139; Figure B-140; Figure B-141; Figure B-142; Figure B-143; Figure B-144). Median annual loss of dicamba in subsurface leaching from the simulated green, Wahiawa soil, and Kolekole soil is 5.4 g $ha^{-1}\ yr^{-1}$, 2.57 g $ha^{-1}\ yr^{-1}$, and 2.87 g $ha^{-1}\ yr^{-1}$, respectively. Maximum or worst case annual leaching loss of dicamba beneath the root zone as the percent of total application from the simulated green, Wahiawa soil, and Kolekole soil is 18.2 percent, 10.9 percent, and 11.2 percent, respectively. These levels indicate a significant potential for leaching losses.

Simulated annual mass loss of dicamba beneath the root zone is high. Concentration in leachate from all three simulated soils often is very detectable from April through December (Appendix B; Table B-29; Table B-30; Table B-31). The greatest annual mass loss of dicamba from the putting green occurs in 1963 which is year with relatively high overall leaching (Appendix B: Figure B-7, Figure B-139). Extremely large surface losses of dicamba from the simulated green during the large storm event in April of 1974 significantly reduced the level of compound available for loss by leaching after the storm. The maximum subsurface loss from the fairway soils occurs in 1974 which is the result of a single extremely large leaching event (Appendix B: Figure B-8; Figure B-9; Figure B-140; Figure B-141).

On average subsurface losses of dicamba is greatest in the months during spring application and the three months after the fall application (Appendix B: Figure B-142; Figure B-143; Figure B-144). During the spring application of dicamba, subsurface losses are greatest during April. After the September pesticide application, fall leaching losses are spread between September, October, and November (Appendix B: Figure B-142; Figure B-143; Figure B-144). On average subsurface movement of dicamba is greater following the spring application than the fall application.

Evaluation of the return period for leaching of dicamba at the 80 percent and 90 percent shows a significant risk of detectable amounts of dicamba leaching past the root zone (Table 3.7-80; Table 3.7-81; Table 3.7-82). The risk of subsurface movement of dicamba in the three soils increases in the following order: USGA Green < Kolekole < Wahiawa. The largest maximum loss of dicamba past the root zone is from the simulated USGA Green. However, simulated subsurface losses from all soils is high.

There is a high risk of subsurface and moderate risk of surface loss of dicamba from all of the simulated soils. Use of dicamba on greens and fairway soils should be carefully considered. If this pesticide is considered for use, the following management practices should be considered: (1) application should be limited to once a year with possible selection of an alternate herbicide; (2) restriction of use prior to anticipated storm events; and (3) only allowing application in June, July, and August.

Table 3.7-77. Mean Annual Flux of Dicamba from a 30 Year Simulation of an Established USGA Green on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	0.00	0.00	407.25
Maximum	15037.69	0.53	40107865.41
Mean	732.78	0.04	8973297.43
SD	2760.54	0.10	11353565.51
Median	0.53	3.24E-05	5419891.48

Table 3.7-78. Mean Annual Flux of Dicamba from a 30 Year Simulation of an Established Wahiawa Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	1.94E-05	2.38E-08	5166.84
Maximum	22876.33	4.95	23993964.74
Mean	1715.89	0.55	4933021.56
SD	4413.03	1.11	6505305.43
Median	172.42	0.08	2569716.95

Table 3.7-79. Mean Annual Flux of Dicamba from a 30 Year Simulation of an Established Kolekole Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	1.64E-05	1.98E-08	4977.30
Maximum	22609.24	4.89	24736208.14
Mean	1711.39	0.55	5223323.13
SD	4374.71	1.10	6808536.58
Median	168.64	0.08	2868549.04

Table 3.7-80. Risk Level of Annual Dicamba Transport from an Established USGA Green at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Dicamba Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff (g ha^{-1} yr^{-1})	0.24	0.90
Sediment (g ha^{-1} yr^{-1})	3.00E-05	8.00E-05
Leachate (g ha^{-1} yr^{-1})	12.68	27.84

Table 3.7-81. Risk Level of Annual Dicamba Transport from an Established Wahiawa Fairway Soil at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Dicamba Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff (g ha^{-1} yr^{-1})	1.22	3.57
Sediment (g ha^{-1} yr^{-1})	0.001	0.002
Leachate (g ha^{-1} yr^{-1})	8.19	14.40

Table 3.7-82. Risk Level of Annual Dicamba Transport from an Established Kolekole Fairway Soil at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Dicamba Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff ($g\ ha^{-1}\ yr^{-1}$)	1.22	3.57
Sediment ($g\ ha^{-1}\ yr^{-1}$)	0.001	0.002
Leachate ($g\ ha^{-1}\ yr^{-1}$)	8.42	15.20

General Discussion of Herbicides. The candidate herbicides demonstrate a wide range of physical and chemical characteristics. Combined with the variable climatic conditions and management strategies (e.g. rate of application), the herbicides have a wide range of potential losses in surface runoff and by leaching. However, all of the herbicides are at risk to either surface or subsurface movement.

There is a high risk of surface loss and low to moderate risk of subsurface loss of bensulide from all of the simulated soils. Dicamba and 2,4-D have moderate risk of surface losses and high risk of subsurface movement from all of the simulated soils. DCPA has low potential for leaching, but a moderate risk of surface losses. Although DCPA has low risk of subsurface movement, the products of DCPA decomposition may be at elevated risk of subsurface transport.

Use of all of the candidate herbicides on greens and fairway soils should be carefully considered. Depending on the target weed species and weather conditions, the following management practices should be considered: (1) application limited to once a year; (2) selection of less persistent and less mobile compounds when possible; (3) use of compounds with lower application rates; (4) restriction of use prior to anticipated storm events; (5) only allow application of candidate herbicides in May, June, July, and August.

Nitrogen: Subsurface Fate and Transport

The potential for subsurface movement of nitrogen applied to turfgrass is controlled by a complex interaction of chemical, soil, climatic, and management factors. All of the critical components affecting these relationships are discussed in detail by Balogh and Watson (1992) and Walker and Branham (1992). The principal factors controlling fate and movement of nitrogen in turfgrass systems are (1) the source, rate, extent, and season of application; (2) the rate of nitrogen transformation; (3) the rate of plant uptake and release; (4) timing of fertilizer application in relation to the occurrence of precipitation and irrigation; and (5) control of water movement by soil hydrologic and plant uptake characteristics. Dramatic differences have been reported in the literature for nitrogen leaching losses from turfgrass soils. Reported leaching losses of nitrogen from turfgrass range from no leaching losses to 80 percent leaching loss of the total applied nitrogen (Walker and Branham 1992). In general, soils with a coarse texture (sandy soils vs. finer texture soils) and receiving high levels of soluble nitrogen fertilizer (e.g. ammonium nitrate and urea) are at elevated risk of nitrate leaching (Anderson et al. 1989; Walker and Branham 1992).

Computer simulation of nitrogen fate and subsurface transport on golf courses using LEACHM integrates the essential transport and transformation processes that determine whether nitrate and ammonium are subject to leaching losses (Balogh et al. 1992b). The annual cycle of simulated climate and fertilizer application on the putting green and two fairway soils reflects the interaction of climate, soil characteristics and hydrology, management practices, nitrogen transformation and availability, and turfgrass dynamics. In general, the results of the computer simulation demonstrate that nitrogen losses resulting from the application of water soluble sources are very high on the simulate putting green and moderately high on the simulated fairways (Table 3.7-83; Table 3.7-84; Table 3.7-85).

The following discussion outlines the results of the simulation of nitrate and ammonium leaching losses resulting from the soil, climate and management strategy described in Section 3.7.2 (Table 3.7-8; Table 3.7-12; Table 3.7-13). The use of soluble nitrogen sources with a heavy rate of application represents a worst case condition for both the simulated green and fairway soils. The sand greens are at significantly higher risk for leaching loss of nitrogen compared to the silty clay (Wahiawa) and silty clay loam (Kolekole) soils (Table 3.7-8). Leaching losses of nitrate-nitrogen is much larger than subsurface losses of ammonium-nitrogen (Table 83; Table 84; Table 85). Ammonium, a cation, is adsorbed to the soil cation exchange complex and is far less susceptible to subsurface movement. Nitrate, an anion, is chemically unreactive in dilute solutions and has a low tendency to sorb on the surface of soil or organic colloids. The high solubility of nitrate in solution makes nitrate-nitrogen very susceptible to leaching, especially in sandy soils.

Annual mass movement or leaching of nitrogen beneath the turfgrass root zone is extremely high on the simulated putting green (Table 3.7-83; Appendix B: Figure B-189). The annual loss of nitrogen (nitrate and ammonium) by leaching from the simulated green in the "average" year (1950), a year with the single worst case leaching event (1974), and a year with the highest level of leaching (1965) is 220.5 kg $ha^{-1}\ yr^{-1}$, 116.6 kg $ha^{-1}\ yr^{-1}$, and 163.9 kg ha^{-1}, respectively. As a percent of the total application of nitrogen (ammonium nitrate and urea), annual leaching loss of nitrogen from the simulated green in 1950, 1974, and 1965 is 91.9 percent, 48.6 percent, and 68.3 percent, respectively. These levels indicate significant leaching losses of nitrogen when soluble forms of fertilizer are applied to greens without regard to the occurrence of precipitation or irrigation in any given year.

Monthly subsurface losses of nitrogen from the USGA green are highly variable (Table 83; Appendix B: Figure 189). Nitrogen leaching is highest in those months with elevated levels of available nitrogen in the soil profile coupled with high levels of subsurface percolation. For example in simulation year 1950, a year with a moderate level of annual leaching, the overall highest subsurface loss of nitrogen occurred. An unseasonably large storm in August of 1950 (8/15-16/50: 3.4 inches of rain) resulted in substantial subsurface movement of nitrogen. This nitrogen had accumulated in the profile over the course of four spring and summer applications. This coincidence of percolation and available nitrogen did not occur in 1974 or 1965. A greater proportion of the soil nitrogen is not available for leaching in 1974 and 1965, the years with major single and annual leaching events.

Leaching loss of nitrate from the simulated putting green in the large storm event in April of 1974 exceeded leaching observed in 1950 and 1965 (Appendix B: Figure 189). However, substantial amounts of nitrogen are removed from the soil profile during the fall and winter prior to the spring of 1974. Therefore, the total amount of nitrogen leached from the 1974 green did not exceed levels observed 1950 or 1965 (Table 83). This is not the case with many of the soluble pesticides. Definition of a worst case leaching of nitrogen is in contrast with worst case leaching of soluble pesticides (Balogh and Anderson 1992; Walker and Branham 1992).

Annual mass movement or leaching of nitrogen beneath the turfgrass root zone is high on the simulated fairway soils, although significantly less than from the putting greens (Table 3.7-83; Table 84: Table 85; Appendix B: Figure B-189; Figure 190; Figure 191). The annual loss of nitrogen (nitrate and ammonium) by leaching from the simulated Wahiawa soil in 1950, 1974, and 1965 is 21.5 kg ha^{-1} yr^{-1}, 19.2 kg ha^{-1} yr^{-1}, and 35.9 kg ha^{-1}, respectively. As a percent of the total application of nitrogen, annual leaching loss of nitrogen from the Wahiawa fairway in 1950, 1974, and 1965 is 17.9 percent, 16.0 percent, and 29.9 percent, respectively. The annual loss of nitrogen (nitrate and ammonium) by leaching from the simulated Kolekole soil in 1950, 1974, and 1965 is 20.8 kg ha^{-1} yr^{-1}, 16.7 kg ha^{-1} yr^{-1}, and 35.3 kg ha^{-1}, respectively. As a percent of the total application of nitrogen (ammonium nitrate and urea) annual leaching loss of nitrogen from the simulated green in 1950, 1974, and 1965 is 17.4 percent, 13.9 percent, and 29.4 percent, respectively.

The simulated mass loss of nitrogen from the simulated fairway soils indicate significant leaching losses of nitrogen occur when soluble forms of fertilizer are applied without regard to the occurrence of precipitation or irrigation in any given year. Unlike the very porous putting greens, the fairway soils have greater adsorption surfaces and reduce flow rates. Therefore, monthly leaching losses of nitrogen from the fairway soils remain variable but tend to be less influenced by single large storm events (Table 84; Table 85; Appendix B: Figure 190; Figure 191). Overall, monthly leaching losses of soluble nitrogen occurs predominantly after spring application and during wet fall and winter months.

In any given year the risk of nitrogen leaching beneath the root zone of green and fairway soils is contingent on (1) the level of available nitrogen in relation to active turfgrass growth, (2) the amount of water flux, and (3) timing of rain and irrigation in relation to application of fertilizer. Use of slow release fertilizers will reduce loss leaching losses of nitrogen (Balogh et al. 1992b; Walker and Branham 1992). Timing of nitrogen release from slow release fertilizers in relation to turfgrass uptake is critical for both plant nutrition and reduction of offsite movement (Balogh et al. 1992). Also, unless potentially available nitrogen is removed or composted in clippings, soluble nitrogen made available by transformation processes is still available for late fall and winter leaching (Appendix B: Figure 189; Figure 190; Figure 191).

Table 3.7-83. Simulated Annual and Monthly Leaching of Nitrogen from an Established USGA Green on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Month	"Average" Year[1]		1965[2]		1974[3]	
	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N
	(kg ha^{-1})		(kg ha^{-1})		(kg ha^{-1})	
Jan	0.859	17.866	0.119	3.612	0.555	12.636
Feb	0.117	2.777	0.205	5.498	0.033	0.917
Mar	0.004	0.120	< 0.001	0.003	0.057	5.012
Apr	0.687	27.441	0.862	46.023	0.858	42.400
May	0.063	4.005	0.168	28.837	0.025	3.296
Jun	< 0.001	0.008	< 0.001	0.024	0.002	0.502
Jul	0.073	9.715	0.232	14.065	0.210	19.268
Aug	0.593	68.818	< 0.001	0.009	< 0.001	0.001
Sep	0.002	0.325	< 0.001	0.001	< 0.001	0.020
Oct	0.037	6.178	0.505	9.721	0.025	4.332
Nov	0.351	43.706	0.561	20.794	0.144	26.307
Dec	0.452	36.297	0.432	32.219	< 0.001	0.009
Annual	3.238	217.256	3.084	160.806	1.909	114.700

[1]Climate year 1950 is an "average climate year" with median levels of runoff and leaching compared to the distribution of water movement in the 30 year record.

[2]Worst case leaching year (1965) with the highest annual subsurface leaching of water beneath the root zone (124 cm yr^{-1}).

[3]Worst case leaching year (1974) with a single worst case rain event occurring on 4/19/74 which is within 4 days of the first fertilizer application

Table 3.7-84. Simulated Annual and Monthly Leaching of Nitrogen from an Established Wahiawa Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	"Average" Year[1]		1965[2]		1974[3]	
	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N
Month	(kg ha^{-1})		(kg ha^{-1})		(kg ha^{-1})	
Jan	0.177	4.851	0.068	0.973	0.149	4.572
Feb	0.054	1.802	0.077	1.688	0.010	0.223
Mar	0.003	0.136	< 0.001	0.007	0.015	0.746
Apr	0.097	2.724	0.292	10.465	0.168	8.864
May	0.016	0.527	0.065	6.125	0.007	0.424
Jun	< 0.001	0.002	< 0.001	0.018	< 0.001	0.013
Jul	0.006	0.259	0.101	1.195	0.036	0.683
Aug	0.041	1.613	< 0.001	0.006	< 0.001	< 0.001
Sep	< 0.001	0.013	< 0.001	< 0.001	< 0.001	0.002
Oct	0.004	0.183	0.155	1.868	0.003	0.265
Nov	0.066	3.991	0.206	4.893	0.040	2.984
Dec	0.095	4.816	0.193	7.463	< 0.001	0.005
Annual	0.559	20.917	1.158	34.702	0.428	18.781

[1]Climate year 1950 is an "average climate year" with median levels of runoff and leaching compared to the distribution of water movement in the 30 year record.

[2]Worst case leaching year (1965) with the highest annual subsurface leaching of water beneath the root zone (124 cm yr^{-1}).

[3]Worst case leaching year (1974) with a single worst case rain event occurring on 4/19/74 which is within 4 days of the first fertilizer application

Table 3.7-85. Simulated Annual and Monthly Leaching of Nitrogen from an Established Kolekole Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	"Average" Year[1]		1965[2]		1974[3]	
	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N
Month	(kg ha^{-1})		(kg ha^{-1})		(kg ha^{-1})	
Jan	0.211	4.966	0.067	0.796	0.555	3.959
Feb	0.062	1.490	0.085	1.619	0.033	0.220
Mar	0.004	0.111	< 0.001	0.013	0.057	0.585
Apr	0.096	2.475	0.335	10.096	0.858	7.946
May	0.020	0.603	0.069	6.154	0.025	0.121
Jun	< 0.001	0.004	< 0.001	0.029	0.002	0.005
Jul	0.007	0.223	0.109	1.049	0.210	0.640
Aug	0.051	1.666	< 0.001	0.014	< 0.001	< 0.001
Sep	< 0.001	0.029	< 0.001	< 0.001	< 0.001	< 0.001
Oct	0.004	0.159	0.162	1.664	0.025	0.202
Nov	0.066	3.533	0.241	4.985	0.144	2.596
Dec	0.108	4.935	0.216	7.544	< 0.001	0.011
Annual	0.630	20.194	1.286	33.964	-0.411	16.286

[1]Climate year 1950 is an "average climate year" with median levels of runoff and leaching compared to the distribution of water movement in the 30 year record.

[2]Worst case leaching year (1965) with the highest annual subsurface leaching of water beneath the root zone (124 cm yr^{-1}).

[3]Worst case leaching year (1974) with a single worst case rain event occurring on 4/19/74 which is within 4 days of the first fertilizer application

4.0 SUMMARY AND CONCLUSIONS

This report is prepared in preparation for, and in support of, an overall Environmental Impact Statement (EIS) for the Hawaiian Trust Company's application for a Development Plan Amendment. This portion of the study focuses on the potential impacts of a proposed golf course that is included in the proposed development plan.

The purpose of this phase of the EIS is to accurately assess the potential impacts of a golf course in the proposed development plan. The report presents the assessment of numerous impacts (deleterious as well as innocuous or beneficial impacts) anticipated at the site. Some of the major issues addressed in the report, on a site specific basis include:

1. Leaching and runoff losses of nutrients and pesticides from the golf course during construction and after turfgrass establishment,
2. Soil erosion and runoff losses of sediment and nutrient during construction and losses from disturbed riparian zones,
3. Exposure of beneficial nontarget soil organisms, wildlife, and aquatic systems to pesticides (where possible),
4. Development and resurgence of insect and disease populations resistant to current chemical management schemes,
5. Excessive use of water resources for irrigation, use of effluent water for irrigation, and water re-use issues, and
6. Degradation of stream and lake quality resulting from sediment, chemical, and thermal pollution.

The site under consideration is located in the central part of Oahu, Hawaii, approximately 15 miles from Honolulu in a north by northwesterly direction. The site is at an elevation of about 873 feet and increases to almost 1000 feet in a northeasterly direction. The site consists of approximately 2000 acres of land. The development plan includes residential areas, commercial areas, schools, parks, waterways and a golf course all of which amounts to about 900 acres of developed land. The proposed golf course covers approximately 200 acres. Most of the proposed development occurs in the southern half of the property which is partially bordered by the H-2 Freeway to the south and west. The property is currently leased to the Del Monte Corporation and is planted in pineapple.

Important Findings: Site Conditions

Most of the site is occupied by WaA soils and WaB soils which are the Wahiawa soils with little to moderate slope (generally less than 6% as determined by on-site measurements). On the perimeter of the site there exist several soils of other series that are primarily differentiated with respect to slope. For example, the southern border of the property runs along the Wahiawa Reservoir and associated drainage areas. Here the soils slope steeply to the top of the reservoir from 25 to 90 percent in slope. The characteristics of the main soils occurring at the site are outlined in Table 2.1 which note chemical, physical and land use characteristics and classifications. In general, analysis has shown the soils to be:

- Very productive, of near neutral pH, are well-drained with excellent permeability.
- Suitability for grass land areas and turf appears to be excellent, this is reflected in the fact that bermudagrass is native to the area.
- There is one area that recent field sampling showed to have characteristics not previously mentioned. The KuB soil in the upper half of the property (noted in the map) was found to have a moderately well formed hard pan at about 18 inches in depth. The pan is several inches thick and likely has a quite different permeability and hydraulic conductivity compared to the soil above it. This will act as a barrier to downward water movement and could alter the hydrologic flow path in this particular area. Based on its location and the extent of the soil it is not expected to significantly alter the flow path on a site wide basis (especially given the layout of the proposed course).

Topographic maps of the site indicate that the area has only moderate slope characteristics except for the exceptions noted above. In addition, there is a gully that has formed in the lower southwesterly section of the property that appears to act as a drainage way for excess rainfall.

- The drainage gully likely seeps or empties into the Wahiawa reservoir. Based on the noted permeability of the majority of soils at the site (2-6"/hour), only rainfall in excess of this amount would contribute to significant drainage through the gully area.
- This area should be graded and leveled in the development to prevent runoff from reaching the reservoir.

Climate at the site is generally described as having:

- A mean annual temperature of 72°F,
- Mean rainfall between 40 and 60 inches per year with most of the rain occurring between November and April.

Important hydrologic features include:

- Depth to groundwater is always greater than 6 feet.
- The terrain slopes gently in a generally southerly direction with major drainage occurring in this direction ultimately emptying into the Wahiawa Reservoir and associated drainage areas.
- The soils are deep, very well drained with moderate to moderately high hydraulic conductivities.
- Runoff potential at the site is low (and slow) except in the southern boundary areas where slopes increase to almost 90 percent.

Vegetation at the site consists almost exclusively of pineapple. The only areas not in pineapple are those areas with slopes too severely to support production agriculture. These areas are confined to the immediate vicinity of the reservoir. These areas support an apparently diverse population of plant species.

- The current construction designs should have no effect on the area in terms of cutting/clearing or grading.
- The trees and shrubs in these areas may be affected by offsite transport of chemicals in the event that wind-drift becomes a significant problem. Use of the Integrated Turf Management System (TMS), outlined in this report, will minimize or eliminate this possibility.

Pesticide Use/Impact

We have compiled a list of pesticides that may be used at the proposed golf course. The list was selected based on information regarding use at other golf courses under similar climatic regimes:

TABLE 4-1. PESTICIDE SELECTION

Name	Trade Name	CAS Number	Category*	Family
Bendiocarb	Dycarb	22781-23-3	I	Carbamate
Chlorpyrifos	Dursban	2921-88-2	I	Organo-phosphate
Fenamiphos	Nemacur	22224-92-6	N	Organo-phosphate
Trichlorfon	Proxol	52-68-6	I	Organo-phosphate
Benomyl	Tersan 1991DF	17804-35-2	F	Carbamate
Chlorothalonil	Daconil 2787	1897-45-6	F	Halo-benzene
Metalaxyl	Apron 25W	57837-19-1	F	Dithio-carbamate
Bensulide	Betasan	741-58-2	H	Organo-phosphate
2,4-D	Many	94-75-7	H	Organo-phosphate
DCPA	Dacthal	1861-32-1 1918-00-9 62610393	H	Aryl aliph acid
Dicamba	Banvel	2300-66-5	H	Aryl aliph acid

* I = Insecticide H = Herbicide
F = Fungicide N = Nematocide

Assessment of pesticide behavior at the site is described fully in the report under a number of different scenarios. Below is a table that describes the different factors affecting runoff and pesticide losses (one of the main concerns at the site). We have added a column describing how specific site conditions at Wahiawa may affect runoff.

TABLE 4-2 GENERAL EFFECT OF PESTICIDE BEHAVIOR EXPECTED AT SITE

Factors	General Effect	Site Specific Effect
Rainfall/Pesticide and nutrient application.	Highest pesticide runoff occurs during first major runoff event.	Same. TMS will seek to minimize through proper application technique and timing.
Rainfall intensity.	Runoff occurs when rainfall rate exceeds soil infiltration rate.	Soils at the site have excellent permeability (2-6"/hour). If pesticide and nutrients are applied properly, then runoff potential decreases.
Rainfall amount and duration.	Affects runoff volume and leaching potential. Foliar pesticide washoff related to amount of rain.	Pesticide timing and placement are again factors that the TMS will address to minimize this effect.
Soil texture and organic matter content.	Infiltration rates are affected. Texture affects erodibility and particle transport potential. Organic matter usually increases pesticide adsorption.	Infiltration at site is good due to silty clay texture. Runoff expected to be low under most conditions. However, the soils are high in Al and Fe oxides and could erode if saturated. Presence of turf will minimize this. Organic matter content is 1-3% in most cases, which will aid in adsorption processes.
Soil water content.	High water content will decrease time to runoff.	Not a factor. Soils are very well drained and deep.
Slope.	Increasing slope will increase runoff potential.	Most of the acreage has only 1-6% slopes. Small pockets of the area increase to 10-25%. These can be graded or used as areas with less intensive management (e.g. fairways).

Factors	General Effect	Site Specific Effect
Pesticide solubility.	Soluble pesticides tend to be more readily leached into soil and not removed via runoff. Low solubility pesticides more likely to wash off (if rain duration is significant).	A few of the compounds suggested for use are soluble (e.g. 2,4-D, Dicamba, and Trichlorfon). TMS will carefully monitor use and application timing. If timing is not followed by rainfall, then leaching and runoff potential reduced.
Pesticide sorption.	Pesticides strongly adsorbed near soil or plant surface more likely to wash off. Runoff off amounts will then depend on particle or sediment transport.	Sorption properties of the soils are moderate to high due to amphoteric surfaces and organic matter. However, soil is well aggregated and tends not to erode easily unless saturated.
Persistence of chemicals	High probability of runoff with use of persistent compounds.	Minimize use of these compounds.
Irrigation practices	Sprinkler irrigation may move soluble pesticides into soil and thatch reducing runoff potential.	Addressed in TMS. This will likely be a reasonable approach for reducing runoff. Timing will still be a factor.

Below, we have again constructed a Table that compares different factors relating subsurface pesticide losses to conditions at the site. Quantitative assessment of the movement of pesticides is presented in the modeling section of this report.

TABLE 4-3 SUBSURFACE TRANSPORT OF PESTICIDES EXPECTED AT THE SITE

Factor	Impact on Subsurface Transport	Site Specific Effect
Soil Water Content	Soil water ultimately transports pesticides not absorbed to soil surfaces. Increased soil water levels will increase both water and chemical flux beyond the root zone.	Due to the fact that the soils are very well drained at the site, high rainfall influx can be counter balanced with a rational approach to application and timing.
Hydraulic conductivity	Measure of soil's ability to transmit water and entrained solutes. Soils with high conductivity in relation to initial infiltration (sands) have a greater potential for mass transport of solutes.	Soils are silty clays with many fine pores in the upper soil profile. Conductivity is expected to be moderate and present as manageable in relation to leaching.
Organic Matter and Clay Content	Effect pesticide adsorption, which attenuate leaching potential.	Soils have relatively high adsorption capacity with 1-3% organic matter. Both will aid in reducing subsurface leaching. Adsorption surfaces capable of adsorbing most pesticides chosen.
Thatch Layer	The thatch layer is a continuous organic medium which may form between the turf canopy and the soil. It can act as an effective barrier to pesticide entering soil.	Magnitude of effect in many cases is unknown. In general thatch will decrease amount of pesticide available for subsurface leaching.
Depth to Groundwater	Shallow aquifers more likely to be contaminated.	Data not fully evaluated. (assume >6ft)
Pesticide Sorption Properties	High Kd values suggests that pesticide strongly adsorbed and the potential for leaching is thereby reduced.	Pesticides suggested for use have fairly high Kd values. Should be strongly adsorbed. Most pesticides found in groundwater have Kd values less than 1. Pesticides chosen, easily exceed this value.
Application Rate	Amount of pesticide applied is directly proportional to amount transported.	Reduce application rates and repeated use. Use only on areas requiring treatment. Both will reduce this potential.

There is a wide range of field and chemical conditions that influence potential transport of pesticides to groundwater. When persistent compounds that have high or intermediate mobility are applied to soils with minimal adsorptive capacity and shallow water tables, the leaching process may result in groundwater contamination. On the opposite end of the risk spectrum is the use of pesticides that are rapidly decomposed and/or strongly adsorbed. When these chemical are applied to soils with high adsorptive capacity, deep water tables, and appropriate water management, the probability of pesticide leaching is significantly reduced. However, under certain conditions, even very persistent and immobile compounds, such as chlordane, can be leached to groundwater (Cohen et al., 1990). Therefore the complex suite of conditions controlling the movement of chemicals must be evaluated on a site specific basis. These conditions and how they interact at the site are more fully described in the Modeling Section of the report.

Comparison of Anticipated Pesticide Behavior in Turfgrass to Present Land Use Management

Based on the review of the processes governing the offsite transport of pesticides from the site, it is possible to compare the effect of constructing and managing a golf course to the current agricultural practices at the site.

- **Surface Water Transport:** Surface water transport potential (runoff) will be reduced due to the presence of turfgrass over much of the southern part of the site (see map) compared to runoff under the present pineapple cultivation practices. This will occur through several likely mechanisms. The site at present has significant gully erosion occurring in the southwesterly section of the acreage. Since the topographic features of the area suggest that this represents a significant drainage pathway for the site, the gully acts as a conduit for removal of runoff water from the site. This is further substantiated by the large amount of sediment observed leaving the site with runoff water. Sediment from the site covers the faces of roadcuts and parts of the highway around the reservoir. Development of the site with a turf cover should provide an additional absorptive surface for water, will increase soil stability and infiltration. Re-grading the gullied area will minimize or possibly recapture runoff for storage and possible reuse.

- **Pesticide Transport via Runoff:** This should also be reduced due to golf course development for similar reasons affecting the quantity of water leaving the site as noted above. However, it is also true that pesticide application site wide will be reduced due to the implementation of the TMS program which will seek to reduce the quantity of pesticide applied, will allow application only when needed, and will be timed to avoid predictable climatic situations that could lead to runoff. Present pesticide application at the site appears to be by schedule rather than by need.

- **Pesticide Transport via Erosion (Sediment):** The establishment of turfgrass at the site will definitely decrease the extent of erosion and particle bound pesticide at the site. Turf will cover large areas of now bare soil and overall will provide a "soil cover" for much of the site. Establishment of turf for erosion control is a common and recommended practice of the USDA and SCS.

- **Pesticide Leaching:** Leaching of pesticide at the site should also be reduced compared to the present cultivation practices. Establishment of turf will provide a buffer zone for capture of leachable pesticide presumably due to the high adsorptive capacity of the turf thatch layer. Presently, soluble pesticide that reaches the bare soil is free to leach to the extent determined solely by soil physical parameters and water movement.

Nutrient Use/Loss

The use of fertilizers is an important turfgrass management practice required to maintain the aesthetic quality and turfgrass growth rate to accommodate wear. Public concern is growing regarding the use of fertilizers for turfgrass management and the potential contamination of water supplies associated with golf courses.

On the basis of the review and site specific information, nitrogen, and in particular, nitrate, is the nutrient that would pose the most serious threat from an environmental impact and water quality perspectives. Several conclusions can be inferred:

1. Nitrogen is a relatively easily managed component at the site. It is expected that N fertilization at the site will entail use of relatively insoluble (slow-release) materials for fertilization of turf. Application will be based on initial soil test results, turf requirement, and turf condition throughout the year. TMS strategies will reduce both luxury consumption of N and subsurface leaching. If industrial or municipal effluent are available, these could be used as both a source of water at the site and as an additional source of nitrogen. Application of soluble N compounds for "quick" green up is not recommended.

2. If nitrogen residues are present in a soluble form above a concentration that can be used by the turfgrass and if water moves through thatch or soil, leaching of nitrogen past the root zone can occur. If the nitrogen is not in a soluble form, such as IBDU, leaching losses of nitrogen are significantly reduced.

3. Increasing the rate of nitrogen application to highly sandy greens will lead to a deterioration in drainage water quality. On sandy loam greens, increased nitrogen fertilization commensurate with uptake capacity of specific turfgrass species should not further reduce water quality.

4. Late fall is a common time for nitrogen fertilization. However, the agronomic benefits derived from this practice may be lost by the adverse environmental impacts in areas with vulnerable groundwater characteristics. Heavy fall fertilization is to be avoided.

5. Establishment of turfgrass at the site will result in soils with a high infiltration capacity thereby reducing the potential for nutrient loss and subsequent water quality deterioration by runoff. Numerous studies demonstrate that runoff of water from turfgrass is limited. Even on sites with 9 to 12 percent slopes with silt loam soil, runoff loss of N is rarely observed. It should be noted that high rates of infiltration will reduce surface runoff, but in exchange the rates of subsurface movement of water is increased. Timing of fertilizer application against the needs of the grass will reduce or eliminate subsurface leaching.

6. The leaching of fertilizer nitrogen applied to turfgrass at the site will be related to: soil texture and degree of conductivity of soil water; the amount of subsurface movement of water; nitrogen source, formulation, rate, and timing; and irrigation and rainfall. Significant leaching of nitrate will occur when soluble nitrogen is applied at a rate higher than normal on turfgrass grown on sandy soil. The potential for subsurface loss of nitrogen is further increased when the turfgrass is irrigated at a rate in excess of plant use, evapotranspiration, and soil storage.

7. If fertilization of turfgrass at the site does pose a threat to surface water and groundwater quality, several management options are available to minimize or eliminate the problem. Limiting irrigation to replacement of soil moisture used by the cover, use of slow release sources of nitrogen, and less sandy soils would significantly reduce or eliminate nitrate leaching from turfgrass. Timing of fertilizer application in relation to active uptake and potential runoff events as well as the use of realistic nitrogen application rates are primary methods to reduce nonpoint source losses of nitrogen from turfgrass systems. These recommendations are clarified in the Turf Management System.

8. Phosphorus fertilization will not pose a groundwater quality threat at the site. The soils of the area have an extremely high P adsorption capacity which will prevent subsurface leaching. Fertilization will be based on soil test results and turf requirement. Phosphorus enrichment of catchments and waterways in the vicinity of the proposed course could occur during construction phase where bare soil could be exposed to erosion. This will be minimized or eliminated by using barriers (fences) or other trap devices for preventing offsite movement of soil lost during excavation or grading activities.

Turfgrass Selection

Of the different potential warm season grasses, it is likely that the best candidates for the proposed golf course at the site would be bermudagrass or Zoysiagrass. Bermudagrass appears to be the most likely candidate since the it is native to the area and hence expresses adaptability to the climatic/soil/environmental conditions of central Oahu. A comparison of the two types of turfgrasses is presented below.

TABLE 4-4. COMPARISON OF BERMUDAGRASSES AND ZOYSIAGRASSES

Characteristic	Bermudagrasses	Zoysiagrasses
Plant description:		
leaf texture	Fine	Medium to fine
shoot density	High	Medium to high
Growth Habit	Rhizomes and stolons	Rhizomes and stolons
Seed Head	Short, few to numerous	Short and minimal
Adaptation:		
heat hardiness	Excellent	Excellent
low temperature hardiness	Poor	Poor to intermediate
drought resistance	Excellent	Excellent
shade tolerance	Very poor	Good
soil adaptation	Wide range	Wide range
salt tolerance	Good	Good
wear tolerance	Very good	Excellent
Establishment		
method	Vegetative	Vegetative
rate	Excellent	Poor
recuperative potential	Excellent	Excellent, but slow
Culture:		
intensity	High to medium	Medium
cutting height (in)	0.25-1.0	0.5-1.0
mower type	Reel	Reel
nitrogen needed (lb/1000sqft/month)	0.8-1.8	0.5-1.0
thatching tendency	High	Medium to high
Pest:		
diseases	Brown patch, dollar spot, spring dead spot, Helminthosporium	Brown patch, dollar spot, rust, Helminthosporium
insects	Sod bedworms, armyworms, mole crickets, bermudagrass mite, fruit fly	Hunting billbugs, army worms, mole crickets, sod bedworms
other	Nematodes	Nematodes

Bermudagrass is best adapted to moderately well drained, fertile soils of relatively fine texture but will tolerate a wide range of soil types. Bermudagrass growth is usually better on fine textured than coarse textured soils because of the higher fertility level and soil moisture retention associated with fine textured soils. Bermudagrass tolerates a wide range in soil pH (usually 5.5 to 7.5.) Salt tolerance is also quite good.

The improved bermudagrasses form a very dense, uniform turf of high quality when grown under proper conditions (climatic and cultural). It is utilized in the warm humid regions on lawns, parks, golf courses (fairways, greens, tees, roughs), roadsides, airfields, athletic fields, general lawn areas. It is especially suited for golf courses due to its excellent wear tolerance and recuperative potential.

Bermudagrass does require a medium to high intensity level of cultivation. Tolerance to close mowing is good because of its prostrate growth habit. Since bermudagrass is responsive to fertilization and irrigation, a high intensity of culture is generally needed to obtain optimum turfgrass quality. Bermudagrass is quite prone to thatching because of the vigorous growth rate. Common disease problems of bermudagrass include Helminthosporium, brown patch, dollar spot, Fusarium patch, Pythium blight, and spring dead spot. Common pests include sod bedworms, armyworms, mole crickets, mites, fruit flies, and nematodes. It is also intolerant of the triazine herbicides.

Several possible cultivars could be used at the site. For example, fairways and tees could be composed of Tifway bermudagrass, while greens could be composed of Tidwarf or Tifgreen cultivars. Some of the characteristics of these cultivars are noted below.

TABLE 4-5 CHARACTERISTICS AND USE OF CULTIVARS

Cultivar	Characteristics	Use
Tidwarf	Dark green color, fine texture, high shoot density, slow growth rate. Medium culture intensity.	Improved shade tolerance, superior tolerance to low mowing, used on greens.
Tifgreen	Dark green color, very fine texture, high shoot density, high intensity culture.	Excellent drought and wear tolerance, good recuperative potential, prone to 2,4-D injury, used on greens.
Tifway	Dark green, medium texture, high shoot density, vigorous growth, prone to thatching.	Used widely on fairways and tees.

Based on this initial assessment, we would probably recommend Tidwarf for use on greens, since selection of a cultivar that can be maintained with lower inputs of fertilizer and pesticide is a desirable quality from an environmental perspective. If the course were in a more arid region, we would have selected the more drought tolerant Tifgreen cultivar.

Zoysiagrass forms a uniform, dense, high quality turf with excellent drought and heat hardiness. It grows well on soils similar to those of the site (moderately acid to neutral with fine texture and moderate to excellent drainage characteristics). It also exhibits excellent salt tolerance. Its most desirable feature for this site would be the moderate level of cultivation required to maintain high quality. Its N requirement is much lower than bermudagrass (roughly one-half to two-thirds) and as such may be used in buffer strips, in areas around sandtraps, and even around the aprons of bermudagrass greens. Zoysiagrass is also free of major disease problems relative to the other turfgrasses. As such it could be used in many areas on the course to decrease the overall input of water, fertilizer and pesticide at the proposed golf course site.

Wind-Drift

After reviewing the literature and examining other studies aimed at assessing the potential for determining offsite wind-drift, we have concluded that no reasonable modeling approach can be used to yield estimates with any certainly. Rather, we suggest that a monitoring system be employed at the site that is capable of determining pesticide drift from the site.

We also note that if the TMS plan is implemented within the guidelines suggested here, that wind-drift can be minimized in most cases and eliminated in others. Implementation of the TMS will reduce the potential for pesticide loss from the site especially compared to present land use management.

Effluent Water Use and Recycling/Solid Waste Disposal

A water source now being used for irrigating golf courses and which will be of considerable interest in the future is effluent water. Turfs can accept effluent water containing moderate levels of heavy metals and other elements which cannot be used in crop production because of potential problems entering the human food chain or restricting crop yield. Thus, turf irrigation offers one of the best approaches to disposing of certain types of effluent water. In addition, many golf courses are in reasonable delivery distance of treatment plants. The proposed course should make use of this type of water, if available, in order to minimize pressure on limited groundwater supplies.

Sewage treatment plants have three levels of possible treatment. The primary level is concerned with solids removal. The secondary level removes many dissolved impurities, while the tertiary level removes even more impurities. Each level is more expensive. In contrast, soils function

as very efficient water filters and offer an economical means of advanced water treatment. Soils have a great capacity to handle organic wastes.

The reliability of an effluent water is a positive factor. In addition, the cost can be fairly attractive compared with that of other alternatives. In some areas, effluent water is available at no cost or at only the pumping charge involved. In other areas, effluent water is being sold for from 25 to 35 percent of the price of domestic water. The cost of effluent water will probably rise in the future but still remains an economically compared with that of other sources.

Chemical analyses of typical effluent have shown that nitrogen, chiefly in the form of ammonia, is present in an amount of 60 to 100 pounds per acre foot of water, while potassium is in the 200 pound range and phosphates between 60 and 100 pounds. Thus, each effluent water source may serve as a bonus source of N, P and K. Obviously, if effluent is used, it should be consistently monitored for these nutrients and figured in to the total nutrient requirement of the turf in order to avoid application of excess N and P.

Use of effluent water at the site will have to take into consideration the following factors related to safe use of effluent:

- Some chemicals present in effluent may be injurious to turfgrass growth, and for this reason the water used for irrigation should be continually monitored as suggested EPA regulations. The main chemical problems arise from industrial contaminants such as brine, heavy metals, and stable organic compounds.

- Five elements are of particular concern and should be frequently determined in the effluent water. These are cadmium (Cd), copper (Cu), nickel (Ni), zinc (Zn) and boron (B). Current guidelines suggest the following maximum levels for turfgrass:

Cd: 5 ppb	Cu: 200 ppb	Ni: 500 ppb
Zn: 5 ppm	B: 1 ppm	

- The site managers may want to consider complying with California regulations for Waster Water Reclamation Plants with Direct Filtration. This regulation will require a very high degree of effluent such that the water would be unrestricted in use.

In addition to effluent water use and reuse it is recommended that the proposed golf course development plan include appropriate protocols for solid-waste storage and disposal. The solid-waste at the site is likely to include both pesticide containers and remnants and turfgrass clippings. All pesticides at the site should be handled and stored according to manufacturers instructions and in compliance with all local, state and federal regulations. Turfgrass clippings from mowing operations can, in many cases, be directly returned to rough areas adjacent to the green or fairway from which they were removed or composted in a site remote from the playing area.

5.0 GLOSSARY

absorptance - The ratio of the radiant flux absorbed by a body to that incident upon it. Also called absorption factor.

acid - A compound that dissociates in aqueous solution to yield hydrogen ions.

acid soil - A soil containing a prevalence of hydrogen ions (H+) in the soil solution (active acidity) and held to the surface of soil particles (potential acidity). The pH extends below pH 7, depending on the degree of hydrogen ion prevalance. Soils become acid by removal of the base-forming cation, calcium, magnesium, sodium, and potassium through cropping or through leaching subsequent to their dislocqation from the surface of collodal soil particles by anions and their replacement by hydrogen ions derived from acids, such as nitric acid in rainfall, nitrification processes, and applied acid-forming fertilizers.

activation energy - The amount of energy required to bring all molecules in 1 mol of a substance to their reactive state at a given temperature.

activity - (i) A dimensionless measure of the deviation of the chemical potential of a substance from its value in some state which, for convenience, is chosen as standard state. It is defined by the equation: u=u + RT ln a, where u is the chemical potential in a state in which activity is a, u is the chemical potential in the standard state (where a=1.0), R is the molar gas constant, and T is the absolute temperature. (ii) Informally, it may be taken as the effective concentration of a substance in a solution.

activity coefficient - The ratio between the activity and the concentration of a substance in a solution. The activity coefficient is referred to as molal, rational, o molar, depending on whether the concentration scale is molal, mole fraction, or molar, respectively.

adsorption - The process by which atoms, molecules, or ions are taken up and retained on the surfaces of solids by chemical or physical binding, e.g., the adsorption of cations by negatively charged minerals.

adsorption complex - Various organic and inorganic substances in soil capable of adsorbing ions and molecules.

adsorption isotherm - A graph of the quantity of a given chemical species bound to an adsorption complex, at fixed temperature, as a function of the concentration of the species in a solution that is in equilibrium with the complex.

adsorbed phase - ions or molecules held to surfaces by the process noted above.

aerobic - (i) Having molecular oxygen as a part of the environment. (ii) Growing only in the presence of molecular oxygen, as aerobic organisms. (iii) Occurring only in the presence of molecular oxygen (said of certain chemical or biochemical process such as aerobic decomposition).

aggregate - A unit of soil structure, usually formed by natural processes in contrast with artificial processes, and generally <10mm in diameter.

air dry - (i) The state of dryness at equilibrium with the water content in the surrounding atmosphere. The actual water content will depend upon the relative humidity and temperature of the surrounding atmosphere. (ii) To allow to reach equilibrium in water content with the surrounding atmosphere.

alkali - A compound of hydrogen and oxygen with one of the elements sodium, potassium, or the radical ammonium

(NH_4) etc., characterized by great solubility in water and capable of neutralizing acids.

alkali soil - One having a high degree of alkalinity (pH 8.5 or higher) or high in exchangeable sodium (15% or higher) -- or both, so that the growth of most crops if reduced.

alkaline soil - Precisely, a soil have a pH greater that 7.0; practically, one have a pH above 7.3.

allophane - An aluminosilicate with primary short-ranged structural order. Occurs as exceedingly small spherical particles especially in soils formed from volcanic ash. Also, it occurs in podzolic soils formed on weathered granite in a cool moist climate.

alluvial - Pertaining to processes or materials associated with transportation or deposition by running water.

alluvium - Sediments deposited by running water of streams and rivers. It may occur on terraces well above present streams or in the normally flooded bottom land of existing streams.

alumina (Aluminum Oxide Al_2O_3) - Alumina occurs in small quantities in phosphate rock along with a small percentage of iron and other impurities. The alumina and iron in phosphate rock are objectionable. The maximum amount of alumina and iron in the rock is often guaranteed in the contract, many contracts being made on a basis of not more than 3 to 4% combined iron and alumina (as oxides).

aluminum (Al) - A widely distributed element, commonly found as silicate in various clays and rocks. While aluminum may be essential to the growth of some plants, the amount required, if any, is very small. The supply in all soils is abundant. Some acid soils contain sufficient aluminum in soluble form to kill certain plants.

alunite - A hydrated sulfate of aluminum and potash mineral. There are large deposits in Utah and other Western states. The potash is insoluble in water, but is rendered soluble by roasting. Alunite was processed for potash during the potash shortage of World War I. It is not competitive with today's sources.

ammonia (NH_3) - A chemical compound composed of 82.25% nitrogen and 17.75% hydrogen. At ordinary temperatures, it is a colorless, pungent gas about one-half as heavy as air. Prior to the rise of the synthetic ammonia industry, the major source of ammonia was a by product from the coking of coal in which the nitrogen of the coal is liberated as ammonia liquor and converted to ammonium sulfate, and more recently, to ammonium phosphate. The major supply now is made by direct synthesis from nitrogen in the atmosphere and hydrogen, usually derived from petroleum products. Fertilizer use of ammonia, both byproduct and synthetic, includes that used for direct application to the soil and in irrigation waters, for oxidation to nitric acid utilized in the production of nitric phosphates and ammonium, calcium, sodium and potassium nitrates, and for the production of nitrogen solutions, ammonium sulfate, ammonium phosthates, urea, ammoniated superphosphate fertilizers, and liquid fertilizers.

ammonia fixation - Chemisorption of ammonia (NH_3), and possibly ammonium, by the organic fraction of the soil.

ammonia volatilization - Mass transfer of nitrogen as ammonia gas from soil, plant, or liquid systems to the atmosphere.

ammonification - The biological process leading to the formation of the ammoniacal nitrogen from nitrogen and nitrogen-containing organic compounds.

ammonium fixation - The process of converting exchangeable or soluble ammonium ions to those occupying positions similar to K+ in the micas. They are counter-ions entrapped in the ditrigonal voids in the plane of basal oxygen atoms of some phyllosilicates as a result of concentration of the interlayer space. The fixation may occur spontaneously with some minerals in aqueous suspensions, or as a result of heating to remove interlayer water in others. Ammonium ions so adsorbed are exchangeable only after expansion of interlayer space.

amorphous material - Noncrystalline constituents that either do not fit the definition of allophane or it is not certain if the constituent meets allophane criteria.

anaerobic - (i) The absence of molecular oxygen. (ii) Growing in the absence of molecular oxygen (such as anaerobic bacteria). (iii) Occurring in the absence of molecular oxygen (as a biochemical process).

anion - The ion in solution carrying one or more negative electric charges depending on its valence or combining power with positively charge cations: *e.g.* NO_3, H_2PO, SO_4^{3}, Cl, HB_4O_7, and $HMoO_4$. Anions and cations are always present in the liquid phase of fertilizers.

anion exchange capacity - The sum total of exchangeable anions that a soil can adsorb. Expressed as centimoles of charge per kilogram of soil (or of other adsorbing material such as clay).

available water - The portion of water in a soil that can be absorbed by plant roots. It is the amount of water released between in situ field capacity and the permanent wilting point (usually estimated by water content at soil matric potential of -1.5 MPa).

backscattered electron image - Electron image formed by back-scattered electrons. High atomic-number compounds are brighter than low atomic number compounds.

basalt - a dark, fine-grained igneous rock.

basic slag - A by-product in the manufacture of steel, containing lime, phosphorous, and small amounts of other plant nutrients such as sulfur, Mn, and Fe.

bedrock - The solid rock underlying soils and the regolith in depths ranging from zero (where exposed by erosion) to several hundred centimeters.

biodegradable - A substance capable of being decomposed by biological processes.

biomass - (i) The total mass of living microorganism in a given volume or mass of soil. (ii) The total weight of all microorganism in a particular environment.

birnessite - $(Na_{0.7}Ca_{0.3})Mn_7O_{14}.2.8H_2O$. A black manganese oxide that is common in iron-manganese nodules of soils. It has a layer structure.

BOD (biochemical oxygen demand) - The quantity of oxygen used in the biochemical oxidation of organic matter in a specified time, at a specified temperature, and under specific conditions. An indirect measure of the concentration of biologically degradable material present in organic wastes.

bulk density, soil (Pb) - The mass of dry soil per unit bulk volume. The bulk volume is determined before drying to constant weight at 105 C. The value is expressed in grams per cubic centimeter.

buried soil - Soil covered by an alluvial, loessal, or other depositional surface mantle of new material, usually to a depth greater than the thickness of the solum.

calcareous soil - Soil containing sufficient free $CaCO_3$ and/or $MgCO_3$ to effervesce visibly when treated with cold

0.1*M* HCl. These soils usually contain from as little as 10 to as much as 200g kg^{-1} $CaCO_3$ equivalent.

calcium (Ca) - This is a hart, brittle metal which is too reactive to use in its elemental state. Familiar forms are the oxide (quick lime), the carbonate (limestone), and various salts. It is essential for plant growth and is one of the secondary fertilizer elements.

carbon cycle - The sequence of transformations whereby carbon dioxide is converted to organic forms by photosynthesis or chemosynthesis, recycled through the biosphere (with partial incorporation into sediments), and ultimately returned to its original state through respiration or combustion.

cation - The ion in solution carrying one or more positive charges of electricity depending on its valence. The common soil cations are calcium (Ca^{+2}), magnesium (Mg^{+2}), sodium (Na+), potassium (P+), and hydrogen (H+).

cation exchange - The interchange between a cation in solution and another cation on the surface of any negatively charged material such as clay colloid or organic colloid.

cation exchange capacity (CEC) - The sum of exchangeable cations that a soil, soil constituent, or other material can absorb at a specific pH. It is usually expressed in centimoles or charge per kilogram of exchanger ($cmol_c\ kg^{-1}$).

chelates - Certain organic chemicals, known as chelating agents, from ring compounds in which a metal is held between two or more atoms strongly enough to diminish the rate at which it becomes fixed by soil, thereby making it more available for plant uptake.

chemical potential - (i) The intensive variable that determines equilibrium with respect to matter flux. The chemical potential is the partial derivative of the Gibbs free energy with respect to the mass variable (e.g., the mole number) of a component of a thermodynamic system, calculated with absolute temperature, applied pressure, mass variables for all other components of the system, and any other independent, extensive variables, held fixed. (ii) Informally, it is the capacity of a solution or other substance to do work by virtue of its chemical composition.

chemical signature - Chemical composition of a substance that defines a unique relationship of the elements within a sample.

chemical weathering - The breakdown of rocks and minerals due to chemical activity, primarily due to the presence of water and components of the atmosphere. See weathering.

chemigation - The process where fertilizers and pesticides are applied into irrigation water to fertilize crops and control pests.

chlorite - A layer-structured group of silicate minerals of the 2:1 type that has the interlayer filled with a positively charged metal-hydroxide octahedral sheet. There are both trioctahedral (e.g., M = Fe^{2+}, Mg^{2+}) and dioctahedral (M = Al^{3+}) varieties.

chronosequence - A sequence of related soils that differ, one from the other, in certain properties primarily as a result of time as a soil-forming factor.

clastic - Composed of broken fragments of rocks and minerals.

clastic pocesses - Smaller particles are produced by the breakage of larger particles.

classification, soil - The systematic arrangement of soils into groups or categories on the basis of their characteristics. Broad groupings are made on the basis of general characteristics and subdivisions on the basis of more detailed differences in specific properties. The USDA soil classification system (*Soil Taxonomy*) was adapted for use in publications by the National Cooperative Soil Survey on 1 Jan. 1965. Abridged statements of diagnostic features, orders and suborders are listed alphabetically. Great groups are named by adding a prefix to the suborder name.

clay - (i) A soil separate consisting of particles < 0.002 mm in equivalent diameter. See soil separates. (ii) A textural class. See soil texture.

clay films - Coatings of clay on the surfaces of soil peds and mineral grains and in soil pores. (Also called clay skins, clay flows, illuviation cutans, argillans or tonhautchen.)

clay mineral - (i) Any crystalline inorganic substance of clay size (i.e., < 2 um equivalent spherical diameter). (ii) Any phyllosilicate of clay size.

cleavage surfaces - Cracks or irregular crystal deformations where weathering and mechanical breakage can occur due to irregularities/weaknesses in structure.

clinopyroxene - long chain silicates.

coarse fragments - Rock or mineral particles > 2.0 mm in diameter.

coarse texture - The texture exhibited by sands, loamy sands, and sandy loams except very fine sandy loam.

colloid - In soils, mineral or organic particles of submicroscopic size.

concretion - A local concentration of a chemical compound, such as calcium carbonate or Fe oxide, in the form of a grain or nodule of varying size, shape, hardness, and color.

conditioners - (conditioning materials, anti-caking agents) Inert materials such as rice hull meal, peanut hull meal, vermiculite, peat, and organic waste materials are frequently used as separating agents in nongranular fertilizers to keep the particles from being cemented together in the form of cakes or lumps. Finely divided, dry, bulky, inert powders such as diatomaceous earth, siliceous dusts and clays are in common use as coating agents to decrease the caking tendency of granular materials. Conditioning agents will prevent caking only when the moisture content of the product is sufficiently low to inhibit the formation of crystalline bridges between particles or granules.

constant-charge surface - A mineral surface carrying a net electrical charge whose magnitude depends only on the structure and chemical composition of the mineral itself. Constant charge surfaces usually arise from isomorphous substitution in mineral structures.

constant-potential surface - A solid surface carrying a net electrical charge which may be positive, negative, or zero, depending on the activity of one or more species of ion (called a potential-determining ion) in a solution phase contacting the surface. For minerals common in soils, the potential-determining ion usually is H^+ or OH^-, but any ion that forms a complex with the surface may be potential-determining. See also pH-dependent charge.

covalent bonding - Bonds that result from sharing (or partly sharing) of electrons between atoms.

crust - A soil-surface layer, ranging in thickness from a few millimeters to a few tens of millimeters, that is much more compact, hard and brittle, when dry, than the material immediately beneath it.

crystal - A regular arrangement of atoms in space.

crystal structure - The orderly arrangement of atoms in a crystalline material.

crystalline rock - A rock consisting of various minerals that have crystallized in place from magma. See igneous rock and sedimentary rock.

Darcy's law - (i) A law describing the rate of flow of water through porous media. (Named for Henry Darcy of Paris, who formulated it in 1856 from extensive work on the flow of water through sand filter beds.) As formulated by Darcy the law is: $Q = KS(H + e)/e$ where Q is the volume of water passed in unit time, S is the area of the bed, e is the thickness of the bed, H is the depth of water on top of the bed, and "K is a coefficient dependent on the nature of the sand," and for cases "when the pressure under the filter is equal to the weight of the atmosphere." (ii) Generalization for three dimensions: The rate of viscous flow of water in isotropic porous media is proportional to, and in the direction of, the hydraulic gradient. (iii) Generalization of other fluids: The rate of viscous flow of homogenous fluids through isotropic porous media is proportional to, and in the direction of, the driving force.

degradation - The process whereby a compound is transformed into simpler compounds, although products more complex than the starting material may be formed.

denitrification - Reduction of nitrate or nitrite to molecular nitrogen or nitrogen oxides by microbial activity (dissimilatory nitrate reduction) accompanied by the escape of nitrogen oxide and nitrogen into the air or by chemical reactions involving nitrite (chemical denitrification).

deposit - Material left in a new position by a natural transporting agent such as water, wind, ice, or gravity, or by the activity of man.

desert varnish - A glossy sheen or coating on stones and gravel in arid regions.

diffuse double layer - A heterogeneous system that consists of a solid surface having a net electrical charge, together with an ionic swarm under the influence of the solid and a solution phase that is in direct contact with the surface.

diffusion (nutrient) - The movement of nutrients in soil that results from a concentration gradient.

dinitrogen fixation - The conversion of free nitrogen to nitrogen compounds; the assimilation of free nitrogen from the soil air by soil organisms and the formation of nitrogen compounds.

dioctahedral - An octahedral sheet or a mineral containing such a sheet that has two-thirds of the octahedral sites filled by trivalent ions such as aluminum or ferric Fe.

dispersant - Any of various soluble chemicals which, when added in small proportion to a clay-water slurry, will affect the surface charge on the ultimate clay particles in such a manner that the particles become mutually repulsive. The resultant particle repulsion discourages flocculation of particles, promotes wetting of the ultimate particles, and reduces viscosity of the slurry.

disperse - (i) To break up compound particles, such as aggregates, into the individual component particles. (ii) To distribute or suspend fine particles, such as clay, in or throughout a dispersion medium, such as water.

dispersion - A term used in relation to solute movement. See hydrodynamic dispersion.

dissolution rate - Amount of mineral or mineral surface dissolving per unit of time.

dolomite - A natural mineral, a double carbonate of calcium and magnesium, ($MgCO_3.CaCO_3$). It may be thought of as a limestone in which one-half of the calcium has been replaced by magnesium. It is useful for neutralizing acid soils in the same manner that limestone is used. In theory 100 pounds of dolomite is equal to 109 pounds of calcium carbonate for neutralizing soil acids. Dolomite limestone reacts more slowly with acids than high calcic limestone and is much less likely to release ammonia from its salts. It also supplies plant food magnesium.

ecology - The branch of biology that deals with the mutual relations among organisms, and between organisms and their environment.

Eh - The potential that is generated between an oxidation or reduction half-reaction and the H electrode in the standard state.

electron microprobe (EMPA) - Device for determining the trace element and major mineralogical associations within a particle.

electrostatic attraction - Attraction of positively charged ions to negatively charged ions.

eluvial horizon - A soil horizon that has been formed by the process of eluviation. See illuvial horizon.

erosion - (i) The wearing away of the land surface by running water, wind, ice or other geological agents, including such processes as gravitational creep. The following terms are used to describe different types of water erosion:

accelerated erosion - Erosion much more rapid than normal, natural, geological erosion, primarily as a result of the influence of the activities of man or, in some cases, of animals.
geological erosion - The normal or natural erosion caused by geological processes acting over long geological periods. Synonymous with *natural erosion*.
gully erosion - The erosion process whereby water accumulates in narrow channels and, over short periods, removes the soil from this narrow area to considerable depths, ranging from 0.5 m to as much as 25 to 30 m.
interrill erosion - The removal of a fairly uniform layer of soil on a multitude of relatively small areas by splash due to raindrop impact and by film flow.
natural erosion - Wearing away of the earth's surface by water, ice, or other natural agents under natural environmental conditions of climate, vegetation, etc., undisturbed by man. See *geological erosion*.
normal erosion - The gradual erosion of land used by man which does not greatly exceed natural erosion. See *natural erosion*.
rill erosion - An erosion process in which numerous small channels of only several centimeters in depth are formed; occurs mainly on recently cultivated soils. See rill.
sheet erosion - The removal of soil from the land surface by rainfall and surface runoff. Often interpreted to include rill and interrill erosion.
splash erosion - The detachment and airborne movement of small soil particles caused by the impact of raindrops on soils.

erosion - (ii) Detachment and movement of soil or rock by water, wind, ice, or gravity. The following terms are used to describe different types of water and wind erosion:
saltation - (i) The bouncing or jumping action of soil particles 0.1 to 0.5 mm in diameter by wind, usually at a height < 15 cm above the soil surface, for relatively short distances. (ii) The bounding or jumping action of mineral particles, including gravel or stones, effected by the energy of flowing water. (iii) The bounding or jumping movement of material downslope in response to gravity.

surface creep - (i) The rolling of dislodged soil particles 0.5 to 1.0 mm in diameter by wind along the soil surface. (ii) The slow movement of soil and rock debris which is usually not perceptible except through extended observation.
suspension - The movement of soil particles usually < 0.1 mm diameter through the air, usually at a height of > 15 cm above the soil surface, for relatively long distances.
universal soil loss equation (USLE) - An equation for predicting *A*, the average annual soil loss in mass per unit area per year, and is defined as $A = RKLSPC$, where R is the rainfall factor, K is the soil erodibility factor, L is the length of slope, S is the percent slope, P is the conservation practice factor, and C is the cropping and management factor.
wind erosion equation - An equation for predicting E, the average annual soil loss due to wind in mass per unit area per year, and is defined as $E = IKCLV$, where I is the soil erodibility factor, K is the soil ridge roughness factor, C is the local climatic factor, L is the field width, and V is the vegetative factor.

erosion classes - A grouping of erosion conditions based on the degree of erosion or on characteristic patterns. (Applied to accelerated erosion; not to normal, natural, or geological erosion.) Four erosion classes are recognized for water erosion and three for wind erosion. Specific definitions for each vary somewhat from one climatic zone, or major soil group, to another.

erosion pavement - A layer of coarse fragments such as sand or gravel, remaining on the surface of the ground after the removal of fine particles by erosion.

erosion potential (EI) - A numerical value expressing the inherent erodibility of a soil or maximum potential erosion. In the Universal Soil Loss Equation (under clean tillage, up and down slope) $EI = RKLS/T$.

erosional surface - A land surface shaped by the erosive action of ice, wind, or water; but usually as the result of running water.

erosivity - The potential ability of water, wind, gravity, etc. to cause erosion.

evapotranspiration - The combined loss of water from a given area, and during a specified period of time, by evaporation from the soil surface and by transpiration from plants.

exchange capacity - The total ionic charge of the absorption complex active in the absorption of ions. See anion exchange capacity and cation exchange capacity.

exchangeable anion - A negatively charged ion held on or near the surface of a solid particle by a positive surface charge and which may be replaced by other negatively charged ions.

exchangeable cation - A positively charged ion held on or near the surface of a solid particle by a negative surface charge of a colloid and which may be replaced by other positively charged ions in the soil solution. Often determined as the salt-extractable minus water-soluble cations in a saturation extract, and expressed in centimoles of charge per kilogram.

exchangeable cation percentage - The extent to which the absorption complex of a soil is occupied by a particular cation. It is expressed as follows:

$$ECP = \frac{\text{Exchangeable cation (cmol kg}^{-1}\text{ soil)}}{\text{Cation exchange capacity (cmol kg}^{-1}\text{ soil)}} \times 100.$$

exchangeable sodium fraction - The fraction of the cation exchange capacity of a soil occupied by sodium ions.

exchangeable sodium percentage - Exchangeable sodium fraction expressed as a percentage.

exchangeable sodium ratio - The ratio of exchangeable sodium (cmol kg^{-1} soil) to all other exchangeable cations (cmol kg^{-1} soil).

exudate - Low molecular weight metabolites that enter the soil from plant roots.

feldspar - Any of a group of crystalline minerals consisting of silicates of Al with either potassium, sodium, calcium or barium.

ferrihydrite - $Fe_5HO_8 \cdot 4H_2O$. A dark reddish-brown, poorly crystalline Fe oxide mineral that forms in wet soils. Occurs in concretions and placic horizons and often can be found in ditches and pipes that drain wet soils.

fertilizer - Any substance containing one or more recognized plant nutrient(s) which is used for its plant nutrient content and which is designed for use or claimed to have value in promoting plant growth.

fine sand - (i) A soil separate. See soil separates. (ii) A soil textural class. See soil texture.

fulvic acid - (i) The mixture of organic substances remaining in solution upon acidification of a dilute alkali extract from soil, in which case the expression *fulvic acid fraction* is often used, and (ii) the *colored* material that remains in solution after removal of humic acid by acidification.

geomorphic surface - A portion of the landscape specifically defined in space and time that has determinable geographic boundaries and is formed by one or more agencies during a given time period.

geographic information system - A method of overlaying large volumes of spatial data of different kinds. The data are referenced to a set of geographical coordinates and encoded in a form suitable for handling by a digital computer. Different data planes can be overlain, statistically analyzed, and used to make estimates of soil and land suitabilities.

geomorphology - The science that studies the evolution of the earth's surface. The science of landforms. The systematic examination of landforms and their interpretation as records of geologic history.

Gibbs free energy - The thermodynamic potential for a system whose independent variables are the absolute temperature, applied pressure, mass variables, and other independent, extensive variables. The change in Gibbs free energy, as a system passes reversibly from one state to another at constant temperature and pressure, is a measure of the work available in that change of state.

gibbsite - $Al(OH)_3$. A mineral with a platy habit that occurs in highly weathered soils and in laterite. Also, may be prominent in the subsoil and saprolite of soils formed on crystalline rock high in feldspar.

glacial drift - Rock debris that has been transported by glaciers and deposited, either directly from the ice or from the melt-water. The debris may or may not be heterogeneous.

glaciers - Large masses of ice that formed, in part, on land by the compaction and recrystallization of snow. They may be moving downslope or outward in all directions because of the stress of their own weight or they may be retreating or be stagnant.

glaciofluvial deposits - Material moved by glaciers and subsequently sorted and deposited by streams flowing from the melting ice. The deposits are stratified and may occur in the form of outwash plans, deltas, kames, eskers, and kame terraces. See glacial drift and till.

geothite - FeOOH. A yellow-brown Fe oxide mineral. Geothite is very common and is responsible for the brown color in many soils.

ground water - That portion of the water below the surface of the ground at a pressure equal to or greater than atmospheric. See water table.

halloysite - A member of the kaolin subgroup of clay minerals. It is similar to kaoline in structure and composition except that hydrated varieties occur that have interlayer water molecules and they are usually tubular or spheroidal particles. Halloysite is most common in soils formed from volcanic ash, but also occurs in subsoil and saprolite of soils formed on acid crystalline rock.

heavy metals - Those metals which have densities > 5.0 Mg m^{-3}. Metallic elements which are located in the transitional series of the periodic chart of elements. In agronomic usage these include the metallic elements Cu, Fe, Mn, Mo, Co, Zn, Cd, Hg, Ni, and Pb. These metals are not required in plant nutrition and usually are found in relatively small amounts in nature. Toxicity to plants could result with high concentrations of some heavy metals in soils, and problems in animal and human health may result if heavy metal concentrations in the diet are above certain levels.

hematite - Fe_2O_3. A red Fe oxide mineral that contributes red color to many soils.

hue - One of the three variables of color. It is caused by light of certain wavelengths and changes with the wavelength.

humic acid - The dark-colored organic material that can be extracted from soil by various reagents (e.g., dilute alkali) and that is precipitated by acidification to pH 1 to 2.

hydraulic conductivity - See soil water.

hydraulic gradient (soil water) - A vector (macroscopic) point function that is equal to the decrease in the hydraulic head per unit distance through the soil in the direction of the greatest rate of decrease. In isotropic soils, this will be in the direction of the water flux.

hydraulic head - The elevation with respect to a specific reference (level), using the soil surface, at which water stands in a piezometer connected to the point in question in the soil. Its definition can be extended to soil above the water table if the piezometer is replaced by a tensiometer. The hydraulic head in systems under atmospheric pressure may be identified with a potential expressed in terms of the height of a water column. More specifically, it can be identified with the sum of gravitational and matric potentials, and may be termed *hydraulic potential*, particularly in the sense of energy (or work) per unit weight of water.

hydraulic conductivity - The proportionality factor in Darcy's law as applied to the viscous flow of water in soil, i.e., the flux of water per unit gradient of hydraulic potential. If conditions require that the viscosity of the fluid be divorced from the conductivity of the medium, it is convenient to define the permeability of the soil as the conductivity divided by the fluidity of the fluid. For the purpose of solving the partial differential equation of the nonsteady-state flow in unsaturated soil it is often convenient to introduce a variable termed the soil water diffusivity.

hydrodynamic dispersion - The process wherein the solute concentration in flowing solution changes in response to the interaction of solution movement with the pore geometry of the soil, a behavior with similarity to diffusion but only taking place when solution movement occurs.

hydrogen bond - The chemical bond between a hydrogen atom of one molecule and two unshared electrons of another molecule.

hydrology - The science dealing with the distribution and movement of water.

agrohydrology - The science dealing with the distribution and movement of water and soil solution to and from the root zone in agricultural land, and with the distribution and movement of irrigation and surface water in conveyance systems on agricultural land.

ground-water hydrology - The science dealing with the movement of the soil solution in the saturated zone of the soil profile.

soil hydrology - The science dealing with the distribution and movement of the soil solution in the soil profile.

surface hydrology - The science dealing with the distribution and conveyance of water on the soil surface.

hydrophobic soils - Soils that are water repellent, often due to dense fungal mycelial mats or hydrophobic substances vaporized and reprecipitated during fire.

hydroxy-aluminum interlayers - Polymers of general composition $[Al(OH)_{x}]^{+n}$ which are absorbed on interlayer cation exchange sites. Although not exchangeable by unbuffered salt solutions, they are responsible for a considerable portion of the titratable acidity (and pH-dependent charge) in soils.

hydroxyl group - -OH group, undergoes pH dependent dissociation.

hydroxy-interlayered vermiculite - A vermiculite with partially filled interlayers of hydroxy-aluminum groups. It is normally dioctahderal in both the interlayer and the vermiculite layer. It is common in the coarse clay fraction of acid surface soil horizons. It has intermediate cation exchange properties between vermiculite and chlorite. Synonyms are "chlorite-vermiculite intergrade; vermiculite-chlorite intergrade."

hyperthermic - A soil temperature regime that has mean annual soil temperatures of 22°C or more and > 5° C difference between mean summer and mean winter soil temperatures at 50 cm below the surface. Isohyperthermic is the same except the summer and winter temperatures differ by < 5°C.

igneous rock - Rock formed from the cooling and solidification of magma, and that has not been changed appreciably since its formation.

illite - The mica component of a structurally mixed fine grained mica and smectite or vermiculite. Sometimes the entire mixture is referred to as illite. Illites are dioctahedral.

illuvial horizon - A soil layer or horizon in which material carried from an overlying layer has been precipitated from solution or deposited from suspension. The layer of accumulation. See eluvial horizon.

illuviation - The process of deposition of soil material removed from one horizon to another in the soil; usually from an upper to a lower horizon in the soil profile. See eluviation.

infiltration - The downward entry of water into the soil through the soil surface.

infiltration flux (or rate) - The volume of water infiltrated downward into the soil per unit cross-sectional soil area

in unit time, with dimensions of velocity (i.e., $M^3 m^{-2} s^{-1} = m s^{-1}$.

intrinsic permeability - The property of a porous material that expresses the ease with which gases or liquids flow through it. Often symbolized by $k = Kn/pg$ where K is the Darcy hydraulic conductivity, n is the fluid viscosity, p is the fluid density, and g is the acceleration of gravity. Dimensionally, k is an area $[L^2]$. See permeability and soil water.

ion activity - Informally, the effective concentration of an ion in solution. Numerically, it approaches the value of the ionic concentration at infinite dilution of be ion under consideration and otherwise satisfies the formal, thermodynamic relationship between activity and chemical potential as applied to a single ionic species.

ion selective electrode - An electrochemical sensor, the potential of which (in conjunction with a suitable reference electrode) depends on the logarithm of the activity of a given ion in aqueous solution.

ion selectivity - The relative absorption of an ion by the solid phase in relation to the absorption of other ions. The relative absorption of an ion by a root in relation to absorption of other ions.

ionic activity coefficient - The ratio between ionic activity and an ionic concentration measured on an appropriate scale. In an aqueous solution at low ionic strength, the ionic activity coefficient may be defined by the Debye-Huckel equation.

ionic strength - A parameter that estimates the interaction between ions in solution. It is calculated on one-half the sum of the products of ionic concentration and the square of ionic charge for all the charged species in a solution.

ions - Atoms, groups of atoms, or compounds, which are electrically charged as a result of the loss of electrons (cations) or the gain of electrons (anions).

ion oxides - Group name for the oxides and hydroxides of Fe. Includes the minerals geothite, hematite, lepidocrocite, ferrihydrite, maghemite, and magnetite. Sometimes referred to as "free Fe oxides," "sesquioxides," or "hydrous oxides."

irrigation methods - The manner in which water is intentionally applied to an area. The methods and the manner of applying the water are as follows:

border-strip - The water is applied at the upper end of a strip with earth boarders to confine the water to the strip.

check-basin - The water is applied rapidly to relatively level plots surrounded by levees. The basin is a small check.

corrugation - The water is applied to small, closely spaced furrows, frequently in grain and forage crops, to confine the flow of irrigation water to one direction.

flooding - The water is released from field ditches and allowed to flood over the land.

furrow - The water is applied to row crops in ditches made by tillage implements.

sprinkler - The water is sprayed over the soil surface through nozzles from a pressure system.

subirrigation - The water is applied in open ditches or tile lines until the water table is raised sufficiently to wet the soil.

trickle - Water applied under low pressure from small openings.

wild-flooding - The water is released at high points in the field and distribution is uncontrolled.

isoelectric point - The pH value of a solution in equilibrium with a constant potential surface whose net electrical charge is zero and is dependent only on the presence of H^+, OH^-, or H_2O to form species on the surface

isomorphous substitution - The replacement of one atom by another of similar size (but not necessarily of the same valence) in a crystal structure without disrupting or seriously changing the structure.

isotopically exchangeable ion - An ion, bonded to a soluble or solid substance, that can exchange with similar isotopically labeled ions in solution in a specified period of time. As equilibrium is approached, the ratio of native to isotopically labeled ions approaches the same value for each reactive form in which the ion occurs.

Jarosite - A pale yellow potassium Fe sulfate mineral.

kaolin - A subgroup name of Al silicates with a 1:1 layer structure. Kaolinite is the most common clay mineral in the subgroup. Also, a soft, usually white rock composed largely of kaolinite.

kaolinite - A clay mineral of the kaolin subgroup. Its general formula is $Al_2Si_2O_5(OH)_4$. It has a 1:1 layer structure composed of shared sheets of Si-O tetrahedrons and Al-(O,OH) octahedrons.

kriging - A method based on the theory of regionalized variables for predicting without bias and minimum variance the spatial distribution of earth components, including soil properties.

labile - A substance that is readily transformed by microorganisms or is readily available to plants.

lacustrine deposit - Material deposited in lake water and later exposed either by lowering the water level or by elevation of the land.

landform - A three-dimensional part of the land surface, formed of soil, sediment, or rock that is distinctive because of its shape, that is significant for land use or to landscape genesis, that repeats in various landscapes, and that also has a fairly consistent position relative to surrounding landforms.

landscape - All the natural features such as fields, hills, forests, water, etc., which distinguish one part of the earth's surface from another part. Usually that portion of land or territory which the eye can comprehend in a single view, including all its natural characteristics.

Landsat satellites - Unmanned satellites collecting data in the visible, near infrared and, with Landsat D, the thermal region.

lattice - A regular geometric arrangement of points in a plane or in space. Lattice is used to represent the distribution of repeating atoms or groups of atoms in a crystalline substance. A lattice is a mathematical concept. It has no mass.

lattice energy - The energy required to separate the ions of a crystal to an infinite distance from each other.

layer charge - Magnitude of charge per formula unit balanced by ions of opposite charge external to the unit layer.

layer silicate minerals - Minerals with the sheet silicate structures of the phyllosilicates.

leaching - Removal of soluble material from a system by passage of a liquid through it. In agriculture, leaching refers to the downward movement of free water (percolation) out of the plant root zone. It occurs when the amount of rainfall or irrigation water entering the soil becomes greater than its water-holding capacity. On western irrigated lands, leaching is intentionally brought about to remove accumulations of soluble salts from soils.

lead sulfides - metal sulfide of Pb and sulfur.

lepidocrocite - FeOOH. An orange ion oxide mineral that is found in mottles and concretions of wet soils.

lithiophorite - $(Al, Li)MnO_2(OH)_2$. A black manganese oxide that is common in iron-manganese nodules of acid soils. It has a layer structure.

lithosequence - A group of related soils that differ, one from the other, in certain properties primarily as a result of differences in the parent rock as a soil-forming factor.

loam - A loose soil of mixed clay, sand and silt.

loess - Material transported and deposited by wind and consisting of predominantly silt-sized particles.

lysimeter - (i) A device for measuring percolation and leaching losses from a column of soil under controlled conditions. (ii) A device for measuring gains (irrigation, precipitation, and condensation) and losses (evapotranspiration) by a column of soil.

maghemite - Fe_2O_3. A dark reddish-brown, magnetic Fe oxide mineral chemically similar to hematite, but structurally similar to magnetite. Often found in well-drained, highly weathered soils of tropical regions.

magnetic susceptibility - ratio of magnetism induced in the sample to the intensity of the magnetic field that produced it. A function of magnetic content.

magnetite - Fe_3O_4. A black, magnetic Fe oxide mineral usually inherited from igneous rocks. Often found in soils as black magnetic sand grains.

manganese oxides - A group term for oxides of manganese. They are typically black and frequently occur in soils as nodules and coatings on ped faces usually in association with Fe oxides. Birnessite and lithiophorite are common Mn oxide minerals in soils.

maintenance application - Application of fertilizer materials in amounts and at intervals to maintain available soil nutrients at levels necessary to produce a desired yield.

map, large-scale - A map having a scale of 1:100 000 or larger.

map, medium-scale - A map having a scale from 1:100 000, exclusive, to 1:1000 000, inclusive.

map, small-scale - A map having a scale smaller than 1:1 000 000.

map unit - (i) A conceptual group of one to many delineations identified by the same name in a soil survey that represent similar landscape areas comprised of either: (1) the same kind of component soil, plus inclusions, or (2) of two or more kinds of component soils, plus inclusions, Or (3) of component soils and miscellaneous area, plus inclusions, or (4) of two or more kinds of component soils that may or may not occur together in various delineations but all have similar, special use and management plus inclusions, or (5) of a miscellaneous area and included soils. (ii) A loose synonym for a delineation. See delineation, component soil, inclusion, soil consociation, soil complex, soil association, undifferentiated group, miscellaneous areas.

mean atomic number - weighted average of the atomic number of the elements in a particular compound.

medium-texture - Intermediate between fine-textured and coarse-textured (soils). (It includes the following textural classes: very fine sandy loam, loam, silt loam, and silt.)

metamorphic rock - Rock derived from preexisting rocks but that differ from them in physical, chemical, and mineralogical properties as a result of natural geological processes, principally heat and pressure, originating within the earth. The preexisting rocks may have been igneous, sedimentary, or another form of metamorphic rock.

mica - A layer-structured aluminosilicate mineral group of the 2:1 type that is characterized by its high layer charge, which is usually satisfied by potassium. The major types are muscovite, biotite, and phologopite.

micron - A unit of length equivalent to 39.37 millionths of an inch or 0.001 mm. One millimeter equals 1000 microns. A useful unit in dealing with particle size.

micronutrient - A chemical element necessary for plant growth found in small amounts, usually < 100 mg kg^{-1} in the plant. These elements consist of B, Cl, Cu, Fe, Mn, Mo, and Zn. Frequently referred to as trace or minor elements.

microrelief - (1) Small scale, local differences in topography, including mounds, swales, or pits that are usually < 1 m in diameter and with elevation differences of up to 2 m. (ii) Differences in topography altered by tillage operations, generally over an area of about 1 m^2 with elevation differences of a few centimeters or less.

microsite - A small volume of soil where biological or chemical processes differ from those of the soil as a whole, such as a anaerobic microsite of a soil aggregate or the surface of decaying organic residues.

mineralization - The conversion of an element from an organic form to an inorganic state as a result of microbial activity.

mineralogical analysis - The estimation or determination of the kinds or amounts of minerals present in a rock or in a soil.

mineral soil - A soil consisting predominantly of, and having its properties determined predominantly by, mineral matter. Usually contains < 200 g kg^{-1} organic carbon (<120-180 g kg^{-1} if saturated with water), but may contain an organic surface layer up to 30 cm thick.

montmorillonite - An Al silicate (smectite) with a layer structure composed of two silica tetrahedral sheets and a shared Al and magnesium octahedral sheet. Montmorillonite has a permanent negative charge that attracts interlayer cations that exist in various degrees of hydration thus causing expansion and collapse of the structure (i.e., shrink-swell). Its general formula is $Si_4Al_{1.5}Mg_{0.5}O_{10}(OH)_2CA_{0.25}$. The calcium is exchangeable.

nitrates - The salts of nitric acid may be formed by the action of nitric acid on metals or alkalies.

nitrate reduction (biological) - The process whereby nitrate is reduced by plants and microorganisms to ammonium for cell synthesis (nitrate assimilation, assimilatory nitrate reduction) or to various lower oxidation states (N_2, N_2O, NO, NO_2^-) by bacteria using nitrate as the terminal electron acceptor in anaerobic respiration (respiratory nitrate reduction, dissimilatory nitrate reduction, denitrification).

nitrification - Biological oxidation of ammonium to nitrite and nitrate, or a biologically induced increase in the oxidation state of nitrogen.

nitrogen (N) - A colorless, odorless, inert gas, constituting about four-fifths of the air. Nitrogen is a constituent of every living cell. It is a part of chlorophyll, of protein, and of many other substances in animals and plants. As a fertilizer it is needed in large amounts by all growing crops. It promoted growth of leaf and stem and inceases plant plant vigor.

nitrogen cycle - The sequence of biochemical changes undergone by nitrogen wherein it is used by a living organism, transformed upon the death and decomposition of the organism, and converted ultimately to its original state of oxidation.

olivines - greenish mineral that is a complex silicate (tetrahedron) of Mn and Fe.

orthophosphate - A salt of orthophosphoric acid such as NH_4HPO_4, $CaHPO_4$, or K_2HPO_4.

overburden - (i) Material recently deposited by a transportation mode, that occurs immediately superjacent to the surface horizon of a contemporaneous soil. (ii) A term used to designate disturbed or undisturbed material of any nature, consolidated or unconsolidated, that overlies a deposit of useful materials, ores, lignites, or coals, especially those deposits mined from the surface by open cuts.

oxidation state - The number of electrons to be added (or subtracted) from an atom in a combined state to convert it to the elemental form.

parent material - The unconsolidated and more or less chemically weathered mineral or organic matter from which the solum of soils is developed by pedogenic processes.

particle density - The density of the soil particles, the dry mass of the particles being divided by the solid (not bulk) volume of the particles, in contrast with bulk density. Units are Mg m^{-3}.

particle size - The effective diameter of a particle measured by sedimentation, sieving, or micrometric methods.

permanent wilting point - The largest water content of a soil at which indicator plants, growing in that soil, wilt and fail to recover when placed in a humid chamber. Often estimated by the water content at -1.5-MPa soil matric potential.

permeability, soil - (i) The ease with which gases, liquids, or plant roots penetrate or pass through a bulk mass of soil or a layer of soil. Since different soil horizons vary in permeability, the particular horizon under question should be designated. (ii) The property of a porous medium itself that ease with which gases, liquids, or other substances can flow through it, and is the same as intrinsic permeability. See intrinsic permeability, Darcy's law, and soil water.

pH_c* - The pH value of any solution, soil or compound is simply a number denoting its degree of acidity or alkalinity. The calculated pH that a water would have if it were in equilibrium with calcium carbonate. Numerically, pH_c* is equal to (pK_2 - pK_s) + p(Ca + Mg) + pAlk, where p(Ca + HCO_3), respectively, and pK_2 and pK_s are the negative logarithms of the second dissociation constant of H_2CO_3 and the solubility constant of $CaCO_3$, respectively, both corrected for ionic strength. It is used in conjunction with the measured pH of a water to determine if $CaCO_3$ will precipitate from the water, or if the water will dissolve $CaCO_3$ as it passes through a calcareous soil.

pH-dependent charge - The portion of the cation or anion exchange capacity which varies with pH. See acidity, residual.

pH, soil - The negative logarithm of the hydrogen ion activity of a soil. The degree of acidity (or alkalinity) of a soil as determined by means of a glass, quinhydrone, or other suitable electrode or indicator at a specified moisture content or soil-water ratio, and expressed in terms of the pH scale.

phase associations - Major accumulative phases of metals (i.e. with what minerals or surfaces are ions associated within a given sample).

phosphate - A salt of an ester of phosphoric acid. In the fertilizer industry, however, the term phosphate is usually applied to any phosphatic material used as a fertilizer.

phosphorus (P) - An acid-forming element which combines readily with oxygen to form the oxide P_2O_5, which in turn combines readily with water to form orthophosphoric acid (H_3PO_4). Many soils are naturally deficient in phosphorus. It is absolutely indispensible to life. Every cell contains it as a necessary constituent. A plentiful supply in the soil promotes rapid growth, hastens maturity, and stimulates flower, seed, and fruit production.

phytotoxicity - Degree to which a material is injurious (poisonous) to vegetation. It is specific for particular kinds or types of plants.

physical weathering - The breakdown of rock and mineral particles into smaller particles by physical forces such as frost action. See weathering.

porosity - The volume of pores in a soil sample (nonsolid volume) divided by the bulk volume of the sample.

potassium (K) - Pure metallic potassium is a soft, bright metal which looks somewhat like lead. When exposed to the air it oxidizes rapidly, and with water it combines to form caustic potash. To preserve the metal, it must be kept covered with oil. Much of the potassium present in soils is in the form of insoluble silicates and can only become available when the rock is weathered. Available potassium stimulates the growth of strong stems, imparts resistance to disease, and is necessary to form starch, sugar, and oil and transfer them through plants.

primary mineral - A mineral that has not been altered chemically since deposition and crystallization from molten lava. See secondary mineral.

pyroclastics - A general term applied to detrital volcanic materials that have been explosively or aerially ejected from a volcanic vent.

pyrophosphate - A class of phosphorus compounds produced by the reaction of either anhydrous ammonia or potassium hydroxide with pyrophosphoric acid (H_3PO_4). The main polyphosphate species in polyphosphate fertilizers.

pyroxenes - Any of the various minerals that are long-chain silicates and usually contain aluminum, calcium, sodium, manganese, or iron.

quartz - A common, often transparent crystalline mineral composed of silica and oxygen.

quenching texture - Texture produced by rapid cooling.

reference electrode - An electrode that maintains an invariant potential under the conditions prevailing in an electrochemical measurement and thereby permits measurement of the potential of an ion-selective or other sensing electrode.

remote sensing - In the broadest sense, the measurement or acquisition of information of some property of an object or phenomenon, by a recording device that is not in physical or intimate contact with the object or phenomenon under study; e.g., the utilization at a distance (as from aircraft, spacecraft, or ship) of any device and its attendant display for gathering information pertinent to the environment, such as measurements of force fields, electromagnetic radiation, or acoustic energy. The technique employs such devices as the camera, lasers, and radio frequency receivers, radar systems, sonar, seismographs, gravimeters, magnetometers, and scintillation counters.

rhizomes - A specialized rootlike plant stem that forms shoots above and roots below.

rill - A small, intermittent water course with steep sides; usually only several centimeters deep and, hence, no obstacle to tillage operations.

rill erosion - See erosion (ii).

riparian zones - of or related to the bank of a streat, river or lake.

river wash - Barren alluvial areas, usually coarse-textured, exposed along streams at low water and subject to shifting during normal high water. A miscellaneous area.

rock land - Areas containing frequent rock outcrops and shallow soils. Rock outcrops usually occupy from 25 to 90% of the area. A miscellaneous area.

rock outcrop - Consists of exposures of base bedrock, other than lava flows and rock-lined pits. Most rock outcrops are of hard rock, but some are soft rock.

rosettes - A mineral texture consisting of blades oriented in a flower like arrangement.

runoff - That portion of the precipitation on an area which is discharged from the area through stream channels. That which is lost without entering the soil is called *surface runoff* and that which enters the soil before reaching the stream is called *ground water runoff* or *seepage flow* from ground water. (In soil science "runoff" usually refers to the water lost by surface flow; in geology and hydraulics "runoff" usually includes both surface and subsurface flow.)

saline soil - A nonsodic soil containing sufficient soluble salt to adversely affect the growth of most crop plants. The lower limit of saturation extract electrical conductivity of such soils is conventionally set a 0.4 siemens per meter. Actually, sensitive plants are affected at half this salinity and highly tolerant ones at about twice this salinity.

salt-affected soil - Soil that has been adversely modified for the growth of most crop plants by the presence of soluble salts, exchangeable sodium, or both.

salt tolerance - The ability of plants to resist the adverse, nonspecific effects of excessive soluble salts in the root medium. Salt tolerance is distinguished from tolerances to specific ions (e.g., Na^+ and Cl^-) or solutes (e.g., H_3BO_3) and from nutritional imbalances. Salt tolerance can be expressed for specified conditions; one useful expression for salt tolerance in terms of two parameters is: a.) The maximum salt concentration that does not decrease the marketable yield below that in a nonsaline medium, and; b.) The yield decrease per unit increment in salinity above the threshold.

sand - (i) A soil particle between 0.05 and 2.0 mm in diameter. (ii) Any one of five soil separates, namely: very coarse sand, coarse sand, medium sand, fine sand, and very fine sand. See soil separates (iii) A soil textural class. See soil texture.

saturate - (i) To fill all the voids between soil particle with a liquid. (ii) To form the most concentrated solution possible under a given set of physical conditions in the presence of an excess of the solute. (iii) To fill to capacity, as the absorption complex with a cation species; e.g. H^+-saturated, etc.

saturated soil paste - A particular mixture of soil and water. At saturation, the soil paste glistens as it reflects light, flows slightly when the container is tipped, and the paste slides freely and cleanly from a spatula.

saturation extract - The solution extracted from a soil at its saturation water content.

scanning electron microscopy (SEM) - A device for specimen examination under ultra high magnification.

scoria land - Areas of slaglike clinkers, burned shale, and fine-grained sandstone; characteristic of burned-out coal beds. Such areas commonly support a sparse cover of grasses, but are of low agricultural value. A miscellaneous area.

second bottom - The first terrace above the normal flood plain of a stream.

secondary mineral - A mineral resulting from the decomposition of a primary mineral or from the reprecipitation of the products of decomposition of a primary mineral. See **primary mineral**.

sediment - Transported and deposited particles derived from rocks, soil, or biological material.

sedimentary rock - A rock formed from materials deposited from suspension or precipitated from solution and usually being more or less consolidated. The principal sedimentary rocks are sandstones, shales, limestones, and conglomerates.

sedimentation - The process of sediment deposition.

sedimentology - The science dealing with the study of processes of sedimentation and sediment properties.

segregated ice - Massive ice in a soil pedon, which is relatively free of soil particles.

selectivity coefficient - A conditional equilibrium coefficient for an ion exchange reaction that is expressed in terms of concentration variables for the exchangeable ions and either concentration variables or activities of the ions in solution.

sequential chemical extraction - Removal of metals from a sample by use of a successively more aggressive set of chemical reagents.

sesquioxides - A general term for oxides and hydroxides of Fe and Al.

size fractionation - separation of sample particles into discrete size ranges.

slag - Solid by-product of ore smelting process.

smectite - A group of 2:1 layer structured silicates with a high cation exchange capacity and variable interlayer spacing. Formerly called the montmorillonite group. The group includes di- and trioctahedral members.

sodium absorption ratio (SAR) - A relation between soluble sodium and soluble divalent cations which can be used to predict the exchangeable sodium percentage of soil equilibrated with a given solution. It is defined as follows:

$$SAR = \frac{(\text{sodium})}{(\text{calcium} + \text{magnesium})^{1/2}}$$

where concentrations, denoted by parentheses, are expressed in moles per liter.

soil - (i) The unconsolidated mineral or material on the immediate surface of the earth that serves as a natural medium for the growth of land plants. (ii) The unconsolidated mineral or organic matter on the surface of the earth that has been subjected to and influenced by genetic and environmental factors of: parent material, climate (including water and temperature effects), macro- and microorganisms, and topography, all acting over a period of time and producing a produce - soil - that differs from the material from which it is derived in many physical, chemical, biological, and morphological properties, and characteristics.

soil characteristics - Soil properties which can be described or measured by field or laboratory observations, e.g., color, temperature, water content, structure, pH, and exchangeable cations.

soil chemistry - The branch of soil science that deals with the chemical constitution, chemical properties, and chemical reactions of soils.

soil complex - (i) A kind of map unit used in soil surveys comprised of delineations, each of which shows the size, shape and location of a landscape unit composed of two or more kinds of component soils, or component soils and a miscellaneous area, plus allowable inclusions in either case. The bodies of component soils and the miscellaneous area are too small to be individually delineated at the scale of 1:24 000. Several to numerous bodies of each kind of component soil or the miscellaneous area are apt to occur in each delineation. The proportions of the components may vary appreciably from one delineation to another and all of the components need not occur in every delineation though they will be present in most delineations. (ii) Formerly defined as in (i) but the scale of mapping was not specified.

soil conditioners - Polyelectrolytes, such as complex vinyl and acrylic compounds and certail cellulose and lignin derivatives. They tend to agglomerate soil colloids and produce a crumb structure in the soil. They increase the permeability of the soil to air and water and increase its resistance to crusting when it dries out.

soil extract - The solution separated from a soil suspension or from a soil by filtration, centrifugation, suction, or pressure. (May or may not be heated prior to separation.)

soil formation factors - The variable, usually interrelated natural agencies that are active in and responsible for the formation of soil The factors are usually grouped into five major categories as follows: parent rock, climate, organisms, topography, and time.

soil geography - The branch of physical geography that deals with the areal distributions of soils.

soil horizon - A layer of soil or soil material approximately parallel to the land surface and differing from adjacent genetically related layers in physical, chemical, and biological properties or characteristics such as color, structure, texture, consistency, kinds and number of organisms present, degree of acidity or alkalinity, etc.

soil management - (i) The sum total of all tillage and planting operations, cropping practices, fertilizer, lime, irrigation, herbicide and insecticide application, and other treatments conducted on or applied to a soil for the production of plants. (ii) The branch of soil science that deals with the items listed in (i).

soil management groups - Groups of taxonomic soil units with similar adaptations or management requirements for one or more specific purposes, such as: adapted crops or crop rotations, drainage practices, fertilization, forestry, highway engineering, etc.

soil map - A map showing the distribution of soils or other soils map units in relation to the prominent physical and cultural features of the earth's surface.

soil mineral - (i) Any mineral that occurs as a part of or in the soil. (ii) A natural inorganic compound with definite physical, chemical, and crystalline properties (within the limits of isomorphism), that occurs in the soil. See clay mineral.

soil mineralogy - The branch of soil science that deals with the homogeneous inorganic materials found in the earth's crust to the depth of weathering or of sedimentation.

soil morphology - (i) The physical constitution, particularly the structural properties, of a soil profile as exhibited by the kinds, thickness, and arrangement of the horizons in the profile, and by the texture, structure, consistency, and porosity of each horizon. (ii) The structure characteristics of the soil or any of its parts.

soil separates - Mineral particles, < 2.0 mm in equivalent diameter, ranging between specified size limits. The names and size limits of separates recognized in the United States are: *very coarse sand*, 2.0 to 1.0 mm; *coarse sand*, 1.0 to 0.5 mm; *medium sand*, 05 to 0.24 mm, *fine sand*, 0.25 to 0.10 mm; *very fine sand*, 0.10 to 0.05 mm; *silt*, 0.05 to 0.002 mm; and *clay*, < 0.002 mm.

soil survey - The systematic examination, description, classification, and mapping of soils in an area. Soil surveys are classified according to the kind and intensity of field examination. Also, the program of the National Cooperative Soil Survey that includes developing and implementing standards for describing, classifying, mapping, writing, and publishing information about soils of a specific area.

soil test - A chemical, physical, or biological procedure which estimates a property of the soil pertinent to the suitability of the soil to support plant growth. (Sometimes used as a adjective to define fractions of soil components, e.g., "soil test phosphorus".)

soil texture - The relative proportions of the various soil separates in a soil as described by the classes of soil texture shown in Fig. 1. The textural classes may be modified by the addition of suitable adjectives when coarse fragments are present in substantial amounts; for example, "stony silt loam" or "silt loam, stony phase." (For other modifications see coarse fragments.) The sand, loamy sand, and sandy loam are further subdivided on the basis of the proportions of the various sand separates present.

soil water diffusivity - The hydraulic conductivity divided by the differential water capacity (care being taken to be consistent with units), or the flux of water per unit gradient of moisture content in the absence of other force fields.

solid phase - Solid matrix of primary, secondary or amorphous materials.

solubility - To be available to pants a nutrient must be at least slightly soluble in the soil solution. The amount of substance that will dissolve at a given temperature in 100 parts of water is known as its solubility. The solubility of some fertilizer chemicals in pure water at 32° F. Solubility of most chemicals is slightly higher at higher temperatures; that of others, especially ammonium and potassium nitrates, increases rapidly with temperature. The presence of other substances in the solution may either increase or decrease the solubility.

specific surface - The solid-particle surface area (of a soil or porous medium) divided by the solid-particle mass or volume, expressed in m^2kg^{-1} or $m^2\ m^{-3} = m^{-1}$, respectively.

species/forms - The chemical form of an element in a sample.

stones - Rock fragments > 25 cm in diameter if rounded, and > 38 cm along the greater axis if flat. See coarse fragments.

stony - Containing sufficient stones to interfere with or to prevent tillage. To be classified as stony, > 0.01% of the surface of the soil must be covered with stones. Used to modify soil class, as *stony clay loam or clay loam, stony phase*. See coarse fragments.

structural charge - The charge (usually negative) on a mineral caused by isomorphous substitution within the mineral layer. (Expressed as moles of charge per kilogram of clay.)

sulfur cycle - The sequence of transformations undergone by sulfur wherein it is used by living organisms, transformed upon death and decomposition of the organism, and converted ultimately to its original state of oxidation.

surface analysis by laser ionization (SALI) - Spectroscopic device for probing surfaces for different metals.

surface area -The area of the solid particles in a given quantity of soil or porous medium. See also specific surface.

surface-charge density - The excess of negative or positive charge per unit of surface area of soil or soil mineral.

surface soil - The uppermost part of the soil, ordinarily moved in tillage, or its equivalent in uncultivated soils and ranging in depth from 7 to 20 cm. Frequently designated as the "surface layer," the "Ap layer," or the "Ap horizon."

surfactants - Substances that have the property of lowering surface tension of liquids when dissolved in them. They are of three types: nonionic, anionic, and cationic, but only the first two are used in fertilizer manufacture. Anionic surfactants include many different types of complex alkyl aryl sodium sulfonates and sulfates. The nonionic include numerous complex ethers and alcohols. Hundreds of different surfactants are available.

suspending agent - In production of suspension fertilizers, a suspending agent is added to prevent settling of crystals or other solid materials during storage or shipment. At present, the major material used as the suspending agent for suspension fertilizers is colloidal attapulgite clay.

talc - A magnesium silicate mineral with a 2:1 type layer structure but without isomorphous substitutions. May occur in soils as an inherited mineral. It is trioctahedral.

talus - Fragments of rock and other soil material accumulated by gravity at the foot of cliffs or steep slopes.

terrace - (i) A level, usually narrow, plain bordering a river, lake, or the sea. Rivers sometimes are bordered by terraces at different levels. (ii) A raised, more or less level or horizontal strip of earth usually constructed on or nearly on a contour and supported on the downslope side by rocks or other similar barrier and designed to make the land suitable for tillage and to prevent accelerated erosion. For example, the ancient terraces built by the Incas in the Andes. (iii) An embankment with the uphill side sloping toward and into a channel for conducting water, and the downhill side having a relatively sharp decline; constructed across the direction of the slope for the purpose of conducting water from the area above the terrace at a regulated rate of flow and to prevent the accumulation of large volumes of water on the downslope side of cultivated fields. The depth of the channel, the width of the terrace ridge, and the spacings of the terraces on a field are varied with soil types, cropping systems, climatic conditions, and other factors.

throughfall - That portion of precipitation that falls through or drips off of a plant canopy.

tidal flats - Areas of nearly flat, barren mud periodically covered by tidal waters. Normally these materials have an excess of soluble salt. A miscellaneous area.

till - (i) Unstratified glacial drift deposited by ice and consisting of clay, silt, sand, gravel, and boulders, intermingled in any proportion. (ii) To prepare the soil for seeding; to seed to cultivate the soil.

toposequence - A sequence of related soils that differ, one from the other, primarily because of topography as a soil-formation factor. See clinosequence.

trioctahedral - An octahedral sheet that has all of the sites filled, usually by divalent ions such as magnesium or ferrous Fe.

truncated - Having lost all or part of the upper soil horizon or horizons.

tuff - Volcanic ash usually more or less stratified and in various states of consolidation.

tundra - A level or undulating treeless plain characteristic of arctic regions.

Turf Management System (TMS) - A management system that combines all cultural management factors for sustained productivity of an acceptable level of quality for turfgrass, course profitability and the integrity of ecosystems on and in the vicinity of the golf course.

ultrasonic sieve shaker - Device used for mechanically separating particles according to grain size.

underground runoff (seepage) - Water that seeps toward stream channels after infiltration into the ground.

unsaturated flow - The movement of water in soil in which the pores are not completely filled with water.

urea - A white crystalline, or granular, solid synthesized from ammonia and carbon dioxide under high temperature and pressure. Urea has wide use in solid and liquid complex fertilizers and for direct application. It is used in foliage sprays with or without the addition of pesticides and micronutrients.

vermiculite - A highly charged layer-structured silicate of the 2:1 type that is formed from mica. It is characterized by absorption preference for potassium and cesium over smaller exchange cations. It may be di- or trioctahedral.

vesicular - Contains large and small bubbles and pores produced by the release of gasses held in solution in the molten slag but released during cooling and frozen in.

water table - The upper surface of ground water or that level in the ground where the water is at atmospheric pressure.

water table, perched - The water table of a saturated layer of soil which is separated from an underlying saturated layer by an unsaturated layer (vadose water).

water tension (or pressure) - The equivalent negative pressure in the soil water. It is equal to the equivalent pressure that must be applied to the soil water to bring it to hydraulic equilibrium through a porous permeable wall or membrane, with a pool of water the same composition. See soil water.

water use efficiency - Dry matter or harvested portion of crop produced per unit of water consumed.

weathering - All physical and chemical changes produced in rocks, at or near the earth's surface, by atmospheric

agents. See chemical and physical weathering.

wetland - An area of land that has hydric soils and hydrophytic vegetation.

windbreak - A planting of trees, shrubs, or other vegetation, usually perpendicular or nearly so to the principal wind direction, to protect soil, crops, homesteads, roads, etc., against the effects of winds, such as wind erosion and the drifting of soil and snow.

X-ray fluorescence (XRF) - Non-destructive device for determining the trace element composition of a sample.

X-ray diffraction (XRD) - Device for determining the mineralogy of a sample.

X-ray photo-electron spectroscopy (XPS) - Spectroscopic device for probing top-layer of surface for chemical information of metals absorbed to the surface.

zinc (Zn) - A bluish-white metallic element that forms salts with acids. It is essential to plant growth. It is recognized as one of the micronutrient elements.

6.0 REFERENCES

Ahmad, S., Johnson-Cicalese, J.M., Dickson, W.K. and Funk, C.R. 1986. Endophyte-enhanced resistance in perennial ryegrass to the bluegrass billbug. *Sphenophorus parvulus. Entomol. Exp. Appl.* 41:3-10.

Ahmadi, M.S., Haderlie, L.C. and Wicks, G.A. 1980. Effect of growth stage and water stress on Barnyardgrass *(Echinochloa crus-galli)* control and on glyphosate absorption and translocation. *Weed Sci.* 28(3):277-282.

Ahmed, W. 1977. The Effectiveness of Predators of Rice Field Mosquitoes in Relation to Pesticide Use in Rice Culture. Ph.D. Thesis, University of California, Davis, CA, 56 pp. *Dissert. Abstr. Int.* B 37(9):430B.

Ahuja, L.R., Sharpley, A. N. and Lehman, O.R. 1982. Effect of soil slope and rainfall characteristics on phosphorus in runoff. *J. Environ. Qual.* 11(1):9-13.

Alabaster, J. S. 1969. Survival of fish in 164 herbicides, insecticides, fungicides, wetting agents and miscellaneous substances. *Int. Pest Control* 11(2):29-35.

Aldrich, S.R. 1984. Nitrogen management to minimize adverse effects on the environment in Hauck, R.D. (Ed.) *Nitrogen in Crop Production.* Am. Soc. Agron., Crop Sci. Soc. Am., Soil Sci. Soc. Am., Madison, WI, pp. 663-673.

Alexander, M. 1977. *Introduction to Soil Microbiology.* John Wiley & Sons, New York, 467 pp.

Alexander, H. C., Gersich, F. M. and Mayes, M. A. 1985. Acute toxicity of four phenoxy herbicides to aquatic organisms. *Bull. Environ. Contam. Toxicol.* 35(3):314-321.

Ali, A. and Mulla, M. S. 1977. The IGR diflubenzuron and organophosphorus insecticides against nuisance midges in man-made residential-recreational lakes. *J. Econ. Entomol.* 70(5):571-577.

Ali, A. and Mulla, M. S: 1978a. Declining field efficacy of chlorpyrifos against chironomid midges and laboratory evaluation of substitute larvicides. *J. Econ. Entomol.* 71(5):778-782.

Ali, A. and Mulla, M. S. 1978b. Effects of chironomid larvicides and diflubenzuron on nontarget invertebrates in residential-recreational lakes. *Environ. Entomol.* 7(1):21-27.

Allen, G.E. and Bath, J.E. 1980. The conceptual and institutional aspects of integrated pest management. *BioScience* 30(10):658-664.

Anderson, G. 1980. Assessing organic phosphorus in soils. in Khasawneh, F.E. (Ed. chair.). *The Role of Phosphorus in Agriculture.* Am. Soc. Agron., Crop Sci. Soc. Am., Soil Sci. Soc. Am., Madison, WI pp. 411-431.

Anderson, J.L., Balogh, J.C. and Waggoner, M. 1989. Soil Conservation Service Procedure Manual: Development of Standards and Specifications for Nutrient and Pesticide Management. Section I &
II. USDA Soil Conservation Service. State Nutrient and Pest Management Standards and Specification Workshop, St. Paul, MN, July 1989, 453 pp.

Armstrong, D. A., Buchanan, D. V. and Caldwell, R. S. 1976. A mycosis caused by *Lagenidium* sp. in laboratory-reared larvae of the dungeness crab, *Cancer magister*, and possible chemical treatments. *J. Invertebr. Pathol.* 28:329-336.

Arnold, T.B. and Potter, D.A. 1987. Impact of a high-maintenance lawn-care program on nontarget invertebrates in Kentucky bluegrass turf. *Environ. Entomol.* 16(1):100-105.

Atilano, R.A. and Busey. P. 1983. Susceptibility of St. Augustinegrass germ plasm to *Pyricuarita grisea. Plant Dis.* 67(7):782-783.

Bacon, C.W. Lyons, P.C. Porter, J.K. and Robbins, J.D. 1986. Ergot toxicity from endophyte-infected grasses: A review. *Agron. J.* 78:106-116.

Baker, R. 1986. Biological control: an overview. *Can. J. Plant Pathol.* 8:218-221.

Bailey, H. C. and Liu, D. H. W. 1980. *Lumbriculus variegatus*, a benthic oligochaete, as a bioassay organism. in Eaton, J. C., Parrish, P. R. and Hendricks, A. C. (Eds.). *Aquatic Toxicology*, ASTM STP 707. pp. 205-215.

Balogh, J.C. and Anderson, J.L. 1992. Environmental impacts of turfgrass pesticides. in Balogh J.C. and Walker. W.J. (Eds) *Golf Course Management and Construction: Environmental Issues.* Lewis Publishers, Chelsea, MI Chapter 4.

Balogh, J. C. and Gordon, G. A. 1987. Climate variability and soil hydrology in water resource evaluation. Phase I Project Report. National Science Foundation, ISI-87053. NTIS #PB90-203183/A05. 92 pp.

Balogh, J. C. and Walker, W. J. (eds.). 1992. Golf course management and construction: Environmental Issues. Lewis Publishers, Inc. Chelsea, MI. 951 pp.

Balogh, J. C. and Watson, J. R., Jr. 1992. Role and conservation of water resources. *In* Balogh, J. C. and Walker, W. J. (eds.). Golf course management and construction: Environmental Issues. Lewis Publishers, Inc. Chelsea, MI. pp. 39-104.

Balogh, J. C., Gibeault, V. A., Walker, W. J., Kenna. M. P. and Snow, J. T. 1992a. Background and overview of environmental issues. *In* Balogh, J. C. and Walker, W. J. (eds.). Golf course management and construction: Environmental Issues. Lewis Publishers, Inc. Chelsea, MI. pp. 1-37.

Balogh, J. C., Leslie, A. R., Walker, W. J., and Kenna. M. P. 1992b. Development of integrated management systems for turfgrass. *In* Balogh, J. C. and Walker, W. J. (eds.). Golf course management and construction: Environmental Issues. Lewis Publishers, Inc. Chelsea, MI. pp. 355-439.

Balogh, J.C. and Madison, F.W. 1985. Runoff treatment from a turkey production facility. *Trans. ASAE* 28(5):1476-1481.

Banerjee, A.C. 1969. Sex attractants in sod webworms. *J. Econ. Entomol.* 62(3):705-708.

Barrow, N.J. and Shaw, T.C. 1975. The slow reactions between soil and anions: 3. The effect of time and temperature on the decrease in isotopically exchangeable phosphate. *Soil Sci.* 119:190-197.

Baysa, B.O., Halisky, P.M. and White, J.F., Jr. 1987. Inhibitory interactions between *Acremonium* spp. and the mycoflora from seeds of *Festuca and Lolium. Phytopathol.* 77:115.

Beard, J. B. 1973. *Turfgrass Science and Culture.* Prentice-Hall, Englewood Cliffs, NJ, 658 pp.

Beard, J. B. 1982. *Turf Management for Golf Courses.* Macmillan Publishing Co., New York, 642 pp.

Beauchamp, E.G. 1977. Slow release N. fertilizers applied in fall for corn. *Can. J. Soil Sci.* 57:487-496.

Benijts-Claus, C. and Persoone, G. 1975. La toxicite de trois herbicides sur l'ecosysteme aquatique. *La Tribune Du Cerdeau* 28(383):340-346.

Berry, C.D. and Gudauskas, R.T. 1972. Susceptibility of tall fescue. *Fetuca arundinacea* Schreb., to crown rust *Crop Sci.* 12:101-102.

Bertagnolli, B. L. and Nadakavukaren, M. J. 1970. Effect of 2,4-dichlorophenoxyacetic acid on the fine structure of *Chlorella pyrenoidosa* Chick. *J. Phycol.* 6:98-100.

Bertagnolli, B. L. and Nadakavukaren, M. J. 1974. Some physiological responses of *Chlorella pyrenoidosa* to 2,4-dichlorophenoxyacetic acid. *J. Exp. Bot.* 25(84):180-188.

Birge, W. J., Black, J. A. and Bruser, D. M. 1979. Toxicity of Organic Chemicals to Embryo-larval Stages of Fish. Ecol. Res. Ser. EPA-560/11-79-007, Office of Toxic Substances, U.S. Environ. Prot. Agency, Washington, D.C., 60 pp.

Biro, P. 1979. Acute effects of the sodium salt of 2,4-D on the early developmental stages of bleak, *Alburnus alburnus*. *J. Fish Biol.* 14(1):101-109.

Black, W. M. and Neely, D. 1975. Effect of soil-injected benomyl on resident earthworm populations. *Pestic. Sci.* 6:543-545.

Bohm, H. H. and Muller, H. 1976. Model studies on the accumulation of herbicides by microalgae. *Naturwissenschaften* 63(6):296.

Boike, A. H.,Jr., Rathburn, C. B., Jr., Lang, K. L., Masters, H. M. and Floore, T. G. 1985. Current status on the florida abate monitoring program - Susceptibility levels of three species of mosquitoes during 1984. *J. Am. Mosq. Control Assoc.* 1(4):498-501.

Boumaiza, M., Ktari, M. H. and Vitiello, P. 1979. Toxicite de divers pesticides utilises en tunisie pour *Aphanius fasciatus Nardo*, 1827 *(Pisces, Cyprinodontidae)*. *Arch. Inst. Pasteur Tunis* 56(3):307-342.

Bredakis, E.J. and Steckel, J.E. 1963. Leachable nitrogen from soils incubated with turfgrass fertilizers. *Agron. J.* 53:145-147.

Brede, A.D. and Brede, J.L. 1988. Establishment clipping of tall fescue and companion annual ryegrass. *Agron J.* 80(1):27-30.

Brede, A.D. and Duich, J.M. 1984a. Initial mowing of Kentucky blue-grass-perennial ryegrass seedling turf mixtures. *Agron J.* 76(5):711-714.

Brede, A.D. and Duich, J.M. 1984b. Establishment characteristics of Kentucky bluegrass perennial ryegrass turf mixtures as affected by seeding rate and ratio. *Agron. J.* 76(6):875-879.

Brede, A.D. and Duich, J.M. 1986. Plant interaction among *Poa annua*, *Poa pratensis*, *and Lolium perenne* turfgrasses. *Agron. J.* 78(1):179-184.

Brezonik, P.L. 1969. Eutrophication: The process and its modeling potential. in Putnam, H.D. (Ed.) Modeling the Eutrophication Process, Proc. Wrkshop., Dept. Environ. Eng., University of Florida, Gainesville, pp. 68-116.

Brezonik, P.L. (Chairman). 1978. Nitrates: An environmental assessment. National Academy of Sciences, Washington D.C., Chapters 1, 8, 9.

Britton, M.P. 1969. Turfgrass diseases. in Hanson, A.A. and Juska F.V. (Eds.) *Turfgrass Science*. Agron. Monogr. 14:288-335. Am. Soc. Agron., Madison, WI.

Brown, J. R. and Chow, L. Y. 1974. The effect of Dursban on micro-flora in non-saline waters in Coulston, P., Frederick, and Korte, F. (eds.). *Environmental Quality and Safety Supplement*. Vol. 3. Pesticides, Intl. Union of Pure and Applied Chemistry, Third Intl. Congress, Helsinki, Finland. pp. 774-779.

Brown, J. R., Chow, L. Y. and Deng, C. B. 1976. The effect of Dursban upon fresh water phytoplankton. *Bull. Environ. Contam. Toxicol.* 15(4):437-441.

Brown, K.W., Duble, R.W. and Thomas, J.C. 1977. Influence of management and season on fate of N applied to golf greens. *Agron. J.* 69(4):667-671.

Brown K.W., Thomas, J.C. and Duble, R.L. 1982. Nitrogen source effect on nitrate and ammonia leaching and runoff losses from greens. *Agron. J.* 74(6):947-950.

Brown, W., Jr., Cranshaw, W. and Rasmussen-Dykes, C. 1989. Educational, environmental and economic impacts of integrated pest management programs for landscape plants. in Leslie, A.R. and Metcalf, R.L. (Eds.) Integrated Pest Management for Turfgrass and Ornamentals. Office of Pesticide Programs. 1989-625-030. U.S. Environmental Protection Agency, Washington, D.C., pp. 57-75.

Bruneau, A. H., Watkins, J. E. and Brandenburg, R. L. 1992. Integrated pest management. *In* Waddington, D. V., Carrow, R. N. and Shearman, R. C. (eds.). Turfgrass. ASA-CSSA-SSSA Monogr. 32. Amer. Soc. Agron., Crop Sci. Soc. Am. Soil Sci. Soc. Am. Madison, WI. pp. 889-919-533.

Bruton, B.D., Toler, R.W. and Reinert, J.A. 1983. Combined resistance in St. Augustinegrass to the southern chinch bug and the St. Augustine decline strain of panicum mosaic virus. *Plant Dis.* 67:171-172.

Buettner, M.R., Ensign, R.D. and Boe, A.A. 1976. Plant growth regulator effects on flowering of *Poa pratensis* L. under field conditions. *Agron. J.* 68(2):410-413.

Burpee, L.L. and Goulty, L.G. 1984. Suppression of brown patch disease of creeping bentgrass by isolates of nonpathogenic *Rhizoctonia spp. Phytopathol.* 74:692-694.

Burpee, L.L., Kaye, L.M., Goulty, L.G. and Lawton, M.B. 1987. Suppression of gray snow mold on creeping bentgrass by an isolate of *Typhula phacorrhiza*. *Plant Dis.* 71:97-100.

Busey, P. 1989. Progress and Benefits to Humanity from Breeding Warm-Season Grasses for Turf. in Sleper, D.A., Asay, K.H. and Pedersen, J.F. (Eds.) *Contributions from Breeding Forage and Turf Grasses*. CSSA Spec. Publ. No. 15. Crop Sci. Soc. Am., Madison, WI, pp. 49-70.

Busey, P. and Center B.J. 1987. Southern chinch bug *(Hemiptera: Heteroptera: Lygaeidae)* overcomes resistance in St. Augustinegrass. *J. Econ. Entomol.* 80(3):608-611.

Busey, P., Reinert, J.A. and Atilano, R.A. 1982. Genetic and environmental determinants of zoysia grass adaption in a subtropical region. *J. Am. Soc. Hort. Sci.* 107(1):79-82.

Bush, L., Boling, J. and Yates, S. 1979. Animal disorders. in Buckner, R.C. and Bush, L.P. (Eds) *Tall Fescue*. Agron. Monogr. 20:247-306. Am. Soc. Agron., Crop Sci. Soc. Am., Soil Sci. Soc. Am., Madison, WI.

Buslovich, S. Yu. and Borushko, N. V. 1976. Chloroderivatives of phenoxyacetic acid as antagonists of thyroid hormones. *Farmakol. Toksikol.* (Moscow.) (4):481-483.

Butcher, J. E., Boyer, M. G. and Fowle, C. D. 1977. Some changes in pond chemistry and photosynthetic activity following treatment with increasing concentrations of chlorpyrifos. *Bull. Environ. Contam. Toxicol.* 17(6):752-758.

Buta, J.G., Spaulding, D.W. and Reed, A.N. 1987. Differential growth responses of fractionated turfgrass seed leachates. *HortScience* 22(6):1317-1319.

Butler, G. L., Deason, T. R. and O'Kelley, J. C. 1975. The effect of atrazine, 2,4-D, methoxychlor, carbaryl and diazinon on the growth of planktonic algae. *Br. Phycol. J.* 10(4):371-376.

Butler, P. A. 1963. A review of Fish and Wildlife Service I Investigations During 1961 and 1962. Circular No. 7. U. S. Dept. Int. Fish Wildl. Serv., Washington, D.C., 25 pp.

Butler, P. A. 1964. Commercial fishery investigations. in Pesticide-Wildlife Studies, 1963. U. S. Dept. Int. Fish and Wildl.

Serv. Circular 199. 28 pp.

Caldwell, R. S., Buchanan, D. V., Armstrong, D. A., Mallon, M. H. and Millemann, R. E. 1979. Toxicity of the herbicides 2,4-D, DEF, propanil and trifluralin to the dungeness crab, *Cancer magister. Arch Environ. Contam. Toxicol.* 8(4):383-396.

Cantor, K.P., Blair, A., and Zahn, S.H. 1988. Health effects of Agrichemicals in groundwater: What do we know? in Agricultural Chemicals and Groundwater Protection: Emerging Management and Policy. Proceedings of a Conference, Oct. 22-23, 1987, Freshwater Foundation, St. Paul, MN, pp. 27-42.

Carpenter, L. A. and Eaton, D. L. 1983. The disposition of 2,4,-dichlorophenoxyacetic acid in rainbow trout. *Arch. Environ. Contam. Toxicol.* 12(2):169-173.

Carpentier, A. G., Mackenzie, D. L. and Frank, R. 1988. Residues and efficacy of two formulations of 2,4-D on aquatic macrophytes in Buckhorn Lake, Ontario. *J. Aquat. Plant Manage.* 26:29-37.

Carrow, R.N., Shearman, R.C. and Watson, J.R. 1990. Turfgrass. in Stewart, B.A. and Nielsen D.R. (Eds)*Irrigation of Agricultural Crops.* Agron. Monogr. 30:889-919. Am. Soc. Agron., Crop. Sci. Soc. Am. Sil Sci. Am., Madison, WI.

Carsel, R. F., Mulkey, L. A.; Lorber, M. N. and Baskin, L. B. 1985. The pesticide root zone model (PRZM): A procedure for evaluating pesticide leaching threats to groundwater. Ecol. Modelling 30:49-69.

Carsel, R. F., Nixon, W. B. and Balentine, L. G. 1986. Comparison of pesticide root zone model predictions with observed concentrations for the tobacco pesticide metalaxyl in unsaturated zone soils. Environ. Toxicol. Chem. 5:345-353.

Carsel, R. F., Smith, C. N., Mulkey., Dean, J. D. and Jowise, P. 1984. Users manual for the pesticide root zone model (PRZM). Release 1. EPA-600/3-84-109. U. S. Environmental Protection Agency, Athens, GA. 216 pp.

Carter, F. L. and Graves, J. B. 1972. Measuring effects of insecticides on aquatic animals. *La. Agric.* 16(2):14-15.

Chapman, R.A. 1979. Diseases and nematodes. in Buckner. R.C. and Bush, L.P. (Eds) *Tall Fescue.* Agron. Monogr. 20:307-318. Am. Soc. Agron., Crop Sci. Soc. Am., Soil Sci. Soc. Am., Madison, WI.

Cheah, M. L., Avault, J. W., Jr., and Graves, J. B. 1980. Some effects of rice pesticides on crawfish. *La. Agric.* 23(2):8,9,11.

Chinnaswamy, R. and Patel, R. J. 1983. Effect of pesticide mixtures on the blue-green alga *Anabaena flos-aquae. Microbios Lett.* 24:141-143.

Chouhan, M. S., Verma, D. and Pandey, A. K. 1983. Herbicide induced haematological changes and their recovery in a freshwater fish, *Puntius ticto* (Ham.). *Comp. Physiol. Ecol.* 8(4):249-251.

Clark, J.D. and Haynes, K.P. 1990. Sex attractant for the bluegrass webworm *(Lepidotera: Pyralidae) J. Econ. Entomol.* 83(3):856-859.

Clark, J. R., Patrick, J. M., Jr., Middaugh, D. P. and Moore, J. C. 1985. Relative sensitivity of six estuarine fishes to carbophenothion, chlorpyrifos,and fenvalerate. *Ecotoxicol. Environ. Saf.* 10(3):382-390.

Clarke, B.B., Johnson-Cicalese, J.M. and Funk, C.R. 1989. Development of Perennial Ryegrass Cultivars with Improvement Resistance to *Rhizoctonia* Brown Patch. in Sixth Int. Turf. Res. Conf. Tokyo, Japan, pp. 337-340.

Cockfield, S.D. and Potter, D.A. 1984a. Predatory insects and spiders from suburban lawns in Lexington, Kentucky. *Great Lakes Entomol.* 17(3):179-184.

Cockfield, S.D. and Potter, D.A. 1984b. Predation of sod webworm (*Lepidoptera: Pyralidae*) eggs as affected by chlorpyrifos

application to Kentucky bluegrass. *J. Econ. Entomol* 77(6):1542-1544.

Cockfield, S.D. and Potter, D.A. 1985. Predatory arthropods in high- and low-maintenance turfgrass. *Can. Entomol.* 117:423-429.

Cohen, S. Z., Creeger, S. M., Carsel, R. F. and Enfield, C. G. 1984. Potential for pesticide contamination of groundwater resulting from agricultural uses. *In* Kruger, R. F. and Sieber, J. N. (eds.). Treatment and Disposal of pesticide wasters. ACS Symp. Ser. No. 259. American Chemical Society. Washington D. C. pp. 297-325.

Cohen, S.Z., Nickerson, S., Maxey, R., Dupuy, A.,Jr. and Senita, J.A. 1990. Ground water monitoring study for pesticides and nitrates associated with golf courses on Cape Cod. *Ground Water Monit. Rev.* 10(1):160-173.

Colbaugh, P.F. and Elmore, C.L. 1985. Influence of water on pest activity. in Gibeault, V.A. and Cockerham, S.T. (Eds.) *Turfgrass Water Conservation.* University of California, Riverside, Division of Agriculture and Natural Resources, pp. 113-129.

Cook, M. E. and Swait, S.A.J. 1975. Effects of some fungicide treatments on earthworm populations and leaf removal in apple orchards. *J. Hort. Sci.* 50:495-499.

Cook, R.J. and Baker, K.F. 1983. *The Nature and Practice of Biological Control of Plant Pathogens.* American Phytopathological Society, St. Paul, MN, 539 pp.

Cooke, A. S. 1972. The effects of DDT, dieldrin and 2,4-D on amphibian spawn and tadpoles. *Environ. Pollut.* 3:51-68.

Cooper, R.J., Vittum, P.J. and Bhowmik, P.C. 1987. Urban lawn integrated pest management (IPM): Results of a pilot program, in Eltzerman, A.W. (Ed.) *Proc. Symp. New Directions in Urban Int. Pest. Manag: An Environ. Mandate.* Am. Chem. Soc. Symp. Series pp. 543-544.

Cope, O. B. 1965. Sport fishery investigations. in U.S. Fish Wildl. Serv. Circ. 226. pp. 51-63.

Cope, O. B., Wood, E. M. and Wallen, G. H. 1970. Some chronic effects of 2,4-D on the bluegill *(Lepomis macrochirus). Trans Am. Fish. Soc.* 99(1):1-12.

Cope, W.A. 1982. Inhibition of germination and seedling growth of eight forage species by leachants from seeds. *Crop. Sci.* 22(6):1109-1111.

Corbet, P.S. 1981. Non-entomological impediments to the adoption of integrated pest management. *Prot. Ecol.* 3:181-202.

CPCR 1992. Crop Protection Chemicals Reference. Chemical and Pharmaceutical Press, John Wiley and Sons, New York, NY. 1892 pp.

Crocker R.L. and Whitcomb, W.H. 1980. Feeding niches of the big-eyed bugs *Geocoris bullatus, G. punctipe, and G. uliginosus (Hemiptera: Lygaeidae: Geocorinae) Environ. Entomol.* 9(5):508-513.

Crocker, R.L., Toler R.W., Beard, J.B., Engelke, M.C. and Kubica-Breier, J.S. 1989. St. Augustinegrass antibiosis to southern chinch bug *(Hemiptera: Lygaeidae)* and to St. Augustine decline strain of panicum Mosaic virus. *J. Econ. Entomol.* 82(6):1729-1732.

Crosby, D. G. and Tucker, R. K. 1966. Toxicity of aquatic herbicides to *Daphnia magna. Science* 154:289-290.

Crosby, D. G., Tucker, R. K. and Aharonson, N. 1966. The detection of acute toxicity with *Daphnia magna. Food Cosmet. Toxicol.* 4:503-514.

Dahlgren, R. B. and Linder, R. L. 1971. Effects of polychlorinated biphenyls on pheasant reproduction, behavior, and survival.

J. Wildl. Manage. 35(2):315-318.

Dalton, G.E. 1975. *Study of Agricultural Systems*. Applied Science Publishers, London, England.

Daniel, T.C., McGuire, P.E., Stoffel, D. and Miller, B. 1979. Sediment and nutrient yield from residential construction sites. *J. Environ. Qual.* 8(3):304-308.

Daniel, T. C., Wendt, R. C., McGuire, P. E. and Stoffel, D. 1982. Nonpoint source loading rates from selected land uses. *Water Res. Bull.* 18(1):117-120.

Darwazeh, H. A. and Mulla, M. S. 1974. Toxicity of herbicides and mosquitoe larvicides to the mosquito fish *Gambusia affinis*. *Mosq. News* 34(2):214-219.

Das, B. and Singh, P. K. 1977. Mutagenecity of pesticides in blue-green algae. *Microbios Lett.* 5(19-20):103-107.

Davey, R. B., Meisch, M. V. and Carter, F. L. 1976. Toxicity of five ricefield pesticides to the mosquitofish, *Gambusia affinis*, and green sunfish, *Lepomis cyanellus*, under laboratory and field conditions in Arkansas. *Environ. Entomol.* 5(6):1053-1056.

Davidson, J.M., Rao, P.S.C. and Nkedi-Kizza, P. 1983. Physical processes influencing water and solute transport in soils. in Nelsen, D.W., Elrick, D.E. and Tanji, K.K. (Eds.). *Chemical Mobility and Reactivity in Soil Systems*. Special Publ. No. 11. Soil Sci. Soc. Am., Madison, WI, pp. 35-47.

Davidson, R.L. and Roberts, R.J. 1968. Influence of plants, manure, and soil moisture on survival and liveweight grain of two scarbaeid larvae. *Entomol. Exp. Appl.* 11:305-314.

Davidson, R.L., Wiseman, J.R. and Wolf, V.J. 1972. Environmental stress in the pasture scarab Sericesthis nigrolineata Boisd. II. Effects of soil moisture and temperature on survival of first-instar larvae. *J. Appl. Ecol.* 9:799-806.

Davies, P. E. 1987. Physiological, anatomic and behavioral changes in the respiratory system of *Salmo gairdneri* Rich. on acute and chronic exposure to chlorothalonil. *Comp. Biochem. Physiol.* 87C(1):113-119.

Davies, P. E. 1988. Disappearance rates of chlorothalonil (TCIN) in the aquatic environment. *Bull. Environ. Contam. Toxicol.* 40(3):405-409.

Davis, R.R. 1969. Nutrition and fertilizers. in Hanson, A.A. and Juska, F.V. (Eds.) *Turfgrass Science*. Agron. Mongr. 14:130-150. Am. Soc. Agron., Madison, WI

Davis, H. C. and Hidu, H. 1979. Effects of pesticides on embryonic development of clams and oysters and on survival and growth of the larvae. *Fish. Bull.* 67(2):393-404.

Dean, H.A., Schuster, M.F., Boling, J.C. and Riherd, P.T. 1979. Complete biological control of *Antonina graminis* in Texas with *Neodusmetia sangwani*. *Bull. Entomol. Soc. Am.* 25:262-267.

Dernoeden, P.H. 1987. Management of take-all patch of creeping bentgrass with nitrogen, sulfur and phenyl acetate. *Plant Dis.* 71(3):226-229.

Dernoeden, P.H. 1989. Symptomatology and management of common turfgrass diseases in transition zone and northern regions. in Leslie, A.R. and Metcalf, R.L.(Eds) Integrated Pest Management for Turfgrass and Ornamentals, Office of Pesticide Programs. 1989-625-030. U.S. Environmental Protection Agency, Washington D.C., pp. 273-296.

Dest, W.M. and Allinson, D.W. 1981. Influence of Nitrogen and Phosphorus Fertilization of the Growth and Development of *Poa annua* L. in Sheard, R.W. (Ed.) Proc. 4th Int. Turfgrass Res. Conf. Guelph, Ontario, pp. 325-332.

Devitt, D.a. and Morris, R.L. 1989. Growth of common bermudagrass as influenced by plant growth regulators, soil type and nitrogen fertility. *J. Environ. Hort.* 7(1):1-8.

Dive, D., Leclerc, H. and Persoone, G. 1980. Pesticide toxicity on the ciliate protozoan *Colpidium campylum*: Possible consequences of the effect of pesticides in the aquatic environment. *Ecotoxicol. Environ. Saf.* 4:129-133.

Dixon, R. D. and Brust, R. A. 1971. Field testing of insecticides used in mosquito control, and a description of the bioassay technique used in temporary pools. *J. Econ. Entomol.* 64(1):11-14.

Dodson, J. J. and Mayfield, C. I. 1979a. The dynamics and behavioral toxicology of aquakleen (2,4-D butoxyethanol ester) as revealed by the modification of rheotropism in rainbow trout. *Trans. Am. Fish. Soc.* 108(6):632-640.

Doe, K. G., Ernst, W. R., Parker, W. R., Julien, G. R. J. and Hennigar, P. A. 1988. Influence of pH on the acute lethality of fenitrothion, 2,4-D, and aminocarb and some pH-altered sublethal effects of aminocarb on aminocarb. *Can. J. Fish. Aquat. Sci.* 45(2):287-293.

Domek, J.M. and Johnson, D.T. 1987. Evidence of sex pheromone in the green June beetle, *Cotinus nitida (L.)(Coleptera: Scarabaeidae)*. *J. Entomol. Sci.* 22(3):264-267.

Donigian, A. S., Jr. and Carsel, R. F. 1987. Modeling impact of conservation tillage practices on pesticide concentrations in ground and surface waters. J. Environ. Toxicol. Chem. 6(4):241-250.

Donigian, A. S., Jr. and Rao, P. S. C. 1986a. Overview of terrestrial processes and modeling. *In* Hern, S. C. and Melancon, S. M. (eds.). Lewis Publishers, Chelsea, MI. pp. 3-35.

Donigian, A. S., Jr. and Rao, P. S. C. 1986b. Example model testing studies. *In* Hern, S. C. and Melancon, S. M. (eds.). Lewis Publishers, Chelsea, MI. pp. 103-131.

Dudeck, A.E., Reinert, A.E. and Busey, P. 1986. Floriawn St. Augustinegrass. Fla. Agric. Exp. Stat. Circ. No. S-327.

El-Ayouty, E. Y., Khalil, A. I., Ishak, M. M. and Ibrahim, E. A. 1978. Effect of 2,4-D, iron, mercury and bayluscide on the cellular structure of microcystis *Flos-aquae, Oscillatoria amphibia, Coelastrum microporum and Scenedesmus opaliensis*. *Egypt J. Bot.* 21(2):121-130.

El-Khatib, Z. I. and Georghiou, G. P. 1985. Geographic variation of resistance to organophosphates, propoxur and ddt in the southern house mosquito, *Culex quinquefasciatis*, in California. *J. Am. Mosq. Control Assoc.* 1(3):279-283.

El-Refai, A., Fahmy, F. A., Abdel-Lateef, M. F. A. and Imam, A. K. E. 1976. Toxicity of three insecticides to two species of fish. *Int. Pest Control* 18(6):4-8.

Elder, J. H., Lembi, C. A. and Morre, D. J. 1970. Toxicity of 2,4-D and Picloram to Fresh Water Algae. Project C-36-48C, Dept. of Botany and Plant Pathology, Purdue University, U.S. NTIS PB-199 114. 10 pp.

Ellgehausen, H., Guth, J. A. and Esser, H. O. 1980. Factors determining the bioaccumulation potential of pesticides in the individual compartments of aquatic food chains. *Ecotoxicol. Environ. Saf.* 4(2):134-157.

Ellis, B.G., Knezek, B.D. and Jacobs, L.W. 1983. The movement of micronutrients in soils. in Nelsen, D.W., Elrick, D.E. and Tanju, K.K. (Eds) *Chemical Mobility and Reactivity in Soil Systems*. Special Publ. No. 11, Soil Sci Soc. Am., Madison WI, pp. 109-122.

Enfield, C.G. and Ellis, R., Jr. 1983. The movement of phosphorus in soil. in Nelsen, D.W., Elrick, D.E. and Tanji, K.K. (Eds). *Chemical Mobility and Reactivity in Soil Systems*. Special Publ. No. 11. Soil Sci Soc. Am., Madison, WI, pp. 93-107.

Engel, R.E. and Ilnicki, R.D. 1969. Turfweeds and their control. in Hanson, A.A. and Juska, F.V. (Eds) *Turfgrass Science.* Agron. Monogr. 14:240-287. Am. Soc. Agron., Madison, WI.

Environmental Protection Agency, 1983. Dicamba Science Chapters. Office of Pesticides and Toxic Substances, Washington, DC.

Erickson, L. C., Wedding, R. T. and Brannaman, B. L. 1955. Influence of pH on 2,4-dichlorophenoxyacetic and acetic acid activity in *Chlorella. Plant Physiol.* 30:69-74.

Fales, S.L. and Wakefield, R.C. 1981. Effects of turfgrass on the establishment of woody plants. *Agron. J.* 73(4):605-610.

Farm Chemicals Handbook. 1991. *Pesticide and Fertilizer Dictionary.* Meister Publishing Company. Willoughby, OH. 770 pp.

Fay, P.K. and Duke, W.P. 1977. An assessment of allelpathic potential in Avena germplasm. *Weed Sci.* 25:224-228.

Federle, P. F. and Collins, W. J. 1976. Insecticide toxicity to three insects from Ohio ponds. *Ohio J. Sci.* 76(1):19-24.

Felix, H. R., Chollet, R. and Harr, J. 1988. Use of the cell wall-less alga *Dunaliella bioculata* in herbicide screening tests. *Ann. Appl. Biol.* 113(1):55-60.

Fermanian, T.W. and Michalski, R.S. 1989. Weeder: an advisory system for the identification of grasses in turf. *Agron. J.* 81(2):312-316.

Fermanian, T.W., Michalski, R.S., Katz, B. and Kelly, J. 1989. Agassistant: and artificial intelligence system for discovering patterns in agricultural knowledge and creating diagnostic advisory systems. *Agron. J.* 81(2):306-312.

Finkiewicz-Murawiejska, L. 1978. The influence of subacute poisoning with the organophosphate insecticide trichlorfon on morphology of the spinal cord. *Folia Morphol.* (Warszaw) 37(2):135-150.

Finlayson, B. J. and Verrue, K. M. 1985. Toxicities of butoxyethanol ester and propylene glycol butyl ether ester formulations of 2,4-dichlorophenoxy acetic acid (2,4-D) to juvenile salmonids. *Arch. Environ. Contam. Toxicol.* 14(2):153-160.

Fitzgerald, G. P., Gerloff, G. C. and Skoog, F. 1952. Stream pollution: Studies on chemicals with selective toxicity to blue-green algae. *Sewage Ind. Wastes* 24(7):888-896.

Fitzpatrick, G. and Sutherland, D. J. 1978. Effects of the organophosphorous insecticides temephos (Abate) and chlorpyrifos (Dursban) on populations of the salt-marsh snail *Melampus bidentatus. Mar. Biol.* 46(1):23-28.

Fleming, W.E. 1968. Biological control of the Japanese beetle. *U.S. Expt. Agricult. Tech. Bull.* 1383:1-78.

Folmar, L. C. 1976. Overt avoidance reaction of rainbow trout *fry* to nine herbicides. Bull. Environ. Contam. Toxicol. 15(5):509-514.

Forbes, S.A. 1880. Some interaction of organisms. III. *Nat. Hist. Surv. Bull.* 1:3-17.

Fox, R.L. 1981. External phosphate requirements of corps. in Stelly, M. (Ed. in chief) *Chemistry in the Soil Environment.* ASA Spec. Publ. No. 40. Am. Soc. Agron. and Soil Sci. Soc. Am., Madison, WI, pp. 223-239.

Frank, A. M. and Sjogren, R. D. 1978. Effect of temephos and chlorpyrifos on crustacea. *Mosq. News* 38(1):138-139.

Frank, R., Carpentier, A. G. and Mackenzie, D. L. 1987. Monitoring for 2,4-D residues in fish species resident in treated lakes in East-central Ontario 1977-80. *Environ. Monit. Assess.* 9:71-82.

Fraser, P., Chilvers, C., Beral, V. and Hill M.J. 1980. Nitrate and human cancer: A review of the evidence. *Int. J. Epidemiol.* 9:3-11.

Frempong-Boadu, J. 1966. A laboratory study of the effectiveness of methoxychlor, fenthion and carbaryl against blackfly larvae *(Diptera: Simuliidae). Mosq. News* 26(4):562-564.

Frere, M.H. 1976. Nutrient aspects of pollution from cropland. in Stewart, B.A., Woolhiser, D.A., Wischmeier, W.H. Caro, J.H. and Frere, M.H. (Eds.). Control of Water Pollution from Cropland: An Overview. Vol. 2. EPA 600/2-75-026b. U.S. Environmental Protection Agency, Athens, GA and USDA Agricultural Research Service, Washington, D.C., pp. 59-90.

Fry, F.E.J. 1969. Some possible physiological stresses induced by eutrophication. in *Eutrophication: Causes, Consequences, Correctives.* National Academy of Sciences, Washington, D.C. pp. 531-536.

Fry, J.D. and Dernoeden, P.H. 1986. Zoysiagrass competition in two cool-season turfgrasses treated with plant growth regulators. *HortScience* 2(3):464-466.

Funk, C.R. and Clarke, B.B. 1989. Turfgrass Breeding-with Special Reference to Turf-Type Perennial Ryegrass, Tall Fescue and Endophytes. in Sixth Int. Turf. Res. Conf. Tokyo, pp. 3-10.

Funk, C.R., Clark, B.B. and Johnson-Cicalese, J.M. 1989. Role of endophytes in enhancing the performance of grasses used for conservation and turf. in Leslie, A.R. and Metcalf, R.L. (Eds) Integrated Pest Management for Turfgrass and Ornamentals. Office of Pesticide Programs, 1989-625-030. U.S. Environmental Protection Agency, Washington D.C., pp. 203-210.

Funk, C.R., Halisky, P.M., Ahmad, S. and Hurley, R.H. 1985. How Endophytes Modify Turfgrass Performance and Response to Insect Pests in Turfgrass Breeding and Evaluation Trials. in Lemaire, F. (Ed) Proc. Fifth Int. Turf. Res. Conf., Avignon, France, pp. 137-145.

Funk, C.R., Halisky, P.M., Johnson, M.C., Siegel, M.R., Stewart, A.V., Hurley, R.H and Harvey, I.C. 1983. An endophytic fungus and resistance to sod webworms: Association in *Lolium perenne L. Bio/Technology* 1:189-191.

Fytizas, R. and Vassiliou, G. 1980. L'inhibition de la cholinesterase du cerveau de quelques especes de poisson critere de la pollution de la mer par les esters organophosphores. *Meded. Rijksfac. Landbouwwet. Gent.* 45(4):923-927.

Gaylor, M.J. and Frankie, G.W. 1979. The relationship of rainfall to adult flight activity and of soil moisture to oviposition behavior and egg and first instar survival in *Phyllophaga crinita. Environ. Entomol.* 8:591-594.

Gaugler, R. 1981. Biological control potential of neoaplectanid nematodes. *J. Nematol.* 13(3):241-249.

Gaussoin, R.E. and Branham, B.E. 1989. Influence of cultural factors on species dominance in a mixed stand of annual bluegrass/creeping bentgrass. *Crop. Sci.* 29(2):480-484.

Geiger, D. L., Call, D. J. and Brooke, L. T. 1988. Acute Toxicities of Organic Chemicals to Fathead Minnows (*Pimephales promelas*), Vol. 4. Center for Lake Superior Environmental Studies, University of Wisconsin, Superior, WI. 355 pp.

George, J. P., Hingorani, H. G. and Rao, K. S. 1982. Herbicide toxicity to fish-food organisms. *Environ. Pollut. Ser. A Ecol. Biol.* 28(3):183-188.

Georgis, R. and Poinar, G.O., Jr. 1989. Field effectiveness of entomophilic nematodes Neaplectana and Herterohabditis. in Leslie, A.R. and Metcalf, R.L. (Eds.) Integrated Pest Management for Turfgrass and Ornamentals. Office of Pesticide Programs. 1989-625-030. U.S. Environmental Protection Agency, Washington, D.C., pp. 213-224.

Gibeault, V.A. and Cockerham, S.T. (Eds.) 1985. *Turfgrass Water Conservation.* University of California, Riverside, Division of Agriculture and Natural Resources, 155 pp.

Gilbertson, C.B., Norstadt, F.A., Mathers, A.C., Holt, R.F., Barnett, A.P., McCalla, T.M., Onstad, C.A. and Young R.A. 1979. Animal Waste Utilization on Cropland and Pastureland: A Manual for Evaluating Agronomic and Environmental Effects. USDA Util. Rep. 6. EPA-600/2-79-059. Washington, D.C. 135 pp.

Glaser, R.W. and Farrell, C.C. 1935. Field experiments with the Japanese beetle and its nematode parasite, *J.N.Y. Entomol. Soc.* 43:345-371.

Glass, A.D.M. 1973. Influence of phenolic acids on ion uptake. I. Inhibition of phosphate uptake. *Plant Physol.* 51(6):1037-1041.

Goodman, D.M. and Burpee, L.L. 1987. Biological control of dollar spot disease of creeping bentgrass, in *1987 Annual Research Report.* The Guelph Turfgrass Institute, Guelph, Ontario, pp. 76-80.

Gordon, F.C. and Potter, D.A. 1985. Efficiency of Japanese beetle *(Coleoptera:Scarabaeidae)* traps in reducing defoliation of plants in the urban landscape and effect on larval density in turf. *J. Econ. Entomol.* 78(4):774-778.

Goss, R.L. 1974. Effects of Variable Rates of Sulfur on the Quality of Putting Green Bentgrass. in Roberts, E.C. (Ed.) Proc. 2nd Annual Int. Turfgrass Res. Conf. Blacksburg, VA, pp. 172-175.

Goss, D. 1991. Screening procedure for soils and pesticides relative to potential water quality impacts. *In* Using Computer Simulation Models in Pesticide Registration Decision Making. A Symposium/Workshop. Weed Sci. Soc. Am. Louisville KY.

Graber, L.F., Fluke, C.L. and Dexter, S.T. 1931. Insect injury of bluegrass in relation to the environment. *Ecology* 12(3):547-566.

Grant, Z. 1989. Integrated pest management in the golf course industry: A case study and some general considerations. In Leslie, A.R. and Metcalf, R.L. (Eds.) Integrated Pest Management for Turfgrass and Ornamentals. Office of Pesticide Programs. 1989-625-030. U.S. Environmental Protection Agency, Washington D.C., pp. 85-91.

Graves, J.B., Mohamad, R.B. and Clower, D.F. 1978. Beneficial insects also developing resistance. *La. Agric.* 22(1):10-11.

Gross, C.M., Angle, J.S. and Welterlen, M.S. 1990. Nutrient and sediment losses from turfgrass. *J. Environ. Qual.* (19(4):663-668.

Guarino, A. M., Rieck, G., Arnold, S., Fenstermacher, P., Bend, J., Knutson, M. J. and Anderson, J. B. 1976. Distribution and toxicity of selected water pollutants in the spiny dogfish, *Squalus acanthias. Bull. Mt. Desert Isl. Biol. Lab.* 16:50-53.

Gustafson, D. I. 1989. Groundwater ubiquity score: A simple method for assessing pesticide leachability. Environ. Toxicol. Chem. 8:339-357.

Haegele, M. A. and Tucker, R. K. 1974. Effects of 15 common environmental pollutants on eggshell thickness in mallards and *Coturnix. Bull. Environ. Contam. Toxicol.* 11(1):98-102.

Haley, J.e. and Fermanina, T.W. 1989. Flurprimidol effect on the emergence and growth of annual bluegrass and creeping bentgrass. *Agron. J.* 81(2):198-202.

Haley, T. J., Farmer, J. H., Harmon, J. R. and Dooley, K. L. 1975. Estimation of the LD1 and extrapolation of the LD0.1 for five organophosphate pesticides. *Arch. Toxicol.* 34:103-109.

Hall, C.J., Bowhey, C.S. and Stephenson, G.R. 1987. Lateral movement of 2,4-D from grassy inclines.*Proc.Britisg Crop Protect.Conf.*2(3):593-599.

Hamilton, D.W., Schwartz, P.H., Townshend, B.G. and Jester, C.W. 1971. Traps reduce an isolated infestation of Japanese

beetle. *J. Econ. Entomol.* 64(1):150-153.

Hansen, D. J. 1969. Avoidance of pesticides by untrained sheepshead minnows. *Trans. Am. Fish. Soc.* 98(3):426-429.

Hansen, D. J. 1970. Behavior of Estuarine Organisms. U.S. Fish Wildl. Serv., Circ. 335, Washington, D.C. pp. 23-28.

Hansen, D. J. 1972. DDT and malathion: effect on salinity selection by mosquitofish. *Trans. Am. Fish. Soc.* 101(2):346-350.

Hansen, D. J., Schimmel, S. C. and Keltner, J. M., Jr. 1973. Avoidance of pesticides by grass shrimp (*Palaemonetis pugio*). Bull. Environ. Contam. Toxicol. 9(3):129-133.

Hansen, D. J., Goodman, L. R., Cripe, G. M. and MaCauley, S. F. 1986. Early life-stage toxicity test methods for Gulf toadfish (*Opsanus beta*) and results using chlorpyrifos. *Ecotoxicol. Environ. Saf.* 11(1):15-22.

Hansen, S.A., Linn, J.G. and Plegge, S.D. 1987. Water quality for beef and dairy cattle. in Understanding Nitrogen and Agricultural Chemicals in the Environment. AG-BU-3166. University of Minnesota Agric. Ext. Serv. St. Paul, MN, pp. 7-17.

Hanson, A.A. and Juska, F.V. (Eds.). 1969. *Turfgrass Science.* Agron. Monogr. 14. Am. Soc. Agron., Madison, WI, 715 pp.

Hanula, J.L. and Andreadis, T.G. 1988. Parasitic microorganisms of the Japanese beetle *(Coleoptera: Scarabaeidae)* and associated Scarabaeidae larvae in Connecticut soils. *Environ. Entomol.* 17:709-714.

Harder, R.P. and Troll, J. 1973. Antagonism of Trichoderma spp. to sclerotia of Typhula incarnata. *Plant Dis. Rep.* 57:924-926.

Harris, C.R. 1982. Factors invluncing the toxicity of insecticides in soil. in Niemszyk, H.D. and Joyner B.G. (Eds) *Advances in Turfgrass Entomology.* Hammer Graphics, Inc. Piqua, OH, pp. 47-52.

Harrison, J. W. E. and Rees, E. W. 1946. 2,4-D toxicity - I: Toxicity towards certain species of fish. *Am. J. Pharm.* (Dec.): 422-425.

Harrison, S.A. 1989. Effects of Turfgrass Establishment Method and Management on the Quality and Nutrient and Pesticide Content of Runoff and Leachate. Unpubl. Thesis. The Pennsylvania State University, University Park, PA 125 pp.

Hashimoto, Y. and Nishiuchi, Y. 1981. Establishment of bioassay methods for the evaluation of acute toxicity of pesticides to aquatic organisms. *J. Pestic. Sci.* 6(2):257-264.

Haven, D. 1963. Mass treatment with 2,4-D on milfoil in tidal creeks in *VA. Proc. South Weed Conf.* 16:345-350.

Hawxby, K., Tubea, B., Ownby, J. and Basler, E. 1977. Effects of various classes of herbicides on four species of algae. *Pestic. Biochem. Physiol.* 7(3):203-209.

Haygood, R.A. and Mazur, A.R. 1990. Evaluation of Gliocladium virens as a biocontrol agent of dollar spot on bermudagrass. *Phytopathol.* 80:435.

Heath, R. G., Spann, J. W., Hill, E. F. and Kreitzer, J. F. 1972. Comparative Dietary Toxicities of Pesticides to Birds. U.S. Bureau of Sport Fisheries and Wildlife, Special Scientific Report-Wildlife No. 152:1-57.

Hedden, K. F. 1986. Example field testing of soil fate and transport model, PRZM, Dougherty Plain Georgia. *In*

Hern, S. C. and Melancon, S. M. (eds.). Lewis Publishers, Chelsea, MI. pp. 81-101.
Hemingway, J. and Georghiou, G. P. 1983. Studies on the acetylcholinesterase of *Anopheles ablmanus* resistant and susceptible to organophosphate and carbamate insecticides. *Pestic. Biochem. Physiol.* 19(2):167-171.

Herzberg, A. M. 1987. Toxicity of chlorpyrifos (Dursban) in *Oreochromis aureus* and *O. niloticus* and data on its residues in *O. aureus. Bamidgeh* 39(1):13-20.

Hess, F. D. 1980. A chlamydomonas algal bioassay for detecting growth inhibitor herbicides. *Weed Sci.* 28(5):515-520.

Hidaka, H., Hattanda, M. and Tatsukawa, R. 1984. Avoidance of pesticides with medakas (*Oryzias latipes*). *J. Agric. Chem. Soc. Jpn.* (Nippon Nogeikagaku Kaishi) 58(2):145-151.

Hill, A.S., Rings, R.W., Swier, S.R. and Roelofs, W.L. 1979. Sex pheromone of the black cutworm moth, *Agrotis ipsilon. J. Chem. Ecol.* 5:439-457.

Hiltibran, R. C. 1967. Effects of some herbicides on fertilized fish eggs and fry. *Trans. Am. Fish. Soc.* 96:414-416.

Hiltibran, R. C. 1969. Oxygen and phosphate metabolism of bluegill liver mitochondria in the presence of 2,4-dichlorophenoxyacetic acid derivatives. *Trans. Ill. State Acad. Sci.* 62(2):175-180.

Hiltibran, R. C. and Turgeon, A. J. 1977. Creeping bentgrass response to aquatic herbicides in irrigation water. *J. Environ. Qual.* 6(3):263-267.

Hoitink, H.A.J. and Fahy, P.C. 1986. Basis for control of soilborne plant pathogens with composts. *Ann. Rev. Phytopathol.* 24:93-114.

Holck, A. R. and Meek, C. L. 1987. Dose-mortality responses of crawfish and mosquitoes to selected pesticides. *J. Am. Mosq. Control Assoc.* 3(3):407-411.

Holcombe, G. W., Phipps, G. L. and Tanner, D. K. 1982. The acute toxicity of Kelthane, Dursban, disulfoton, pydrin, and permethrin to fathead minnows *Pimephales promelas* and rainbow trout *Salmo gairdneri. Environ. Pollut. Ser. A Ecol. Biol.* 29(3):167-178.

Holmes, J.J. and Davison, J.A. 1984. Integrated pest management for arborist: Implementation of a pilot program. *J. Arbor.* 10(3):65-70.

Holt, E.C. 1969. Turfgrass under warm, humid conditions. in Hanson, A.A. and Juska, F.V. (Eds) *Turfgrass Science* Agron. Monogr. 14:513-528. Am. Soc. Agron., Madison, WI

Hooper, F. N. 1953. The effect of applications of pelleted 2,4-D upon the bottom fauna of Kent Lake, Oakland County, Michigan. *Proc. N.C. Weed Control Conf.* 15:41.

Hopkin, R. and Kain, J. M. 1978. The effects of some pollutants on the survival, growth and respiration of *Laminaria hyperborea. Estuarine Coastal Mar. Sci.* 7(6):531-553.

Horsley, S. W. and Moser, J. A. 1990. Monitoring ground water for pesticides at a golf course - A case study on Cape Cod, Massachusetts. Ground Water Monit. Rev. 10(1):101-108.

Huang, J. C. and Gloyna, E. F. 1968. Effect of organic compounds on photosynthetic oxygenation-I. Chlorophyll destruction and suppression of photosynthetic oxygen production. *Water Res.* 2:347-366.

Hudson, R.H., Tucker, R.K. and Haegle, M.A. 1984. *Handbook of Toxicity to Wildlife.* U.S. Dept. Int. Fish Wildl. Serv. Resource. Publ. No. 153. 2nd ed. Washington, D.C., 90 pp.

Hughes, D. N. 1977. The Effects of Three Organophosphorus Insecticides on Zooplankton and Other Invertebrates in Natural and Artificial Ponds. M.S. Thesis, York University, Toronto, Canada. 100 pp.

Hughes, D. N., Boyer, M. G., Papst, M. H., Fowle, C. D. Rees, G. A. V. and Baulu, P. 1980. Persistence of three organophosphorus insecticides in artificial ponds and some biological implications. *Arch. Environ. Contam. Toxicol.* 9(3):269-279.

Hughes, J. S. and Davis, J. T. 1962. Comparative Toxicity to Bluegill Sunfish of Granular and Liquid Herbicides. in Proc. 16th Ann. Conf. S.E. Game Fish Commissioners. pp. 319-323.

Hughes, J. S. and Davis, J. T. 1963. Variations in toxicity to bluegill sunfish of phenoxy herbicides. *Weeds* 2(1):50-53.

Hughes, J. S. and Davis, J. T. 1964. Effects of Selected Herbicides on Bluegill Sunfish. in Proc. 18th Ann. Conf. S.E. Game Fish Commissioners. pp. 480-482.

Hurlbert, S. H., Mulla, M. S. and Wilson, H. R. 1972. Effects of an organophosphorus insecticide on the phytoplankton, zooplankton, and insect populations of freshwater ponds. *Ecol. Monogr.* 42(3):269-299.

Hurlbert, S. H., Mulla, M. S., Keith, J. O., Westlake, W. E. and Dusch, M. E. 1970. Biological effects and persistence of Dursban in freshwater ponds. *J. Econ. Entomol.* 63:43-62.

Hurto, K. A., Turgeon, A. J. and Spomer, L. A. 1980. Physical characteristics of thatch as a turfgrass growing medium. Agon. J. 72(1):165-167.

Hutson, J. L. and Wagenet, R. J. 1992. LEACHM Leaching Estimation and Chemistry Model. Computer program and documentation. Research Series No. 92-3. New York State College of Agriculture and Life Sciences. Cornell University. Ithaca, NY.

Inabinet, J. R. 1979. Environmental Impact of the South Carolina Public Service Authority's FY'76 Aquatic Weed Control Program in Lake Marion. South Carolina Dept. of Health and Environ. Control, Govt. Announce. Index 21, U.S. NTIS AD-A069 572. 60 pp.

Inglis, A. and Davis, E. L. 1972. Effects of Water Hardness on the Toxicity of Several Organic and Inorganic Herbicides to Fish. Bur. Sport Fish. Wildl. Tech. Paper No. 67, U.S.D.I. 22 pp.

Isensee, A. R. 1976. Variability of aquatic model ecosystem-derived data. In. J. Environ. Stud. 10:35-41.

Jackson, D.W., Vessels, K.J. and Potter, D.A. 1981. Resistance of selected cool and warm season turfgrasses to the greenbug *(Schizaphis graminum) HortScience* 16(4):558-559.

Jackson, T.A., Pearson, J.F. and Stucki, G. 1986. Control of grass grub, *Costelytra zealandica (Cleoptera: Scarabaeidae)* by application of the bacteria *Serratia* spp. causing honey disease. *Bull. Entomol. Res.* 76-69-79.

Jamnback, H. and Frempong-Boadu, J. 1966. Testing blackfly larvicides in the laboratory and in streams. *Bull. W.H.O.* 34:405-421.

Jarvinen, A. W. and Tanner, D. K. 1982. Toxicity of selected controlled release and corresponding unformulated technical grade pesticides to the fathead minnow *Pimephales promelas. Environ. Pollut. Ser. A* 27(3):179-195.

Jarvinen, A. W., Nordling, B. R. and Henry, M. E. 1983. Chronic toxicity of Dursban (chlorpyrifos) to the fathead minnow (*Pimephales promelas*) and the resultant acetylcholinesterase inhibition. *Ecotoxicol. Environ. Saf.* 7(4):423-434.

Jarvis, J.L. 1966. Studies of *Phyllophaga anxia (Coleoptera: Scarabaeidae)* in the sandhills area of Nebraska. *J. Kans. Entomol. Soc.* 39:410-419.

Janssen, D. and Renberg, L. 1976. Distribution and cytogenetic test of 2,4-D and 2,4,5-T phenoxyacetic acids in mouse blood tissues. *Chem. Biol. Interact.* 14:291-299.

Jirasek, J., Adamek, Z., Nguyen, X. T. and Hokman, O. 1978. Estimation of the acute toxicity of the insecticide Dursban for fish. (Stanoveni akutni toxicity insecticidu Dursban pro ryby.). *Acta Univ. Agric. Brno. Fac. Agron.* 26(3):51-56 (CZE) (ENG-ABS); Pestab:3134 (1980).

Johnson, C. R. 1976. Herbicide toxicities in some Australian anurans and the effect of subacute dosages on temperature tolerance. *Zool. J. Linn. Soc.* 59(1):79-83.

Johnson, C. R. 1977. The effects of field applied rates of five organophosphorus insecticides on thermal tolerance, orientation, and survival in *Gambusia affinis affinis* (*Pices: Poeciliidae*). *Proc. Pap. Annu. Conf. Calif. Mosq. Vector Control Assoc.* 45:56-58.

Johnson, C. R. 1978a. Herbicide toxicities in the mosquito fish, *Gambusia affinis. Proc. R. Soc. Queensl.* 89:25-27.

Johnson, C. R. and Prine, J. E. 1976. The effects of sublethal concentrations of organophosphorus insecticides and an insect growth regulator on temperature tolerance in hydrated and dehydrated juvenile western toads, *Bufo Boreas. Comp. Biochem. Physiol.* 53(2A):147-149.

Johnson, D. R. and Hansen, R. M. 1969. Effects of range treatment with 2,4-D on rodent populations. *J. Wildl. Manage.* 33(1):125-132.

Johnson, M.C., Bush, L.P. and Siegel, M.R. 1986. Infection of tall fescue with *Acremonium coenophialum* by means of callus culture. *Plant Dis.* 70:380-382.

Johnson, M.C., Dahlman, D.L., Siegel, M.R., Bush, L.P., Latch, G.C.M., Potter D.A. and Varney, D.R. 1985. Insect feeding deterents in endophyte-infected tall fescue. *Appl. Environ. Microbio.* 49(3):568-571.

Johnson-Cicalese, J.M., Hurley, R.H., Wolf, G.W. and Funk, C.R. 1989. Developing Turfgrass with Improved Resistance to Billbugs. in Sixth Int. Turf. Res. Conf. Tokyo, pp. 107-111.

Johnson, W. W. and Finley, M. T. 1980. Handbook of Acute Toxicity of Chemicals to Fish and Aquatic Invertebrates. Resour. Publ. 137, Fish Wildl. Serv., U. S. Dept. Int., Washington, D.C. 98 pp.

Joshi, P. C. and Misra, R. B. 1986. Evaluation of chemically-induced phototoxicity to aquatic organism using paramecium as a model. *Biochem. Biophys. Res. Comm.* 139(1):79-84.

Jury, W. A., Focht, D. D., Farmer, W. J. 1987. Evaluation of pesticide groundwater pollution potential from standard indices of soil-chemical adsorption and biodegradation. J. Environ. Qual. 16(4):422-428.

Juska, F.V., Cornman, J.F. and Hovin, A.W. 1969. Turfgrass under cool, humid conditions. in Hanson, A.A. and Juska, F.V. (Eds) *Turfgrass Science.* Agron. Monogr. 14:513-528. Am. Soc. Agron., Madison, WI.

Kader, H. A., Thayumanavan, B. and Krishnaswamy, S. 1976. The relative toxicities of ten biocides on *Spicodiaptomus chelospinus* Rajendran (1973) [*Copepoda: Calanoida*]. *Comp. Physiol. Ecol.* 1(3):78-82.

Kageyama, M.E. and Widell, L.R. 1989. Annual bluegrass to bentgrass conversion with turf growth retardents. in Leslie, A.R. and Metcalf, R.L. (Eds.) Integrated Pest Management for Turfgrass and Ornamentals. Office of Pesticide Programs. 1989-625-030. U.S. Environmental Protection Agency, Washington, D.C. pp 307-311.

Kamler, E. 1972. Bioenergetical aspects of the influence of 2,4-D-Na on the early development stages in carp (*Cyprinus carpio* L.). *Pol. Arch. Hydrobiol.* 19(4):451-474.

Kamler, E., Matlak, O. and Srokosz, K. 1974. Further observations on the effect of sodium salt of 2,4-D on early developmental stages of carp (*Cyprinus carpio* L.). *Pol. Arch. Hydrobiol.* 21(34):481-502.

Kamm, J.A. 1982. Use of insect sex pheromones in turfgrass management. in Niemczyk, H.D. and Joyner, B.O. (Eds) *Advances in Turfgrass Entomology.* Hammer Graphics, Piqua, OH, pp. 39-41.

Kamprath, E.J., Broome, S.W., Raja, M.E., Tonapa S., Baird, J.V. and Rice, J.C. 1973. Nitrogen Management, Plant Populations and Row Width Studies with Corn. North Carolina Agricult. Exp. Stn. Tech. Bull. No. 217. Raleigh, NC, 16 pp.

Kanazawa, J. 1983. In vitro and in vivo effects of organophosphorus and carbamate insecticides on brain acetylcholinesterase activity of fresh-water fish, Topmouth gudgeon. *Bull. Nat. Inst. Agric. Sci.* 37C:19-30.

Kaniewska-Prus, M. 1975. The effect of 2,4D-Na herbicide on oxygen consumption and survival of Simocephalus vetulus o.f. muller (Cladocera). *Pol. Arch. Hydrobiol.* 22(4):593-599.

Kane, R.T. and Smiley, R.W. 1983. Plant growth-regulating effects of systemic fungicides applied to Kentucky blue grass. *Agron. J.* 75:469-473.

Karnak, R. E. and Collins, W. J. 1974. The susceptibility to selected insecticides and acetylcholinesterase activity in a laboratory colony of midge larvae, *Chironomus tentans* (*Diptera: Chironomidae*). *Bull. Environ. Contam. Toxicol.* 12(1):62-69.

Kaya, H.K. 1985. Entomogenous nematodes for insect control in IPM systems. in Hoy, M.A. and Herzog, D.C. (Eds) *Bilogical Control in Agricultural IPM Systems.* Academic Press, New York, pp. 283-302.

Kaya, H.K. and Nelsen, C.E. 1985. Encapsulation of Steinernematid and Heterorhabditid nematodes with calcium alginate: A new approach for insect control and other applications *Environ. Entomol.* 14(5):572-574.

Keen, R.A. 1969. Turfgrass under semi-arid and arid conditions. in Hanson A.A. and Juska F.V. (Eds.) *Turfgrass Science.* Agron. Monogr. 14:513-528. Am. Soc. Agron. Madison, WI.

Keeney, D.R. 1982. Nitrogen management for maximum efficiencyd and minimum pollution. in Stevenson, F.J. (Ed.). *Nitrogen in Agricultural Soils.* Agron. Monogr. 22:605-649. Am. Soc. of Agron., Corp Sci. Soc. Am., Soil Sci. Soc. Am., Madison, WI.

Keeney, D.R. 1983. Transformations and transport of nitrogen. in Schaller, F. (Ed.). Proc. Natl. Conf. Agric. Mgmt. and Water Quality, Ames, IA, 26-29 May, 1981, pp. 48-63.

Keeney, D.R. 1986. Sources of nitrate to groundwater. *CRC Crit. Rev. Environ. Control* 16:257-304.

Keogh, R. G. and Whitehead, P. H. 1975. Observations on some effects of pasture spraying with benomyl and carbendazim on earthworm activity and litter removal *F.N.Z.J. Exp. Agric.* 3:103-104.

Khasawneh, F.E. (Ed. chair.) 1980. *The Role of Phosphorus in Agriculture.* Am. Soc. Agron., Crop Sci. Soc. Am., Soil Sci. Soc. Am., Madison, WAI, 910 pp.

Khera, K. S. and Mckinley, W. P. 1972. Pre- and postnatal studies on 2,4,5-trichlorophenoxyacetic acid, 2,4-dichlorophenoxyacetic acid and their derivatives in. *Toxicol. Appl. Pharmacol.* 22:14-28.
King, J. E. and Penfound, W. T. 1946. Effects of two of the new formagenic herbicides on bream and largemouth bass. *Ecology* 27(4):372-374.

Kimber, R.W.L. 1973. Phytotoxicity from plant residues. III. The relative effect of toxins and nitrogen immobilization on the germination and growth of wheat. *Plant Soil* 38:543-555.

King, J. 1971. Competition between established and newly sown grass species. *J. Br. Grassl. Soc.* 26:221-229.

Klausner, S.D., Zwerman, P.J. and Ellis, D.F. 1974. Surface runoff losses of soluble nitrogen and phosphorus under two systems of soil management. *J. Environ. Qual.* 3(1):42-46.

Klein, M.G. 1981a. Advances in the use of *Bacillus popilliae* for pest control. in Burges, H.D. (Ed) *Microbial Control of Pests and Plant Diseases 1970-1980.* Academic Press, London, pp. 183-192.

Klein, M.G. 1981b. Mass trapping for supression of Japanese beetles. in Mitchell, E.R. (Ed) *Management of Insect Pests with Semiochemicals.* Plenum Publishers, New York, pp. 183-190.

Klein, M.G. 1982. Biological suppression of turf insects. in Niemczyk, H.D. and Joyner, B.G. (Eds) *Advances in Turfgrass Entomology.* Hammer Graphics, Inc., Piqua, OH, pp. 91-97.

Klein, M.G. 1988. Pest management of soil-inhabiting insects with microorganisms. *Agric. Ecosys. Environ.* 24:337-349.

Klein, M. 1989. Suppression of white grubs with microorganisms and attractants. in Leslie, A.R. and Metcalf, R.L. (Eds.) Integrated Pest Management for Turfgrass and Ornamentals, Office of Pesticide Programs, 1989-625-030. U.S. Environmental Protection Agency, Washington, D.C. pp. 297-305.

Klein, R. D. 1990. Protecting the aquatic environment from the effects of golf courses. Community & Environmental Defense Associates, Maryland Line, MD. 59 pp.

Kickowski, R. Z. and Zvirgzds, J. 1971. The influence of herbicide 2,4-D-Na on respiration and survival of *Simocephalus vetulus* (O.F.Muller) (Cladocera). *Pol. Arch. Hydrobiol.* 18(4):393-400.

Kickowski, R. Z., Korde, B. and Kaniewska-Prus, M. 1977. The effect of sodium salt of 2,4-D on oxygen consumption of *Misgurnus fossilis* L. During early embryonal development. *Pol. Arch. Hydrobiol.* 24(3):413-421.

Kneebone, W. R., Kopec, D. M. and Mancino, C. F. 1992. Water requirements and irrigation. *In* Waddington, D. V., Carrow, R. N. and Shearman, (eds.). Turfgrass. ASA-CSSA-SSSA Monogr. 32. Amer. Soc. Agron., Crop Sci. Soc. Am. Soil Sci. Soc. Am. Madison, WI. pp. 441-472.

Koehler, F.A., Humenik, F.J., Johnson, D.D. Kreglow, J.M., Dressing, S.A. and Maas, R.P. 1982a. Best Management Practices for Agricultural Nonpoint Source Control II. Commercial fertilizer. USDA Coop. Agree. 12-05-300-472. EPA Interagencyd Agree. AD-12-F-0-037-0. North Carolina Agric. Ext. Serv., Raleigh, NC, 55 pp.

Koehler, F.A., Humenik, F.J., Johnson, D.D. Kreglow, J.M., Dressing, S.A. and Maas, R.P. 1982a. Best Management Practices for Agricultural Nonpoint Source Control II. Sediment. USDA Coop. Agree. 12-05-300-472. EPA Interagencyd Agree. AD-12-F-0-037-0. North Carolina Agric. Ext. Serv., Raleigh, NC, 49 pp.

Korpela, S. and Tulisalo, U. 1974. The residual contact toxicity to honey bees of eight organophosphorous insecticides on rape flowers. *Ann. Ent. Fenn.* 40(1):1-9.

Kramer, J.R., Herbes, S.E. and Allen, H.E. 1972. Phosphorus: analysis of water, biomass, and sediment. in Allen, H.E. and Kramer, J.R., (Eds.) *Nutrients in Water.* John Wiley & Sons, New York, pp. 51-100.

Kudla, A. J. 1984. Hydra reaggregation: A rapid assay to predict teratogenic hazards induced by environmental toxicity. *J. Wash. Acad. Sci.* 74(4):102-107.

Ladd, T.L., Jr. and Buriff, C.R. 1979. Japanese beetle: Influence of larval feeding on bluegrass yields at two levels of soil moisture. *J. Econ. Entomol.* 72(3):311-314.

Ladd, T.L. and Klein, M.G. 1982a. Controlling the Japanese beetle. Home Gard. Bull. No. 159. U.S. Dept. Ag. Govt. Printing Off. 14 pp.

Ladd, T.L. and Klein, M.G. 1982b. Trapping Japanese beetles with synthetic female sex pheromone and food-type lures. in Kydonieus, A.F. and Beroza, M. (Eds) *Insect Suppression with Controlled Release Pheromone Systems.* CRC Press, Boca Raton, FL.

Ladd, T.L., Klein, M.G. and Tumlinson, J.H. 1981. Phenethyl propionate + eugenol + geraniol-(3:7:3) and Japonilure: a highly effective joint lure for Japanese beetles. *J. Econ. Entomol.* 74(6):665-667.

Lal, B. and Singh, T. P. 1987a. Impact of pesticides on lipid metabolism in the freshwater catfish, *Clarias batrachus*, during the vitellogenic phase of its annual reproductive cycle. *Ecotoxicol. Environ. Saf.* 13(1):13-23.

Langford, G.S., Crosthwait, S.L. and Whittington, F.B. 1940. The value of traps in Japanese beetle control *J. Econ. Entomol.* 33(2):318-320.

Latch, G.C.M. and Christensen, M.J. 1985. Artificial infection of grasses with endophytes. *Ann. Appl. Biol.* 107:17-24.

Lee, G.F. 1973. Role of phosphorus in eutrophication and diffuse source control. in Jenkins, S.H. and Ives, K.J. (Eds.) *Phosphorus in Fresh Water and the Marine Environment.* Pergamon Press, Oxford, pp. 111-128.

Leistra, M. and Green, R.E. 1990. Efficacy of soil-applied pesticides. in Cheng, H.H. (Ed.) *Pesticides in the Soil Environment: Processes, Impacts and Modeling.* SSSA Book Series No. 2. Soil Science Society of America, Madison, WI, pp. 401-428.

Lembi, C. A. and Coleridge, S. E. 1975. Selective Toxicity of Detergents and Herbicides to Phytoplankton. Water Resourc. Res. Center, NTIS PB-250 497, Purdue University, West Lafayette, IN, 71 pp.

Leonard, R. A. 1990. Movement of pesticides into surface waters. *In* Cheng, H. H. (ed.). Pesticides in the soil environment: Processes, impacts, and modeling. SSSA Book Series No. 2. Soil Sci. Soc. Am. Madison, WI. pp. 303-349.

Leslie, A.R. 1989a. Societal problems associated with pesticide use in the urban sector. in Leslie, A.R. and Metcalf R.L. (Eds.) Integrated Pest Management for Turfgrass and Ornamentals. Office of Pesticide Programs. 1989-625-030. U.S. Environmental Protection Agency, Washington, D.C., pp. 93-96.

Leslie, A.R. 1989b. Development of an IPM program for turfgrass. in Leslie, A.R. and Metcalf R.L. (Eds.) Integrated Pest Management for Turfgrass and Ornamentals. Office of Pesticide Programs. 1989-625-030. U.S. Environmental Protection Agency, Washington, D.C., pp. 93-96.

Leslie, A.R. 1989c. Pesticide management for local government. *ICMA MIS Report* 21(8):1-14.

Leslie, A.R. and Metcalf R.L. (Eds.) 1989. Integrated Pest Management for Turfgrass and Ornamentals. Office of Pesticide Programs. 1989-625-030. U.S. Environmental Protection Agency, Washington, D.C., 337 pp.

Leuck, D.B., Taliaferro, C.M., Burton, G.W., Burton, R.L. and Bowman M.C. 1968. Resistance in bermudagrass to the fall armyworm. *J. Econ. Entomol.* 61(5):1321-1322.

Levy, R. and Miller, T. W., Jr. 1978. Tolerance of the planarian *Dugesia dorotocephala* to high concentrations of pesticides and growth regulators. *Entomophaga* 23(1):31-34.

Lichtenstein, E. P., Liang, T. T. and Anderegg, B. N. 1973. Synergism of insecticides by herbicides. *Science* 181:847-849.

Linacre, E. T. 1977. A simple formula for estimation evaporation rates in various climates, using temperature data alone. Agricult. Meteor. 18:409-424.

Lincoln, C. and Blair, B.D. 1977. Extension entomology: A critique. *Ann. Av. Entomol.* 22:139-155.

Linden, E., Bengtsson, B. E., Svanberg, O. and Sundstrom, G. 1979. The acute toxicity of 78 chemicals and pesticide formulations against two brackish water organisms, the bleak (*Alburnus alburnus*) and the *Harpacticoid nl. Chemosphere* 8(11/12)843-851.

Liu, D. H. W. and Lee, J. M. 1975. Toxicity of Selected Pesticides to the Bay Mussel (*Mytilus edulis*). Ecol. Res. Ser., EPA-660/3-75-016, U.S. NTIS, PB-243 221. Natl. Environ. Res. Center, U.S. EPA, Corvallis. 102 pp.

Loehr, R.C. 1974. Characteristics and comparative magnitude of nonpoint sources. *J. Water Pollut. Control Fed.* 46:1849-1970.

Logan, T. J., Davidson, J. M., Baker, J. L. and Overcash, M. R. 1987. Effects of conservation tillage on groundwater quality. Lewis Publishers, Inc. Chelsea, MI. 292 pp.

Lorz, H. W., Glenn, S. W., Williams, R. H., Kunkel, C. M., Norris, L. A. and Loper, B. R. 1979. Effects of Selected Herbicides on Smolting of Coho Salmon. Ecol. Res. Ser., EPA-600/3-79-071, Corvallis Environ. Res. Lab., U.S. EPA, Corvallis, OR, 102 p.

Macek, K. J., Hutchinson, C. and Cope, O. B. 1969. The effects of temperature on the susceptibility of bluegills and rainbow trout to selected pesticides. *Bull. Environ. Contam. Toxicol.* 4(3):174-183.

Macek, K. J., Walsh, D. F., Hogan, J. W. and Holz, D. D. 1972. Toxicity of the insecticide Dursban to fish and aquatic invertebrates in ponds. *Trans. Am. Fish. Soc.* 101(3):420-427.

Mackay, D. and Stiver, W. 1991. Predictability and environmental chemistry. *In* Grover, R. and Cessna, A. J. (eds.). Environmental chemistry of herbicides. Vol. 2. CRC Press. Boca Raton, FL., pp. 281-297.

MacPhee, C. and Ruelle, R. 1969. Lethal Effects of 1888 Chemicals Upon Four Species of Fish from Western North America. Univ. of Idaho Forest, Wildl. Range Exp. Station Bull. No. 3, Moscow, ID, 112 pp.

Madison, J.H. 1982. *Principles of Turfgrass Culture.* Robert E. Krieger Publishing Co. Melbourne, FL 431 pp.

Maly, M. and Ruber, E. 1983. Effects of pesticides on pure and mixed species cultures of salt marsh pool algae. *Bull. Environ. Contam. Toxicol.* 30(4):464-472.

Mansell, R.S., McKenna, P.J., Flaig. E. and Hall, M. 1985. Phosphate movement in columns of sandy soil from a wastewater-irrigated site. *Soil Sci.* 140(1):59-68.

Marshall, C. D. and Rutschky, C. W., III. 1974. Single herbicide treatment: Effect on the diversity of aquatic insects in Stone Valley Lake, Huntingdon County, PA. *Proc. Pa. Acad. Sci.* 48:127-131.

Mathias, E.L., Bennett, O.L., Jung, G.A. and Lundberg, P.E. 1971. Effect of two growth regulating chemicals on yield and water use of three perennial grasses. *Agron. J.* 63:480-483.

Matlak, O. 1972. *Sodium* salt (2,4-D) related to embryo and larval development to carp. *Pol. Arch. Hydrobiol.* 19(4):437-449.

Mazur, A.r. 1988. Influence of plant growth regulators on transition of bermudagrass putting green overseeded with perennial ryegrass. *J. Am. Soc. Hort. Sci.* 113(3):367-373.

Mccorkle, F. M., Chambers, J. E. and Yarbrough, J. D. 1977. Acute toxicities of selected herbicides to fingerling channel catfish, *Ictalurus punctatus. Bull. Environ. Contam. Toxicol.* 18(3):267-270.

Meehan, W. R., Norris, L. A. and Sears, H. S. 1974. Toxicity of various formulations of 2,4-D to salmonids in southeast

Alaska. *J. Fish. Res. Board Can.* 31(4):480-484.

Meinhold, V. H., Duble, R. L., Weaver, R. W. and Holt, E. C. 1973. Thatch accumulation in bermudagrass turf in relation to management. Agron. J. 65(5):833-835.

Metcalf, R.L. 1980. Changing role of insecticides in crop protection. *Ann. Rev. Entomol.* 25:219-256.

Metcalf, R.L. 1989. Insect resistance to insecticides. in Leslie, A.R. and Metcalf, R.L. (Eds.) Integrated Pest Management for Turfgrass and Ornamentals, Office of Pesticide Programs 1989-625-030. U.S. Environmental Protection Agency, Washington, D.C. pp. 3-44.

Meyer, W.A. 1982. Breeding disease-resistant cool-season turfgrass cultivars for the United States. *Plant Dis.* 66(4):341-344.

Meyer, W.A. and Funk, C.R. 1989. Progress and benefits to humanity from breeding cool-season grasses for turf. In Sleper, D.A., Asay, K.H. and Pedersen, J.F. (Eds.) *Contributions from Breeding Forage and Turf Grasses.* CSSA Spec. Publ. No. 15. Crop Sci. Soc. Am., Madison, WI pp. 31-48.

Miller, S.A. 1988. Biotechnology-based disease diagnosis. *Plant Dis.* 72:188.

Miller, S.A. and Martin, R.R. 1988. Molecular diagnosis of plant disease. *Ann. Rev. Phytopathol.* 26:409-432.

Miller, S.A., Grothaus, G.D., Peterson, F.P., Rittenburg, J.H., Plumley, K.A. and Lankow, R.K. 1989. Detection and monitoring of turfgrass pathogens by immunoassay. in Leslie, A.R. and Metcalf, R.L. (Eds) Integrated Pest Management for Turfgrass and Ornamentals. Office of Pesticide Programs 1989-625-030. U.S. EPA, Washington D.C., pp. 109-120

Miller, W. E., Peterson, S. A., Greene, J. C. and Callahan, C. A. 1985. Comparative toxicology of laboratory organisms for assessing hazardous waste sites. *J. Environ. Qual.* 14(4):569-574.

Milthrope, F.L. 1961. The nature and analysis of competition between plants of different species in *Mechanisms in Biological Competition. Symp.* Soc.Exp.Biol. No. 15. Academic Press, New York, pp. 330-355.

Minner, D.D. and Butler, J.D. 1985. Drought Tolerance of Cool Season Turfgrasses in Lemaire, F.L. (Ed) Proc. Fifth Int. Turf. Res. Conf., Angers, France pp. 199-212.

Minner, D.D., Dernoeden, P.H., Wehner, D.J. and McIntosh, M.S. 1983. Heat tolerance screening of field-grown cultivars of Kentucky bluegrass and perennial ryegrass. *Agron. J.* 75(5):772-775.

Mitchell, W.H., Morchart, A.L., Cotnoir, L.J. Hesseltine, B.B. and Langston, D.N. III 1978. Effect of soil mixtures and irrigation methods on leaching of N in golf greens. *Agron. J.* 70(1):29-35.

Moffett, J. O. and Morton, H. L. 1972. Toxicity of some herbicidal sprays to honey bees. *J. Econ. Entomol.* 65(1):32-36.

Molyneux, A.S. 1984. The Influence of Temperature on the Infectivity of Hererorhabditid and Steinernematid Nematodes for Larvae of the Sheep Blowfly, *Lucilia cuprina.* Proc. 4th Austral. Appl. Entomol. Res. Conf., pp. 344-351.

Molyneaux, A.S. and Bedding, R.A. 1984. Influence of soil texture and moisture on the infectivity of *Heterorhabditis sp DI and Steinernema glaseri* for larvae of the sheep blowfly. *Nematologica* 30:358-365.

Morris, O.N. 1987. Evaluation of the nematode, *Steinernema feltiae* Filipjev, for the control of the flea beetle, *Phyllotreta cruciferae (Goeze)(Cleoptera Chrysomelidae) Can. Entomol.* 119:95-102.

Morton, T.G., Gold, A.J. and Sullivan, W.M. 1988. Influence of overwatering and fertilization on nitrogen losses from home lawns, *J. Environ. Qual.* 17(1):124-130.

Mosdell, D.K. and Schmidt, R.E. 1985. Temperature and Irrigation Influences on Nitrate Losses of *Poa pratensis* L. Turf. in Proc. Fifth Int. Turf. Res. Conf. Angers, France, pp. 487-494.

Mount, D. I. and Stephan, C. E. 1967. A method for establishing acceptable toxicant limits for fish--malathion and the butoxyethanol ester of 2,4-D. *Trans. Am. Fish. Soc.* 96(2):185-193.

Mount, G. A., Lowe, R. F., Baldwin, K. F., Pierce, N. W. and Savage, K. E. 1970. Ultra-low volume aerial sprays of promising insecticides for mosquito control. *Mosq. News* 30(3):342-346.

Muirhead-Thomson, R. C. and Merryweather, J. 1969. Effect of larvicides on Simulium eggs. *Nature* 221:858-859.

Mulla, M. S. and Khasawinah, A. M. 1969. Laboratory and field evaluation of larvicides against chironomid midges. *J. Econ. Entomol.* 62(1):37-41.

Munson, R.D. 1982. Soil Fertility, fertilizers, and plant nutrition. In Kilmer, V.J. (Eds.) *Handbook of Soils and Climate in Agriculture*. CRC Press, Boca Raton, FL, pp. 269-293.

Murphy, S. R. 1990. Aquatic Toxicity Information Retrieval (AQUIRE): A Microcomputer Database. System documentation. Spectrum Research, Inc. Duluth, MN. 37 pp.

Murray, J. J. and Powell, J. B. 1979. Turf. in Buckner, R. C. and Bush, L.P. (Eds.). *Tall Fescue*. Argon. Monogr. 20:293-306. Am. Soc. Agron., Crop Sci. Soc. Am., Soil Sci. Soc. Am., Madison, WI.

Murphy, S. R. and Balogh, J. C. 1992. DATATOX™: Toxicity & chemical fate personal Computer system. Spectrum Research, Inc., Duluth, MN. 66 pp. and software.

Naqvi, S. M. Z. 1973. Toxicity of twenty-three insecticides to a tubificid worm *Branchiura sowerbyi* from the Mississippi Delta. *J. Econ. Entomol.* 66(1):70-74.

National Academy of Sciences, 1969. *Eutrophication: Causes, Consequences and Correctives*. National Academy Sciences, Washington, D.C.

National Research Council. 1978. *Nitrates: An Environmental Assessment*. National Academy of Sciences, Washington, D.C.

Nelson, E.B. 1988. Biological control of Pythium Blight and Brown Patch of creeping bentgrass. *1988 Cornell Res. Rep.* 2:44-47.

Nelson E.B. and Craft, C.M. 1989a. Evaluation of bacterial antagonists for the biological control of Pythium Blight of turfgrass. *1989 Cornell Res. Rep.* 3:73-77.

Nelson E.B. and Craft, C.M. 1989b. Biological control of Dollar Spot on a creeping bentgrass/annual bluebrass putting green. *1989 Cornell Res. Rep.* 3:68-72.

Nelson E.B. and Craft, C.M. 1990a. Use of disease-suppressive top-dressing for the control of Dollar Spot (*Sclerotinia homoeocarpa*) on a creeping bentgrass putting green. *Phytopathol.* 80:122.

Nelson E.B. and Craft, C.M. 1990b. Application of top-dressings amended with composts and organic fertilizers for the suppression of Brown Patch on a creeping bentgrass putting green. *Phytopathol.* 80:122.

Nelson, E.B. and Craft, C.M. 1991. Introduction and establishment of strains of *Enterobacter cloacae* in golf course turf for the biological control of dollar spot. *Plant Dis.* (in press)

Nelson, J. H. and Evans, E. S., Jr. 1973. Field Evaluation of the Larvicidal Effectiveness, Effects on Nontarget Species and

Environmental Residues of a Slow-release Polymer Formulation of Chlorpyrifos March-October 1973. U.S. NTIS AD/A-002 054. 188 p.

Nelson, J. H., Stoneburner, D. L., Evans, E. S., Jr., Pennington, N. E. and Meisch, M. V. 1976. Diatom diversity as a function of insecticidal treatment with a controlled-release formulation of chlorpyrifos. *Bull. Environ. Contam. Toxicol.* 15(5):630-634.

Nelson, K.E., Turgeon, A.J., and Street, J.R. 1980. Thatch influence on mobility and transformation of nitrogen carriers applied to turf. *Agron. J.* 72(3):487-492.

Newman, E.I. and Miller, M.H. 1977. Allelopathy among some British grassland species. II. Influence of root exudates on phosphorus uptake. *J. Ecol.* 65(2):399-411.

Newman E.I. and Rovira, A.D. 1975. Allelopathy among some British grassland species. *J. Ecol.* 63(3):727-737.

Newton, P.J. Johnson-Cicalese, J.M. and Halinsky, P.M. 1987. The good & bad of endophytes. *Greenworld* 17(2):1-6.

Nielsen, A.P. and Wakefield, R.C. 1975. Effects of growth retardants on the top growth of turfgrass. *Proc. Northeast. Weed Sci. Soc.* 29:403-408.

Nielsen, A.P. and Wakefield, R.C. 1978. Competitive effects of turfgrass on the growth of ornamental shrubs. *Agron. J.* 70(1):39-42.

Nielsen, D.R., Bigger, J.W. and Wierenga, P.J. 1982. Nitrogen transport processes in soil. in Stevenson, F.J. (Ed.) *Nitrogen in Agricultural Soils*. Agron. Monogr. 22:423-448. Am. Soc. Agron. Crop Sci. Soc. Am., Soil Sci. Soc. Am., Madison, WI.

Nielsen, D.R., Wierenga, P.J. and Bigger, J.W. 1983. Spatial soil variability and mass transfers from agricultural soils. in Nelson, D.W., Tanji, K.K. and Elrick, D.E. (Eds.). *Chemical Mobility and Reactivity in Soil Systems*. Soil Sci Soc. Am. Special Pbl. No. 11. Madison, WI, pp. 65-78.

Nilsen, K.N. and Hodges, C.F. 1980. Photomorphogenically defined light and resistance of *Poa pratensis* to *Dreshslera sorokiniana*. *Plant Physiol* 65(5):569-573.

Nilsen, K.N., Hodges, C.F. and Madsen, J.P. 1979a. Enhanced *Drechslera sorokiniana* leaf spot expression of *Poa pratensis* in response to photoperiod and blue-bias light. *Physiol. Plant Pathol.* 14:57-69.

Nilsen, K.N., Hodges, C.F. and Madsen, J.P. 1979b. Pathogenesis of *Drechslera sorokiniana* leaf spot on progressively older leaves of *Poa pratensis* as influenced by photoperiod and light quality. *Physiol. Plant Pathol.* 15:171-176.

Nishiuchi, Y. 1974. Control effect of pesticide to duckweed. *Bull. Agric. Chem. Insp. Stn.* (14):69-72.

Nishiuchi, Y. 1980a. Toxicity of formulated pesticides to fresh water organisms. LXXIV. *Suisan Zoshoku* 28(2):107-112.

Nishiuchi, Y. and Yoshida, K. 1972. Toxicities of pesticides to some fresh water snails. *Bull. Agric. Chem. Insp. Stn.* (12):86-92.

Norberg, T. J. and Mount, D. I. 1985. A new fathead minnow (*Pimephales promelas*) subchronic toxicity test. *Environ. Toxicol. Chem.* 4(5):711-718.

Norland, R. L., Mulla, M. S., Pelsue, F. W. and Ikeshoji, T. 1974. Conventional and new insecticides for the control of chironomid midges. *Proc. Ann. Conf. Calif. Mosq. Control Assoc.* 42:181-183.

Norton, G.A. 1982. Crop protection decision making--An overview. in Austing, R.B. (Ed) *Decision Making in the Practice of Crop Protection*. Monogr. No. 25. Br. Crop Prot. Counc., London, pp. 3-11.

Nus, J.L. and Hodges, C.F. 1985. Effect of water stress infection by *Ustilago striiformis or Urocystis agropyri* on leaf turgor and water potentials of Kentucky blue grass. *Crop. Sci.* 25(2):322-326.

Nyrop, J.P., Huber, B and Wolf W. 1989. Knowledge based systems for use in integrated pest management: Requirements, pitfalls, and opportunities. in Leslie, A.R. and Metcalf, R.L. (Eds) Integrated Pest Management for Turfgrass Ornamentals. Office of Pesticide Programs. 1989-625-030. U.S. Environmental Protection Agency, Washington, D.C., pp. 319-330.

O'Brien, M. C. and Prendeville, G. N. 1979. Effect of herbicides on cell membrane permeability in Lemna minor. *Weed Res.* 19(6):331-334.

O'Leary, A.L., O'Leary, D.J. and Woodhead, S.H. 1988. Screening potential bioantagonists against turf pathogens. *Phytopathol.* 78:1593.

Olsen, S.R. and Khasawneh, F.E. 1980. Use and limitations of physical-chemical criteria for assessing the status of phosphorus in soils. in Khasawneh, F.E. (Ed. chair.) *The Role of Phosphorus in Agriculture.* Am. Soc. Agron., Crop Sci. Soc. Am., Soil Sci. Soc. Am., Madison, WI pp. 361-410.

Omkar and Shukla, G. S. 1984. Toxicity of the herbicide 2,4-D-Na to two species of freshwater prawn of the genus *Macrobrachium. Acta Hydrochim. Hydrobiol.* 12(3):285-289.

Overland, L. 1966. The role of allelopathic substances in the "smother crop" barley. *Am.J. Bot.* 53:423-432.

Palawski, D. U. and Knowles, C. O. 1986. Toxicological studies of benomyl and carbendazim in rainbow trout, channel catfish and bluegills. *Environ. Toxicol. Chem.* 5(12):1039-1046.

Palmer, C. M. and Maloney, T. E. 1955. Preliminary screening for potential algicides. *Ohio J. Sci.* 55(1):1-8.

Peters, E.J. 1968. Toxicity of tall fescue to rape and birdsfoot trefoil seeds and seedlings. *Crop. Sci.* 8L650-653.

Peterson, R. H. 1976. Temperature selection of juvenile atlantic salmon (*Salmo salar*) as influenced by various toxic substances. *J. Fish. Res. Board Can.* 33(8):1722-1730.

Petrakis, J. 1981. Controlling the Japanese beetle without spraying *Golf Course Manage.* 49(6):48.

Petrovic, A.M., Hummel, N.W. and Carroll, M.J. 1986. Nitrogen source effects on nitrate leaching from late fall nitrogen applied to turfgrass. *Agron. Abstr.* p. 137.

Petrovic, A.M. 1990. The fate of nitrogen fertilizers applied to turfgrass. *J. Environ. Qual.* 19(1):1-4.

Phipps, G. L. and Holcombe, G. W. 1985. A method for aquatic multiple species toxicant testing: Acute toxicity of 10 chemicals to 5 vertebrates and 2 invertebrates. *Environ. Pollut. Ser. A Ecol. Biol.* 38(2):141-157.

Poe, S.L. 1981. An overview of integrated pest management. *HortScience* 16:501-506.

Poinar, G.O., Jr. 1979. *Nematodes for Biological Control of Insects.* CRC Press, Boca Raton, FL, 277 pp.

Poinar, G.O. Jr and Georgis, R. 1989. Biological control of social insects with nematodes. in Leslie A.R. and Metcalf, R.L. (Eds) Integrated Pest Management for Turfgrass and Ornamentals. Office of Pesticide Programs. 1989-625-030. EPA, Washington, D.C. pp. 255-269.

Polinka, J.B. 1960a. Effect of lime applications on soil on Japanese beetle larval populations. *J. Econ. Entomol.* 53:476-477.

Polinka, J.B. 1960b. Grub populations in turf varies with pH levels in Ohio soils. *J. Econ. Entomol.* 53:860-863.

Poorman, A. E. 1973. Effects of pesticides on *Euglena gracilis.* I. Growth studies. *Bull. Environ. Contam. Toxicol.* 10(1):25-28.

Potter, D.A. 1980. Flight activity and sex attraction of northern and southern masked chafers in Kentucky turfgrass. *Ann. Entomol. Soc. Am.* 73(4):414-417.

Potter, D.A. 1982. Influence of feeding by grubs of the southern masked chafer on quality and yield of Kentucky bluegrass. *J. Econ. Entomol.* 75(1):21-24.

Potter, D.A. 1986. Urban landscape pest management. in Bennet, G.W. and Owens, J.M. (Eds.) *Advances in Urban Pest Management,* Van Nostrand Reinhold, New York, pp. 219-252.

Potter, D. A., Cockfield, S.D. and Morris, T. A. 1989. Ecological side effects of pesticide and fertilizer use on trufgrass. in Leslie, A. R. and Metcalf, R.L. (Eds.). Integrated Pest Management for Turfgrass and Ornamentals. Office of Pesticide Programs, 1989-625-030. U.S. Environmental Protection Agency, Washington, D.C., pp. 33-44.

Pratt, P.F. (Chairman). 1985. Agriculture and Groundwater Quality. Council for Agricultural Science and Technology. CAST Report No. 103, 62 pp.

Presing, M. and Ponyi, J. E. 1986. Studies on the acute and chronic effect of a 2,4-D-containing herbicide (Dikonirt) on *Eudiaptomus gracilis* (G.O. Sars) (Crustacea, Copepoda). *Arch. Hydrobiol.* 106(2):275-286.

Pritchard, J. B. and James, M. O. 1979. Determinants of the renal handling of 2,4-dichlorophenoxyacetic acid by winter flounder. *J. Pharmacol. Exp. Ther.* 208:280-286.

Quinn, S. A., Cardarelli, N. F. and Gangstad, E. O. 1977. Aquatic herbicide chronicity. *J. Aquat. Plant Manage.* 15:74-76.

Raupp, M.J. and Noland, R.M. 1984. Implementing landscape plant management programs in institutional and residential settings. *J. Arbor* 11(12):349-355.

Raupp, M.J., Smith M.F. and Davidson, J.A. 1989. Educational, environmental and economic impacts of integrated pest management programs for landscape plants. in Leslie, A.R. and Metcalf, R.L. (Eds) Integrated Pest Management for Turfgrass and Ornamentals. Office of Pesticide Programs, 1989-625-030. U.S. EPA, Washington, D.C. pp. 77-83.

Rawls, C. K. 1977. Field studies of shell regrowth as a bioindicator of eastern oyster (*Crassostrea virginica* Gmelin) response to 2,4-D BEE in Maryland tidewaters. *Chesapeake Sci.* 18(3):266-271.

Read, J.C. and Camp, B.J. 1986. The effect of the fungal endophyte *Acremonium coenophialum* in tall fescue on animal performance, toxicity and stand maintenance. *Agron. J.* 78:848-850.

Reardon, R., McManus, M. Kolodny-Hirsh, D. Tichenor, R., Raupp, M. Schwalbe, C., Webb, R. and Meckley, P. 1987. Development and implementation of a gypsy moth integrated pest management program, *J. Arbor.* 13(9):209-216.

Reddy, G.Y., McLean, E.O., Hoyt, G.D. and Logan, T.J. 1978. Effects of soil, cover crop, and nutrient source on amounts and forms of phosphorus movement under simulated rainfall conditions. *J. Environ. Qual.* 7(1):50-54.

Reed D.K., Reed, G.L. and Creighton, C.S. 1986. Introduction of entomogenous namatodes into trickle irrigation system to control striped cucumber beetle, *Acalymma vittatum (Coleoptera: Chrysomelidae) J. Econ. Entomol.* 79:1330-1333.

Regniere, J., Rabb, R.L. and Stinner, R.E. 1981. *Popillia japonica:* Effect of soil moisture and texture on survival and development of eggs and first instar grubs. *Environ. Entomol.* 10(5):654-660.

Rehwoldt, R. E., Kelley, E. and Mahoney, M. 1977. Investigations into the acute toxicity and some chronic effects of selected herbicides and pesticides on several fresh water fish species. *Bull. Environ. Contam. Toxicol.* 18(3):361-365.

Reinert, J.A. 1972. New distribution and host record for the parasitoid *Eumicrosoma benefica*. *Flor. Entomol.* 55(3):143-144.

Reinert, J.A. 1978. Natural enemy complex of the southern chinch bug in Florida. *Ann. Entomol. Soc. Am.* 71(5):728-731.

Reinert, J.A. 1982. A review of host resistance to insects and acarines with emphasis on the southern chinch bug. in Niemczyk, H.D. and Joyner, B.G. (Eds) *Advances in Turfgrass Entomology*. Hammer Graphics, Piqua, OH, pp. 3-12.

Reinert, J.A. and Busey, P. 1984. Resistant varieties. in Walker, T.J. (Ed.) *Mole Crickets in Florida*. Fl. Agricult. Exp. Bull. No. 846. Univ. of Fla, pp. 35-40.

Reinert, J.A. and Dudeck, A.E. 1974. Southern chinch bug resistance in St. Augustine-grass. *J. Econ. Entomol.* 67(2):275-277.

Reinert, J.A. and Short, D.E. 1980. Southern Turfgrass Insect Pests with Emphasis on Mole Cricket Biology and Management. in Proc. 28th Ann. Flor. Turf. Manage. Conf, pp. 33-43.

Reinert, J.A., Busey, P. and Bilz, F.G. 1986. Old world St. Augustinegrasses resistant to the southern chinch bug *(Heteroptera: Lygaeidae)*. *J. Econ. Entomol.* 79(4):1073-1075.

Reinert, J.A., Toler, R.W., Burton, B.D. and Busey, P. 1981. Retention of resistance by mutants of "Floratam" St. Augustinegrass to the southern chinch bug and St. Augustine decline. *Crop Sci.* 21:464-466.

Rettich, F. 1977. The susceptibility of mosquito larvae to eighteen insecticides in Czechoslovakia. *Mosq. News* 37(2):252-257.

Rettich, F. 1979. Laboratory and field investigations in Czechoslovakia with fenitrothion, pirimiphos-methyl, temephos and other organophosphorous larvicides applied as sprays for control of *culex-pipiens-molestus* and ae des-cantans. *Mosq. News* 39(2):320-328.

Rhodes, I. 1968. The growth and development of some grass species under competitive stress. I. Competition between seedlings and established plants. *J. Br. Grassl. Soc.* 23:129-136.

Rhodes, R.C. and Long, J.D. 1974. Run-off and mobility studies on benomyl in soils and turf. *Bull. Environ, Contam. Toxic.* 12(4):385-393.

Rice, E.L. 1974. *Allelopathy*. Academic Press, New York.

Rice, E.L. 1976. Allelopathy and grassland improvement. in Estes, J.R. and Tyrl, R.J. (Ed) *The Grasses and Grasslands of Oklahoma*. Noble Found., Ardmore, OK., pp. 90-111.

Rice, E.L. 1979. Allelopathy--An update, *Bot. Rev.* 45(1):15-109.

Rieke, R.E. and Ellis, B.G. 1974. Effects of Nitrogen Fertilization on Nigrate Movements Under Turfgrass, in Proc. 2nd Int. Turfgrass Res. Conf., pp. 121-130.

Roberts, D. and Miller, T. A. 1970. The Effects of Diatoms on the Larvicidal Activity of Dursban November 1969 - March 1970. Entomological Special Study No. 31-002-71, U.S. Army Environ. Hygiene Agency, United States Dept. of the Army. 14 pp.

Roberts, D. R. and Miller, T. A. 1971. Effects of Polymer Formulations of Dursban and Abate on Non-target Organism Populations April-October 1970. Entomological Spec. Study No. 31-004-71, U.S. NTIS AD-729 342. U.S. Army Environmental Hygiene Agency, Edgewood Arsenal, MD, 24 pp.

Roberts, E. C., Huffine, W. W., Grau, F. V. and Murray, J. J. 1992. Turfgrass Science - Historical overview. *In* Waddington, D. V., Carrow, R. N. and Shearman, (eds.). Turfgrass. ASA-CSSA-SSSA Monogr. 32. Amer. Soc. Agron., Crop Sci. Soc. Am. Soil Sci. Soc. Am. Madison, WI. pp. 1-27.

Robertson, E. B. and Bunting, D. L. 1976. The acute toxicity of four herbicides to 0-4 hour nauplii of *Cyclops vernalis* Fisher (Copepoda, Cyclopoida). *Bull. Environ. Contam. Toxicol.* 16(6):682-688.

Robson, T.O. 1979. Perspectives of biological control of aquatic weeds in temperature climatic zones. *Aquat. Bot.* 3:125-132.

Rodgers, C. A. and Stalling, D. L. 1972. Dynamics of an ester of 2,4-D in organs of three fish species. *Weed Science* 20(1):101-105.

Rodrigues, J. D., Pedras, J. F., Rodrigues, S. D., Silva, J. A. and Klar, A. E. 1980. Tratamento de plantas aquaticas com herbicidas e insecticidas. I. Efeito sobre algumas especies de peixes das bacias dos rios piracicaba e tiete. *Rev. Agric. (Piracicaba)* 55(1/2):5-12.

Rogers, J.N., III, Miller, E.M. and King, J.W. 1987. Growth retardation of bermudagrass with metsulfuron methyl and sulfometuron methyl. *Agron. J.* 79(2):225-229.

Rose-Fricker, C.A., Meyer, W.A. and Kronstad, W.E. 1986. Inheritance of resistance to stem rust *(Puccinia graminis subsp. graminicola)* in six perennial ryegrass *(Lolium perenne) crosses*. *Plant Dis.* 70(7):678-681.

Saha, D.C., Johnson-Cicalese, J.M., Halisky, P.M., van Heemstra, M.I. and Funk, C.R. 1987. Occurrence and significance of endophytic fungi in fine fescues. *Plant Dis.* 71(11):1021-1024.

Saleh, M. S. 1988. Use of plastic formulations of chlorpyrifos and sumithion as mosquito larvicides and their delayed effects on the basal follicle numbers developed. *Anz. Schaedlingskd. Pflanzenschutz Umweltschutz* 61(1):14-17.

Sample, E.C., Soper, R.J. and Racz, G.J. 1980. Reactions of phosphate fertilizer in soils. in Khasawneh, F.E. (Ed. Chair). *The Role of Phosphorus in Agriculture*. Am. Soc. Agron., Crop Sci. Soc. Am., Soil Sci. Soc. Am., Madison, WI, pp. 263-310.

Sanders, H. O. 1969. Toxicity of Pesticides to the Crustacean Gammarus Lacustris. Tech. Paper No. 25, Bur. Sports Fish. Wildl., Fish Wildl. Serv., U.S. Dept. Int. 18 pp.

Sanders, H. O. 1970a. Toxicities of some herbicides to six species of freshwater crustaceans. *J. Water Pollut. Control Fed.* 24(8):1544-1550.

Sanders, H. O. 1972. Toxicity of Some Insecticides to Four Species of Malacostracan Crustaceans. Tech. Paper No. 66, Bur. Sports Fish. Wildl., Fish Wildl. Serv., U.S.Dept. Int. 19 pp.

Sanders, H. O. and Cope, O. B. 1966. Toxicities of several pesticides to two species of Cladocerans. *Trans. Am. Fish. Soc.* 95(2):165-169.

Sanders, H. O. and Cope, O. B. 1968. The relative toxicities of several pesticides to naiads of three species of stoneflies. *Limnol. Oceanogr.* 13(1):112-117.

Sauer, T. J., Fermanich, K. J. and Daniel, T. C. 1990. Comparison of the pesticide root zone model simulated and measured pesticide mobility under two tillage systems. J. Environ. Qual. 19(4):727-734.

Schimmel, S. C., Garnas, R. L., Patrick J. M., Jr. and Moore, J. C. 1983. Acute toxicity, bioconcentration, and persistence of AC 222,705, benthiocarb, chlorpyrifos, and fenvalerate, methyl parathion, and permethrin in in the Estuarine Environment. *J. Agric. Food Chem.* 31(1):104-113.

Schmidt, R.E. and Blaser, R.E. 1969. Ecology and turf management. in Hanson, A.A. and Juska F.V. (Eds) *Turfgrass Science.* Agron. Monogr. 14:217-239. Am. Soc. Agron., Madison, WI.

Schmiege, D.C. 1963. The feasibility of using a neoaplectanid nematode for control of some forest insect pests. *J. Econ. Entomol.* 56:427-431.

Schott, C. D. and Worthley, E. C. 1974. The Toxicity of TNT and Related Wastes to an Aquatic Flowering Plant, '*Lemna perpusilla*' Torr. Edgewood Arsenal Tech. Rep. EB-TR-74016; U.S. NTIS, AD-778 158. Edgewood Arsenal, Aberdeen Proving Grd., MD, 18 pp.

Schroeder, W.J. and Beavers, J.B. 1987. Movement of the entomogenous nematodes of the families Heterorhabditidae and Steinernematidae in soil. *J. Nematol* 19(2):257-259.

Schuler, T.R. 1987. Controlled Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs. Dept. of Environ. Programs. Washington Metropolitan Water Resources Planning Board, Washington, D.C.

Schultz, D. P. and Harman, P. D. 1974. Residues of 2,4-D in pond waters, mud, and fish, 1971. *Pestic. Monit. J.* 8(3):173-179.

Schuster, M.F., Boling, J.C. and Marony, J.J. 1971. Biological control of Rhodesgrass scale by airplane release of an introduced parasite of limited dispersing ability. in Huffaker, C.B. (Ed) *Biological Control* Plenem Press, New York, pp. 227-250.

Schweizer, E.E. 1988. New technological developments to reduce groundwater contamination by herbicides *Weed Tech.* 2(2):223-227.

Scirocchi, A. and Erme, A. D. 1980. Toxicity of seven insecticides on some species of fresh water fishes. *Riv. Parassitol.* 41(1):113-121.

Scott, J. G. and Georghiou, G. P. 1986. Malathion-specific resistance in *Anopheles stephensi* from Pakistan. *J. Am. Mosq. Control Assoc.* 2(1):29-32.

Sears, H. S. and Meehan, W. R. 1971. Residues in fish, wildlife, and estuaries. *Pestic. Monit. J.* 5(2):213-217.

Sergeant, M., Blazek, D., Elder, J. H., Lembi, C. A. and Morre, D. J. 1971. The toxicity of 2,4-D and picloram herbicides to fish. *Proc. Indiana Acad. Sci.* 80:114-123.

Sergant, M., Blazek, D., Elder, J. H., Lembi, C. A., and Morre, D. J. 1970. The Toxicity of 2,4-D and Picloram Herbicides to Fish. U.S.NTIS PB-201 099. Purdue University and Indiana State Highway Comm. JHRP, Publ. No. 24, Lafayette, IN. 22 pp.

Sharpley, A.N. 1985a. Depth of surface soil-runoff interaction as affected by rainfall, soil slope and management. *Soil Sci. Soc. Am. J.* 49(4):1010-1015.

Sheard, R.W., Haw, M.A., Johnson, G.B. and Ferguson, J.A. 1985. Mineral Nutrition of Bentgrass on Sand Rooting Systems. in Proc. Fifth Int. Turf. Res. Conf. Angers, France, pp. 469-485.

Shetlar, D.J. 1989. Entomogenous nematodes for control of turfgrass insects with notes on other biological control agents. in Leslie, A.R. and Metcalf, R.L. (Eds) Integrated Pest Management for Turfgrass and Ornamentals. Office of Pesticide Programs. 1989-625-030. US EPA, Washington, D.C. pp. 225-253.

Shetlar, D.J., Suleman, P.E. and Georgis, R. 1988. Irrigation and use of entomogenous nematodes, *Neoaplectana spp. and Heterorhabditis heliothidis* for control of Japanese peetle grugs in turfgrass. *J. Econ. Entomol.* 81(5):1318-1322.

Shim, J. C. and Self, L. S. 1973. Toxicity of agricultural chemicals to larvivorous fish in Korean rice fields. *Trop. Med.*

15(3):123-130.

Shive, J.B. Jr., and Sisler, H.S. 1976. Effects of ancymidol (a growth retardant) and triarimol (a fungicide) on the growth, sterols and gibberellins of *Phaseolus vulgaris (L.) Plant Physiol.* 57:640-644.

Short, D.E., Reinert, J.A. and Atilano, R.A. 1982. Integrated pest management for urban turfgrass culture in Florida. in Niemczyk, H.D. and Joyner B.G. (Eds) *Advances in Turfgrass Entomology*, Hammer Graphics, Inc., Piqua, OH 150pp.

Shukla, G. S. and OMKAR. 1983a. Toxicity of 2,4-D-Na salt to fresh water prawn, *Macrobrachium lamarrei* (M. Edwards). *Comp. Physiol. Ecol.* 8(4):282-284.

Shukla, G. S. and OMKAR. 1983b. Acute toxicity of insecticides to a freshwater prawn *Macrobrachium lamarrei* (M. Edwards). *Indian J. Environ. Health* 25(1):61-63.

Siefert, R. E. 1987. Effects of Dursban (chlorpyrifos) on Aquatic Organisms in Enclosures in a Natural Pond - Final report. U.S. EPA, Duluth, MN:214 P.

Siegel, M.R. Dahlman, D.L. and Bush L.P. 1989. The role of endophytic fungi in grasses: new approaches to biological control of pests. in Leslie, A.R. and Metcalf, R.L. (Eds) Integrated Pest Management for Turfgrass and Ornamentals, Office of Pesticide Programs, 1989-625-030 U.S. EPA, Washington, D.C. pp. 169-179.

Siegel, M.R. Latch, C.G.M. and Johnson, M.C. 1987. Fungal endophytes of grasses *Ann. Rev. Phytopathol.* 25:293-315.

Sigmon, C. 1979a. Oxygen consumption in *Lepomis macrochirus* exposed to 2,4-D or 2,4,5-T. *Bull. Environ. Contam. Toxicol.* 21:826-830.

Sigmon, C. 1979b. Oxygen consumption in *Daphnia pulex* exposed to 2,4-D or 2,4,5-T. *Bull. Environ. Contam. Toxicol.* 21(6):822-825.

Sigmon, C. F. 1979c. Influence of 2,4-D and 2,4,5-T on life history characteristics of *Chironomus (Diptera: Chironomidae). Bull. Environ. Contam. Toxicol.* 21:596-599.

Sikka, H. C., Butler, G. L. and Rice, C. P. 1976. Effects, Uptake, and Metabolism of Methoxychlor, Mirex, and 2,4-D in Seaweeds. EPA-600/3-76-048, Environ. Res. Lab., U.S. EPA, Gulf Breeze, FL. 39 pp.

Singh, P. K. 1974. Algicidal effect of 2,4-dichlorophenoxy acetic acid on blue-green alga *Cylindrospermum sp. Arch. Microbiol.* 97(1):69-72.

Smiley, R.W. 1983. *Compendium of Turfgrass Diseases.* The Am.Phytopath.Soc. APS Press, St. Paul MI 101 pp.

Smiley, R.W. and Craven-Fowler, M. 1984. *Leptophaeria korrae and Phialophora graminicola* associated with Fusarium blight syndrome of *Poa pratensis* in New York. *Plant Dis.* 68:440-442.

Smith, D.C. and Raupp, M.J. 1986. Economic and environmental assessment of an integrated pest management program for community-owned landscape plants. *J. Econ. Entomol.* 79(1):162-165.

Smith, G. E. and Isom, B. G. 1967. Investigation of effects of large-scale applications of 2,4-D on aquatic fauna and water quality. *Pestic. Monit. J.* 1(3):16-21.

Smolen, M.D., Humenik, F.J., Spooner, J. Dressing, S.A. and Maas, R.P. 1984. Best Management Practices for Agricultural Nonpoint Source Control. IV. Pesticides. U.S.D.A. Coop. Agree. 12-05-300-472. EPA Interagencyd Agree. AD-12-F-0-037-0. North Carolina Agricult. Ext. Serv., Raleigh NC, 87 pp.

Snyder, G.H., Burt, E.O. and Davidson, J.M. 1981. Nitrogen leaching in Bermudagrass Turf. Effect of Nitrogen Sources and Rates. in Proc. Fourth Int. Turfgrass Res. Conf. Guelph, Ontario, Canada, pp. 185-193.

Snyder, G.H., Augustin, B.J. and Davidson, J.M. 1984. Moisture sensor-controlled irrigation for reducing N leaching in bermudagrass turf. *Agron. J.* 76(6):964-969.

Solomon, K. E., Dahlgren, R. B. and Linder. R. L. 1973. Abnormal embryos in eggs of pheasants given 2,4-D or PCB. *Proc. S.D. Acad. Sci.* 52:95-99.

Somashekar, R. K. and Sreenath, K. P. 1984. Effect of fungicides on primary productivity. *Indian J. Environ. Health* 26(4):355-357.

Stadnyk, L., Campbell, R. S. and Johnson, B. T. 1971. Pesticide effect on growth and C14 assimilation in a freshwater alga. *Bull. Environ. Contam. Toxicol.* 6(1):1-8.

Staples, R. E., Kellam, R. G. and Haseman, J. K. 1976. Developmental toxicity in the rat after ingestion or gavage of organophosphate pesticides (Dipterex, Imidan) during pregnancy. *Environ. Health Persp.* 13:133-140.

Starr, J.L. 1983. Assessing nitrogen movement in the field. in Nelsen, D.W., Elrick, D.E. and Tanji K.K. (Eds.) *Chemical Mobility and Reactivity in Soil Systems.* Special Publ. No. 11. Soil Sci. Soc. Am., Madison, WI, pp. 79-92.

Starr, J.L. and DeRoo, H.C., 1981. The fate of nitrogen fertilizer applied to turfgrass. *Crop Sci.* 21(4):531-535.

Stephenson, M. and Mackie, G. L. 1986. Effects of 2,4-D treatment on natural benthic macroinvertebrate communities in replicate artificial ponds. *Aquat. Toxicol.* 9(4-5):243-251.

Stern, V.M., Smith R.F., Van Den Bosch, R. and Hagen, K.S. 1959. The integration of chemical and biological control of spotted alfalfa aphid. *AHilgardia* 29:1-154.

Stewart, B.A., Woolhiser, D.A., Wischmeier, W.H., Caro J.H. and Frere, M.H. 1975. Control of Water Pollution from Cropland: A Manual for Guideline Development. Vol 1, EPA 600/2-75-026a. U.S. EPA, Athens, GA and USDA Agric. Research Service, Washington, D.C. 111 pp.

Stewart, A.V. 1985. Perennial ryegrass seedling resistance to Argentine stem weevel. N.Z. *J. Agric. Res.* 28:403-407.

Stimmann, M.W. and Taliaferro, C.M. 1969. Resistance of selected accession of bermudagrass to phytotoxemia caused by adult tow-lined spittlebugs. *J. Econ. Entomol.* 62:(5)1189-1190.

Street, J.R. 1988. New concepts in turf fertilization. *Landscape Manage.* 2:38-46.

Streu, H.T. 1969. Some Cumulative Effects of Pesticides in the Turfgrass Ecosystem. in *Proc. Scotts Turfgrass Res. Conf.* I. Entomology, Marysville, OH, pp. 53-59.

Streu, H.T. 1973. The turfgrass ecosystem: Impact of pesticides *Bull, Entomol. Soc. Am.* 19:89-90.

Streu, H.T. and Cruz, C. 1972. Control of the chinch bug in turfgrass in the northeast with Dursban insecticide. *Down Earth,* 28(1):1-4.

Streu, H.T. and Gingrich, J.B. 1972. Seasonal activity of the winter grain mite in turfgrass in New Jersey. *J. Econ. Entomol.* 65:427-430.

Strickman, D. 1985. Aquatic bioassay of 11 pesticides using larvae of the mosquito, *Wyeomyia smithii (Diptera: Culicidae). Bull. Environ. Contam. Toxicol.* 35:133-142.

Stringer, A. and Wright, M. A. 1973. The effect of benomyl and some related compounds on *Lumbricus terrestris* and other earthworms. *Pestic. Sci.* 4:165-170.

Stringer, A. and Wright, M. A. 1976. The toxicity of benomyl and some related 2-substituted benzimidazoles to the earthworm *Lumbricus terrestris. Pestic. Sci.* 7:459-464.

Stuanes, A.O. 1984. Phosphorus sorption of soils to be used in wastewater renovation. *J. Environ. Qual.* 13(2):220-224.

Sutker, E.M. and Lucas, L.T. 1987. Biocontrol of *Rhizoctonia solani* in tall fescue turfgrass. *Phytopathol* 77:1721.

Sutton, D. L. and Bingham, S. W. 1970. Uptake and translocation of 2,4-D-1-14C in parrot-feather. *Weed Sci.* 18(2):193-196.

T&OCR 1991. Turf & Ornamental Chemicals Reference. Chemical and Pharmaceutical Press, John Wiley and Sons, New York, NY. 929 pp.

Tamura, S., Chang, C. Suzuki, A. and Kumai, S. 1969. Chemical studies on "clover sickness" Part I. Isolation and structural elucidation of two new isoflavonoids in red clover. *Agric. Biol. Chem.* 33:391-397.

Tang, C. and Young, C. 1982. Collection and identification of allelopathic compounds from the undisturbed root system of bigalta limpograss *(Hemarthria altissima) Plant Physiol.* 69(1):155-160.

Tarjan, A.C. and Busey, P. 1985. Genotypic variability of bermudagrass damage by ectoparasitic nematodes *HortScience* 20(4):675-676.

Tashiro, H. and Steinkraus, K.H. 1966. Virulence of species and strains of milky disease bacteria in the European chafer, *Amphimallon majalis (Razoumowksky) J. Invert. Pathol.* 8:382-389.

Taylor, A.W. and Kilmer, V.J. 1980. Agricultural phosphorus in the environment. in Khasawneh, F.E. (Ed. chair.). *The Role of Phosphorus in Agriculture.* Am. Soc. Agron., Cro0 Sci. Soc. Am., Soil Sci. Soc. Am., Madison, WI, pp. 545-557.

Thayer, A. and Ruber, E. 1976. Previous feeding history as a factor in the effects of temephos and chlorpyrifos on migration of *Gammarus fasciatus (Amphipoda, Crustacea). Mosq. News* 36(4):429-432.

Thirugnanam, M. and Forgash, A. J. 1977. Environmental impact of mosquito pesticides: Toxicity and anticholinesterase activity of chlorpyrifos to fish in a salt marsh habitat. *Arch. Environ. Contam. Toxicol.* 5(4):415-425.

Thursby, G. B., Steele, R. L. and Kane, M. E. 1985. Effect of organic chemicals on growth and reproduction in the marine red alga *Champia parvula. Environ. Toxicol. Chem.* 4(6):797-805.

Timmons, D.R. and Holt, R.F. 1980. Soluble N and P concentrations is surface runoff water. in Knisel, W.G. (Ed) CREAMS: A Field Scale Model for Chemical Runoff and Erosion from Agricultural/Management Systems. USDA Conservation Research Report No. 26. Washington, D.C.

Timmons, D.R., Holt, R.F. and Latterwell, J.J. 1970. Leaching of crop residues as a source of nutrients in surface runoff water. *Water Resource. Res.* 6(5):1367-1375.

Titova, A. A. 1978. Concentration of the herbicide 2,4-D by some higher water plants. *Hydrobiol. J.* 14(4):96-97.

Toler, R.W., Burton, B.D. and Grisham, M.P. 1983. Evaluation of St. Augustinegrass assessions and cultivars for resistance to *Sclerophthora macrospora. Plant Dis.* 67:1008-1010.

Toler, R.W., Beard, J.B., Grisham, M.P. and Crocker, R.L. 1985. Registration of TXSA 8202 and TXSA 8218 St. Augustinegrass germplasm resistant to panicum mosaic virus St. Augustine decline strain. *Crop Sci.* 25:371.

Tomisek, A., Reid, M. R., Short, W. A. and Skipper, H. E. 1957. Studies on the photosynthetic reaction. III. The effects of various inhibitors upon growth and carbonate-fixation in *Chlorella pyrenoidosa*. *Plant Physiol.* 32:7-10.

Tomlin, A. D. and Gore, F. L. 1974. Effects of six insecticides and a fungicide on the numbers and biomass of earthworms in pasture. *Bull. Environ. Contam. Toxicol.* 12(4):487-492.

Trofimova, M. G. 1979. Chronic effect of the herbicide Banvel-d on *Daphnia magna* Straus. *Byull. Mosk. Ova. Ispyt. Prir. Otd. Biol.* 84(3):70-77.

Tsai, S. C. 1978. Control of chironomids in milkfish (*Chanos chanos*) ponds with Abate (temephos) insecticide. *Trans. Am. Fish. Soc.* 107(3):493-499.

Tucker, R. K. and Crabtree, D. G. 1970. Handbook of Toxicity of Pesticides to Wildlife. USDI Fish and Wildlife Ser. Resource Publ. No. 84. Washington, D.C., 131 pp.

Tumlinson, J.H., Klein, M.G., Doolittle, R.E., Ladd, T.L. and Proveaux, A.T. 1977. Identification of the female Japanese beetle sex pheromone: Inhibition of male response by an enantiomer. *Science* 197:789-792.

Turner, T.R. and Waddington, D.V. 1983. Soil Test calibration for establishment of turfgrass monostands. *Soil Sci. Soc. Am. J.* 47(6):1161-1166.

Turner, T. R. and Hummel, N. W., Jr. 1992. Nutritional requirements and fertilization. *In* Waddington, D. V., Carrow, R. N. and Shearman, (eds.). Turfgrass. ASA-CSSA-SSSA Monogr. 32. Amer. Soc. Agron., Crop Sci. Soc. Am. Soil Sci. Soc. Am. Madison, WI. pp. 385-439.

USDA Agricultural Research Service. 1989a. USDA Research Plan for Water Quality. United States Dept. of Agric., Coop. State Res. Serv., State Agric. Exp. Stns. Washington D.C. 14 pp.

USDA Agricultural Research Service. 1989b. Midwest Water Quality Research Initiative Management Systems Evaluation Areas. FY 1990 Guidelines for Proporal Preparation and Submission. Agricultural Chemical Management Research: A Multiagency Focus on Groud Water Quality. United States Dept. of Agric., Coop. State Res. Serv., State Agric. Exp. Stns. Washington D.C. 17 pp.

USDA Forest Service. 1984. Pesticide Background Statements, Vol. 1: Herbicides. Agriculture Handbook No. 633 U.S. Government Printing Office, Washington, DC.

USDA Forest Service. 1989. Vegetation management in the Appalachian Mountains. Appendices. Vol. 2. Section 6. p.2.

USDA Soil Conservation Service. 1972a. Hydrology. In National Engineering Handbook, Section 4. USDA, Soil Cons. Serv., Washington D. C.

USDA Soil Conservation Service. 1972b. Soil survey of islands of Kauai, Oahu, Maui, Molokai, and Lanai, State of Hawaii. USDA Soil Conservation Service and University of Hawaii Agricultural Experiment Station. 232 pp. + maps.

USGA. 1989. Specifications for a method of putting green construction. United States Golf Association: Green Section. Far Hills, NJ. 24 pp.

Valentine, J. P. and Bingham, S. W. 1974. Influence of several algae on 2,4-D residues in water. *Weed Sci.* 22(4):358-363.

Vance, B. D. and Smith, D. L. 1969. Effects of five herbicides on three green algae. *Tex. J. Sci.* 20(4):329-337.

Van Leeuwen, E.R. and Van der Meulen, P.A. 1928. Some phases of the Japanese beetle insecticide investigations. *J. Econ. Entomol.* 21(6):805-813.

Varanka, I. 1979. Effect of some pesticides on the rhythmic adductor muscle activity of fresh-water mussel larvae. *Symp. Biol. Hung.* 19:177-196.

Varco, J.J. and Sartain, J.B. 1986. Effects of phosphorus, sulfur, calcium hydroxide and pH on growth of annual bluegrass. *Soil Sci. Soc. Am. J.* 50(1):128-132.

Vardia, H. K. and Durve, V. S. 1981a. Bioassay study on some freshwater fishes exposed to 2,4-dichlorophenoxyacetic acid. *Acta. Hydrochim. Hydrobiol.* 9(2):219-223.

Vardia, H. K. and Durve, V. S. 1981b. The toxicity of 2,4-D to *Cyprinus carpio* var. *communis* in relation to the seasonal variation in the temperature. *Hydrobiologia* 77(2):155-159.

Vardia, H. K. and Durve, V. S. 1984. Relative toxicity of phenoxy herbicides on *Lebistes* (Poecilia) *reticulatus* (Peters). *Proc. Indian Acad. Sci. Anim. Sci.* 93(7):691-695.

Vardia, H. K., Rao, P. S. and Durve, V. S. 1984. Sensitivity of toad larvae to 2,4-D and endosulfan pesticides. *Arch. Hydrobiol.* 100(3):395-400.

Vargas, J.M., Roberts, D. Danneburger, T.K., Otto, M. and Detweller, R. 1989. Biological management of turfgrass pests and the use of prediction models for more accurate pesticide applications. in Leslie, A.R. and Metcalf, R.L. (Eds) Integrated Pest Man. for Turfgrass and Ornamentals. Office of Pesticide Programs 1989-625-030. U.S. EPA, Washington, D.C. pp. 121-141.

Venkataraman, G.S. and Rajyalakshmi, B. 1972. Relative tolerance of nitrogen-fixing blue-green algae to pesticides. *Indian J. Agric. Sci.* 42(2):119-121.

Verma, D., Chouhan, M. S. and Pandey, A. K. 1984b. Effect of Weedone (a selective 2,4-D herbicide) on neuroendocrine complex of *Puntius ticto* (Ham.). *J. Environ. Biol.* 5(4):249-254.

Villani, M.G. and Wright R.J. 1981. Environmental considerations in soil insect pest management in Rimentel D. (Ed.) *Handbook of Pest Management in Agriculture*, Vol. I CRC Press, Inc., Boca Raton, FL 26 pp.

Villani, M.G. and Wright R.J. 1988a. Use of radiography in behavioral studies of turfgrass infested grub species *(Coleoptera: Scarabaeidae)* larvae infested turfgrass. *J. Econ. Entomol. Bull. Ent. Soc. Am.* 13:132-144.

Vallani, M.G. and Wright, R.J. 1988b. Entomogenous nematodes as biological control agents of european chafer and Japanese beetle *(Coleoptera: Scarabaeidae)* larvae infesting turfgrass. *J. Econ. Entomol.* 81(2):484-487.

Vittum P.J. 1984. Effect of lime applications on Japanese beetle grub populations in Massachusetts soils. *J. Econ. Entomol.* 77:687-90.

Vittum, P.J. 1985. Effect of timing of application on effectiveness of isofenphos, isazophos, and diazinon of Japanese beetle grugs in turf. *J. Econ. Entomol.* 78(1):172-180.

Voight, R. A. and Lynch, D. L. 1974. Effects of 2,4-D and dmso on procaryotic and eucaryotic cells. *Bull. Environ. Contam. Toxicol.* 12(4):400-404.

Volk, R.G. and Loeppert, R.H. 1982. Soil organic matter. in Kilmer, V.J. *Handbook of Soils and Climate in Agriculture*. CRC Press, Boca Raton, FL, pp. 211-268.

Vollenweider, R.A. and Kerekes, J. 1980. The loading concept as basis for controlling eutrophication philosophy and preliminary results of the OECD programme on eutrophication. *Prog. Water Tech.* 12:5-38.

Voronkin, A. S. and Loshakov, Y. T. 1973. Toxic effect of pesticides on *Tubifex tubifex*. *Eksp. Vodn. Toksikol.* 5:169-178.

Waddington, D.V., Turner, T.R. Duich, J.M. and Moberg, E.L. 1978. Effect of fertilization on penncross creeping bentgrass. *Soil Sci. Soc. Am. Proc.* 70(5):713-718.

Waddington, D. V. 1992. Soils, soil mixtures, and soil amendments. *In* Waddington, D. V., Carrow, R. N. and Shearman, R. C. (eds.). Turfgrass. ASA-CSSA-SSSA Monogr. 32. Amer. Soc. Agron., Crop Sci. Soc. Am. Soil Sci. Soc. Am. Madison, WI. pp. 331-383.

Waddington, D. V., Carrow, R. N. and Shearman, R. C. 1992. (eds.). Turfgrass. ASA-CSSA-SSSA Monogr. 32. Amer. Soc. Agron., Crop Sci. Soc. Am. Soil Sci. Soc. Am. Madison, WI. 805 pp.

Wagenet, R. J. and Hutson, J. L. 1986. Predicting the fate of nonvolatile pesticides in the unsaturated zone. J. Environ. Qual. 15(4):315-322.

Wagenet, R. J. and Rao, P. S. C. 1990. *In* Cheng, H. H. (ed.). Pesticides in the soil environment: Processes, impacts, and modeling. SSSA Book Series No. 2. Soil Sci. Soc. Am. Madison, WI. pp. 351-399.

Walker, W.J., Balogh, J. C., Tietge, R. M. and Murphy, S.R. 1990. *Environmental Issues Related to Golf Dourse Construction and Management.* United States Golf Association, Green Section. Far Hills, NJ, 378 pp.

Walker, W.J. and Branham, B. 1992. Environmental impacts of turfgrass fertilization. in Balogh, J.C. and Walker, W.J. (Eds) *Golf Course Management and Construction: Environmental Issues.* Lewis Publishers, Chelsea, MI, Chapter 3.

Wallace, R. R., West, A. S., Downe, A. E. R. and Hynes, H. B. N. 1973. The effects of experimental blackfly (*Diptera: Simuliidae*) larviciding with Abate, Dursban, and methoxychlor on stream invertebrates. Can. Entomol. 105(6):817-831.

Walsh, A. H. and Ribelin, W. E. 1973. The pathology of pesticide poisoning. in Ribelin, W. E. and Migaki, G. (Eds.). *The Pathology of Fishes.* University of Wisconsin Press, Madison, WI pp. 515-541; *Toxicol. Appl. Pharmacol.* 25(3):485 (1973).

Walsh, G. E. 1972. Effects of herbicides on photosynthesis and growth of marine unicellular algae. *Hyacinth Control J.* 10:45-48.

Walsh, G. E. 1983. Cell death and inhibition of population growth of marine unicellular algae by pesticides. *Aquat. Toxicol.* 3(3):209-214.

Walsh, G. E., Kelkner, J. M., Jr., and Matthews, E. 1970. Effects of Herbicides on Marine Algae. U.S. Fish Wildl. Serv., Circ. 335, Washington, D.C. pp. 10-12.

Warren, G.W. and Potter, D.A. 1983. Pathogenicity of *Bacillus popiliae* (*Cyclocephala* strain) and other milky disease bacteria in grubs of the southern masked chafer *(Coleoptera: Scarabaeidae) J. Econ. Entomol.* 76(1):69-73.

Watschke, T.L., Hamilton, G. and Harrison, S. 1988. Is Pesticide runoff from turf increasing *ALA* 9(7):43-44.

Watschke, T.L. and Mumma, R.O. 1989. The Effect of Nutrients and Pesticides Applied to Turf on the Quality of Runoff and Percolating Water. A Final Report to the U.S. Dept. Int., U.S. Geol. Sur. ER 8904. Env. Res. Res. Inst. Penn State University, University Park, PA, 64 pp.

Wauchope, R. D. 1978. The pesticide content of surface water draining from agricultural fields - A review. J. Environ. Qual. 7:459-472.

Wauchope, R. D., Buttler, T. M., Hornsby, A. G., Augustijn-Beckers, P. W. M. and Burt, J. P. 1991. The SCS/ARS/CES pesticide database for environmental decision-making. Rev. Environ. Contam. Toxicol. 123:1-155.

Wearing, C.H. 1988. Evaluating the IPM implementation process. *Ann. Rev. Entomol.* 33:17-38.

Wedding, R. T., Erickson, L. C. and Brannaman, B. L. 1954. Effect of 2,4-dichlorophenoxyacetic acid on photosynthesis and respiration. *Plant Physiol.* 29:64-69.

Wehner, D.J., Minner, D.D., Dernoeden, P.H. and McIntosh, M.S. 1985. Heat tolerance of Kentucky bluegrass as influenced by pre- and post-stress environment. *Agron. J.* 77(3):376-378.

Welch, S.M. 1984. Developments in computer-based IPM extension delivery systems. *Ann. Rev. Entomol.* 29:359-381.

Wessel, R.D. and Polinka J.B. 1952. Soil pH in relation to Japanese beetle populations. *J. Econ. Entomol.* 45:733-735.

Whitcomb, C.R. and Roberts, E.C. 1973. Competition between established tree roots and newly seeded Kentucky bluegrass. *Agron. J.* 65:126-129.

White, E.M. and Williamson, E.J. 1973. Plant nutrient concentrations in runoff from fertilized cultivated erosion plots and prairie in eastern South Dakota. *J. Environ. Qual.* 2(4):453-455.

White, J.F., Jr. 1987. The widespread distribution of endophytes in the Poaceae. *Plant Dis.* 71:340-342.

White, R.H. and Dickens, R. 1984. Thatch accumulation in bermudagrass as influenced by cultural practices. *Agron. J.* 76:19-22.

Wierzbicka, M. 1974. Influence of 2,4-D sodium salt on the survival of some copepoda species. *Pol. Arch. Hydrobiol.* 21(2):275-282.

Wilkinson, H.T. and Avenius, R. 1984. The selection of bacteria antagonistic to *Pythium* spp. pathogenic to turfgrass. *Phytopathol.* 74:812.

Wilkinson, L. 1990. SYSTAT: The system for statistics. Systat, Inc. Evanston, IL. 676 pp.

Wilkinson, S.R. and Mays, D.A. 1979. Mineral nutrition. in Buckner, R.C. and Bush, L.P. (Eds.) *Tall Fescue.* Agron. Monogr. 20:41-73. Am. Soc. Agron., Crop Sci. Soc. Am., Soil Sci. Soc. Am., Madison, WI.

Wischmeier, W. H. and Smith, D. D. 1978. Predicting rainfall erosion losses - A guide to conservation planning. USDA Handb. No. 537. U. S. Govt. Printing Office. Washington D. C.

Wolcott, G.N. 1941. The establishment into Puerto Rico of *Larra americana* Saussure. *J. Econ. Entomol.* 34(1):53-56.

Wong, P.T.W. and Baker, R. 1984. Suppression of wheat take-all and Ophiobolus patch by fluorescent pseudomonads from a Fusarium-suppressive soil. *Soil Biol. Biochem.* 16:397-403.

Wong, P.T.W. and Siviour, T.R. 1979. Control of Ophiobolus patch in *Agrostis* turf using a virulent fungi and take-all suppressive sils in pot experiments. *Ann. Appl. Biol.* 92:191-197.

Woodward, D. F. 1982. Acute toxicity of mixtures of range management herbicides to cutthroat trout. *J. Range Manage.* 35(4):539-540.

Woodward, D. F. and Mayer, F. L., Jr. 1978. Toxicity of three herbicides (butyl, isooctyl, and propylene glycol butyl ether esters of 2,4-D) to cutthroat trout and lake trout. *U.S. Fish Wildl. Serv. Tech. Paper* 97:1-6.

Worthley, E. G. and Schott C. D. 1972. The Comparative Effects of CS and Various Pollutants on Fresh Water Phytoplankton Colonies of Wolffia Papulifera Thompson. Edgewater Arsenal Technical Rept. EATR 4595, U.S. NTIS, AD 736336. 29 pp. Govt. Rept. Announc. Index:72(6).

Wright, M. A. 1977. Effects of benomyl and some other systemic fungicides on earthworms. *Ann. Appl. Biol.* 87(3):520-524.

Younger, V.B. 1985. Physiology of water use and water stress. In Gibeault V.A. and cockerham S.T. (Eds) *Turfgrass Water Conservation.* Univ of Calif. Riverside, Div. of Agric. and Natural Resources, pp. 37-43.

Zimakowska-Gnoinska, D. 1977. Toxicological and physiological aspects of the action of herbicide, sodium salt of 2,4-d on *Asellus aquaticus* L. (Isopoda). *Pol. Arch. Hydrobiol.* 24(3):389-411.

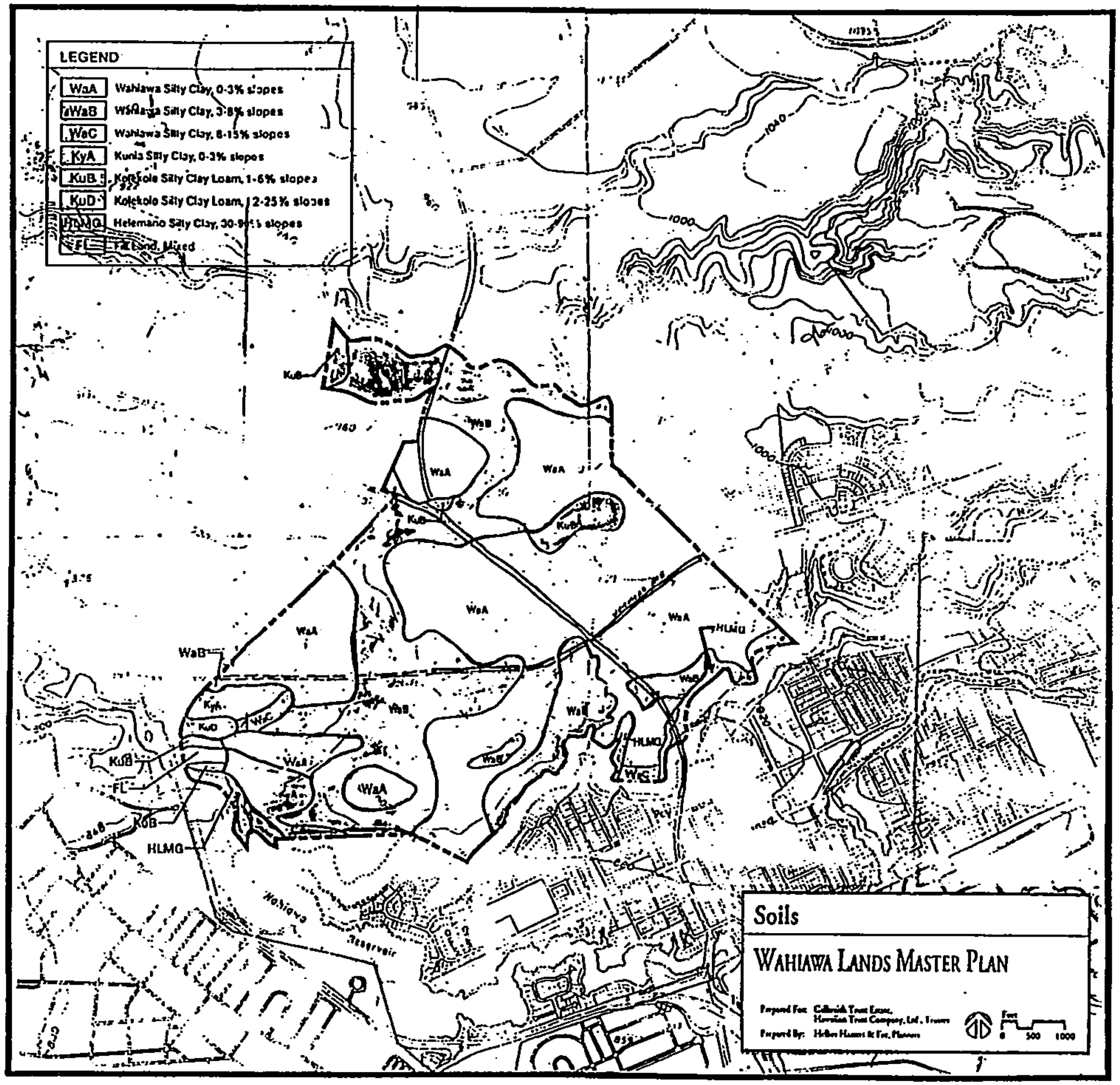
Zimmerman, R.J. and Cranshaw, W.S. 1990. Compatibility of three entomogenous nematodes *(Rhabditida)* in aqueous solutions of pesticides used in turfgrass maintenance. *J. Econ. Entomol.* 83(1):97-100.

Zwerman, P.J., Boulden, D.R., Greweling, T., Klausner, S.D., Lathwell, D.J. and Wilson, D.O. 1971. Management of Nutients on Agricultural Land for Improved Water Quality, EPA-13020-DPB-08/71. Environmental Protection Agencyu and Cornell Univ, Ithaca, New York.

APPENDIX A

APPENDIX A

FIGURE A-1 SOIL MAP OF LOCATION
SHOWING SOIL AND DISTRIBUTION OF SOILS



LEGEND
WaA Wahiawa Silty Clay, 0-3% slopes
WaB Wahiawa Silty Clay, 3-8% slopes
WaC Wahiawa Silty Clay, 8-15% slopes
KyA Kunia Silty Clay, 0-3% slopes
KuB Kolekole Silty Clay Loam, 1-6% slopes
KuD Kolekolo Silty Clay Loam, 12-25% slopes
HLMG Helemano Silty Clay, 30-90% slopes
FL Fill Land, Mixed
WaA
WaB
WaC
KuB
KuD
KyA
HLMG
FL
Wahiawa Reservoir
1000
Soils
WAHIAWA LANDS MASTER PLAN
Feet
0 500 1000

APPENDIX A

TABLE A-1 -- NATIONAL COOPERATIVE SOIL SURVEY SOIL CHARACTERISTICS

Established Series
Rev. RCH-HHS
3/78

WAHIAWA SERIES

The Wahiawa series consists of deep, well drained soils that formed in residuum and alluvium weathered from basalt. Wahiawa soils are on uplands and have slopes of 0 to 25 percent. Mean annual rainfall is about 50 inches and mean annual temperature is about 72° F.

Taxonomic Class: ~~Clayey~~ Very fine, kaolinitic, isohyperthermic ~~Tropeptic~~ Rhodic Eutrustox.

Typical Pedon: Wahiawa silty clay - pineapple. (Colors are for moist soil unless otherwise noted. All textures are "apparent field textures.")

Ap1--0 to 6 inches; very dusky red (2.5YR 2/2) silty clay, dusky red (2.5YR 3/2) dry; moderate medium, fine and very fine granular structure; very hard, friable, sticky and plastic; many roots; many medium, fine and very fine pores; many 1/8 to 1/4 inch black concretions; violent effervescence with hydrogen peroxide; medium acid (pH 5.6); abrupt smooth boundary. (2 to 6 inches thick)

Ap2--6 to 12 inches; dusky red (2.5YR 3/2) moist and dry silty clay; common dark reddish brown (2.5YR 3/4) material from the B horizon mixed by cultivation; moderate coarse subangular blocky structure; hard, firm, sticky and plastic; compact in place; many roots; few fine and very fine tubular pores; many black concretions; violent effervescence with hydrogen peroxide; medium acid (pH 5.8); abrupt wavy boundary. (5 to 8 inches thick)

B21--12 to 16 inches; dark reddish brown (2.5YR 2/4) silty clay, dark reddish brown (2.5YR 3/4) dry; moderate fine and very fine subangular blocky structure; hard, firm, sticky and plastic; common roots; common fine and very fine pores; few coarse tubular pores; many black concretions; strong effervescence with hydrogen peroxide; medium acid (pH 5.6); gradual wavy boundary. (4 to 8 inches thick)

B22--16 to 33 inches; dark reddish brown (2.5YR 2/4) silty clay, dark reddish brown (2.5YR 3/4) dry; moderate and strong fine and very fine subangular blocky structure; hard, friable, sticky and plastic; few roots; common fine and very fine tubular pores; nearly continuous pressure faces; many fine distinct black stains; few black concretions; strong effervescence with hydrogen peroxide; slightly acid (pH 6.5); diffuse wavy boundary. (14 to 20 inches thick)

B23--33 to 45 inches; dark reddish brown (2.5YR 2/4) silty clay, dark reddish brown (2.5YR 3/4) dry; moderate and strong very fine subangular blocky structure; hard, friable, sticky and plastic; common fine and very fine tubular pores; nearly continuous pressure faces; many fine distinct black stains; few black concretions; moderate effervescence with hydrogen peroxide; neutral (pH 7.1); diffuse wavy boundary. (10 to 14 inches thick)

B24--45 to 60 inches; dark reddish brown (2.5YR 2/4) silty clay, dark reddish brown (2.5YR 3/4) dry; moderate and strong very fine subangular blocky structure; hard, friable, sticky and plastic; common fine and very fine tubular pores; few fine black stains; thin patchy clay films; continuous pressure faces; many distinct slickensides up to 2 inches long; very few black concretions; slight effervescence with hydrogen peroxide; neutral (pH 6.9).

Type Location: Honolulu County, Hawaii; 21°26'16" north latitude and 158°00'16' west longitude; junction of Kamehameha Highway and entrance road to Mililani Cemetery; east 0.7 mile then 400 feet north to Dole Corporation field No. 4101, block 30.

Range in Characteristics: Black concretions are on the surface and to depths of 4 to more than 5 feet. Depth to highly weathered basalt ranges from 5 to more than 10 feet. A few boulder cores are in the lower part of the solum. Mean annual soil temperature is about 72° F. The A horizon has dry or moist value of 2 or 3 and chroma of 2 through 4 when dry or moist. The B horizon has hue of 2.5YR or 10R dry or moist, value of 2 or 3, and chroma of 3 through 6 dry and 3 through 5 moist.

Competing Series: These are the Kemoo, Kolea, Kunia and Lihue series. Kemoo soils have an argillic horizon that has thin to moderately thick continuous clay films. Koloa soils are 20 to 40 inches deep to bedrock. Kunia soils lack clay films and pressure faces in the lower part of the B horizon. Lihue soils have an ochric epipedon and do not effervesce with hydrogen peroxide in the lower part of the B horizon.

Geographic Setting: Wahiawa soils are on long, smooth relatively undissected uplands at elevations of 500 to 1,200 feet. Slopes are commonly 1 to 8 percent and range from 0 to 25 percent. The soils formed in residuum and alluvium weathered from basalt. Average annual rainfall is 40 to 60 inches. Mean annual temperature is about 72° F., average January temperature is 69° F., and average July temperature is 73° F.

Geographically Associated Soils: These are the Lahaina, Leilehua and Manana soils and the competing Kunia soils. Lahaina soils have weak structure in the A horizon and lack clay films in the B horizon. Leilehua soils have an argillic horizon, weak structure in the upper part of the B horizon and are extremely acid throughout the sola. Manana soils have an argillic horizon and have thin panlike layers at a depth of 15 -

Wahiawa Series 2

to 50 inches.

Drainage and Permeability: Well drained; slow to medium runoff; moderately rapid permeability.

Use and Vegetation: Used primarily for production of irrigated sugarcane and dryland pineapple, and small areas are in pasture. Natural vegetation is guava (Psidium guajava), koa-haole (Leucaena glauca), lantana (Lantana camara); joee (Stachytarpheta cayennensis), Japanese tea (Cassia leschenaultiana), bermudagrass (Cynodon dactylon), and honohono (Commelina diffusa).

Distribution and Extent: On the medial uplands between the Waianae and Koolau ranges on the Island of Oahu. They are moderately extensive, about 21,000 acres.

Series Established: Honolulu County, Island of Oahu, Hawaii, 1949.

National Cooperative Soil Survey
U.S.A.

HI0003

SOIL INTERPRETATIONS RECORD

MLRA(S): 158
OFP, 7-73
TROPEPTIC EUTRUSTOX, CLAYEY, KAOLINITIC, ISOHYPERTHERMIC

WAHIAWA SERIES

THE WAHIAWA SERIES CONSISTS OF WELL-DRAINED SOILS ON UPLANDS THAT ARE DEVELOPING IN RESIDUUM AND OLD ALLUVIUM DERIVED FROM BASIC IGNEOUS ROCK. THE SURFACE LAYER IS VERY DUSKY-RED AND DUSKY-RED SILTY CLAY ABOUT 12 INCHES THICK. THE SUBSOIL, 48 INCHES OR MORE THICK, IS DARK REDDISH-BROWN SILTY CLAY. DEPTH TO HIGHLY WEATHERED BASALT IS 5 TO MORE THAN 10 FEET. ELEVATIONS RANGE FROM 500 TO 1500 FEET. RAINFALL AMOUNTS TO 40 TO 60 INCHES ANNUALLY, MOST OF IT OCCURS BETWEEN NOV. AND APRIL. MEAN ANNUAL SOIL TEMPERATURE IS 73 F. SLOPES RANGE FROM 0 TO 25 PERCENT.

ESTIMATED SOIL PROPERTIES (A)

DEPTH (IN.)	USDA TEXTURE	UNIFIED	AASHTO	FRACT >3 IN (PCT)	PERCENT OF MATERIAL LESS THAN 3" PASSING SIEVE NO. 4	10	40	200	LIQUID LIMIT	PLASTICITY INDEX
0-60	SIC	MH-K		0					55-65	20-30

DEPTH (IN.)	CLAY (PCT <2MM)	MOIST BULK DENSITY (G/CM3)	PERMEABILITY (IN/HR)	AVAILABLE WATER CAPACITY (IN/IN)	SOIL REACTION (PH)	SALINITY (MMHOS/CM)	SHRINK-SWELL POTENTIAL	EROSION FACTORS K	T	WIND ERod. GROUP	ORGANIC MATTER (PCT)	CORROSIVITY STEEL	CONCRETE
0-60	60-80	0.95-1.00	2.0-6.0	0.11-0.13	6.1-7.3	-	LOW	.17	5	-	1-3	LOW	LOW

FLOODING FREQUENCY	DURATION	MONTHS	HIGH WATER TABLE DEPTH (FT)	KIND	MONTHS	CEMENTED PAN DEPTH (IN)	HARDNESS	BEDROCK DEPTH (IN)	HARDNESS	SUBSIDENCE INIT. (IN)	TOTAL (IN)	HYD GRP	POTENT'L FROST ACTION
NONE			>6.0	-		-		>60		-		B	-

SANITARY FACILITIES (B)

SEPTIC TANK ABSORPTION FIELDS	0-8%: SLIGHT 8-15%: MODERATE-SLOPE 15+%: SEVERE-SLOPE
SEWAGE LAGOON AREAS	0-7%: SEVERE-SEEPAGE 7+%: SEVERE-SLOPE,SEEPAGE
SANITARY LANDFILL (TRENCH)	0-25%: SEVERE-SEEPAGE
SANITARY LANDFILL (AREA)	0-15%: SEVERE-SEEPAGE 15+%: SEVERE-SLOPE,SEEPAGE
DAILY COVER FOR LANDFILL	0-15%: FAIR-TOO CLAYEY 8-15%: FAIR-SLOPE,TOO CLAYEY 15+%: POOR-SLOPE

BUILDING SITE DEVELOPMENT (B)

SHALLOW EXCAVATIONS	0-8%: SLIGHT 8-15%: MODERATE-SLOPE 15+%: SEVERE-SLOPE
DWELLINGS WITHOUT BASEMENTS	0-8%: SLIGHT 8-15%: MODERATE-SLOPE 15+%: SEVERE-SLOPE
DWELLINGS WITH BASEMENTS	
SMALL COMMERCIAL BUILDINGS	0-4%: SLIGHT 4-8%: MODERATE-SLOPE 8+%: SEVERE-SLOPE
LOCAL ROADS AND STREETS	0-8%: SLIGHT 8-15%: MODERATE-SLOPE 15+%: SEVERE-SLOPE
LAWNS, LANDSCAPING AND GOLF FAIRWAYS	

CONSTRUCTION MATERIAL (B)

ROADFILL	0-15%: GOOD 15-25%: FAIR-SLOPE
SAND	UNSUITED-EXCESS FINES
GRAVEL	UNSUITED-EXCESS FINES
TOPSOIL	0-8%: FAIR-TOO CLAYEY 8-15%: FAIR-SLOPE,TOO CLAYEY 15+%: POOR-SLOPE

WATER MANAGEMENT (B)

POND RESERVOIR AREA	0-8%: SEEPAGE 8+%: SLOPE,SEEPAGE
EMBANKMENTS DIKES AND LEVEES	LOW STRENGTH,SEEPAGE
EXCAVATED PONDS AQUIFER FED	NO WATER
DRAINAGE	FAVORABLE
IRRIGATION	0-3%: FAVORABLE 3+%: SLOPE
TERRACES AND DIVERSIONS	0-15%: FAVORABLE 15+%: SLOPE
GRASSED WATERWAYS	0-8%: FAVORABLE 8+%: SLOPE

REGIONAL INTERPRETATIONS

RECREATIONAL DEVELOPMENT (C)

CAMP AREAS	0-8%: MODERATE-TOO CLAYEY 8-15%: MODERATE-SLOPE,TOO CLAYEY 15+%: SEVERE-SLOPE	PLAYGROUNDS	0-2%: MODERATE-TOO CLAYEY 2-6%: MODERATE-SLOPE,TOO CLAYEY 6+%: SEVERE-SLOPE
PICNIC AREAS	0-8%: MODERATE-TOO CLAYEY 8-15%: MODERATE-SLOPE,TOO CLAYEY 15+%: SEVERE-SLOPE	PATHS AND TRAILS	0-15%: MODERATE-TOO CLAYEY 15-25%: MODERATE-SLOPE,TOO CLAYEY

CAPABILITY AND YIELDS PER ACRE OF CROPS AND PASTURE (HIGH LEVEL MANAGEMENT) (D)

CLASS-DETERMINING PHASE	CAPABILITY NIRR	CAPABILITY IRR.	SUGARCANE (TONS) NIRR	SUGARCANE (TONS) IRR.	PINEAPPLE (TONS) NIRR	PINEAPPLE (TONS) IRR.	PINEAPPLE-RATOON (TONS) NIRR	PINEAPPLE-RATOON (TONS) IRR.	PASTURE (AUM) NIRR	PASTURE (AUM) IRR.	NIRR	IRR.	NIRR	IRR.	NIRR	IRR.
0-3%	2C	1		14	43		33		8.1							
3-8%	2E	2E		14	43		33		8.1							
8-15%	3E	3E		13	40		30		6.8							
15-25%	4E			12	30		28		6.8							

WOODLAND SUITABILITY

CLASS-DETERMINING PHASE	ORD. SYM	MANAGEMENT PROBLEMS: EROSION HAZARD	EQUIP. LIMIT	SEEDLING MORT'Y.	WINDTH. HAZARD	PLANT COMPET.	POTENTIAL PRODUCTIVITY: COMMON TREES	SITE INDX	TREES TO PLANT
							NONE		

WINDBREAKS

CLASS-DETERMINING PHASE	SPECIES	HT	SPECIES	HT	SPECIES	HT	SPECIES	HT
ALL	PANAX	15	HORSETAIL CASUARINA	99	BRUSHBOX	60	MEXICAN CYPRESS	60
	OLEANDER	15	SMALLCONE IRONWOOD	80	D BLUEGUM EUCALYPTUS	30	RED IRONBARK	99
	ORANGE JESSAMINE	15	BERMUDA JUNIPER	40	CAJEPUT-TREE	50	NORFOLK-ISLAND PINE	99

WILDLIFE HABITAT SUITABILITY (E)

CLASS-DETERMINING PHASE	POTENTIAL FOR HABITAT ELEMENTS: GRAIN & SEED	GRASS & LEGUME	WILD HERB.	HARDWD TREES	CONIFER PLANTS	SHRUBS	WETLAND PLANTS	SHALLOW WATER	POTENTIAL AS HABITAT FOR: OPENLD WILDLF	WOODLD WILDLF	WETLAND WILDLF	RANGELD WILDLF
0-15%	GOOD	GOOD	GOOD	FAIR	-	GOOD	V. POOR	V. POOR	GOOD	FAIR	V. POOR	-
15-25%	FAIR	GOOD	GOOD	FAIR		GOOD	V. POOR	V. POOR	GOOD	FAIR	V. POOR	-

POTENTIAL NATIVE PLANT COMMUNITY (RANGELAND OR FOREST UNDERSTORY VEGETATION)

COMMON PLANT NAME	PLANT SYMBOL (NLSPN)	PERCENTAGE COMPOSITION (DRY WEIGHT) BY CLASS DETERMINING PHASE				
POTENTIAL PRODUCTION (LBS./AC. DRY WT): FAVORABLE YEARS						
NORMAL YEARS						
UNFAVORABLE YEARS						

FOOTNOTES

A SOIL REACTION IN SURFACE 12 INCHES OF SOILS CONTINUOUSLY USED FOR PINEAPPLE MAY BE AS LOW AS PH 4.0.
B "GUIDE FOR INTERPRETING ENGINEERING USES OF SOILS," NOV. 1971, MODIFIED TO ACCOMODATE SOILS OF HAWAII.
C BASED UPON MODIFICATION OF GUIDE SHEETS IN SOILS MEMORANDUM-69, OCT. 1968, TO ACCOMODATE SOILS OF HAWAII.
D CROP PERIOD FOR SUGARCANE IS 24 MONTHS, PINEAPPLE PLANT CROP IS 24 MONTHS AND RATOON CROP IS 12.
E GUIDES IN SOILS MEMORANDUM 74, JAN. 1972, MODIFIED TO ACCOMODATE SOILS OF HAWAII.

Established Series
Rev. RCH/HHS
5/78

KOLEKOLE SERIES

The Kolekole series consists of well drained soils that formed in alluvium and volcanic ash weathered from basic igneous material. Kolekole soils are on uplands and have slopes of 1 to 25 percent. Mean annual rainfall is about 45 inches and mean annual temperature is about 71°F.

Taxonomic Class: Fine, oxidic, isohyperthermic Ustoxic Humitropepts.

Typical Pedon: Kolekole silty clay loam - pineapple. (Colors are for moist soil unless otherwise noted. Textures are "apparent field textures.")

Ap1--0 to 4 inches; dark reddish brown (5YR 3/3) silty clay loam, reddish brown (5YR 4/4) dry; weak fine and very fine granular structure; slightly hard, very friable, slightly sticky and slightly plastic; many fine roots; many very fine interstitial pores; common very fine shiny specks; common earthy lumps that are difficult to rupture by rubbing; slight effervescence with hydrogen peroxide; extremely acid (pH 4.4); clear smooth boundary. (3 to 6 inches thick)

Ap2--4 to 12 inches; same color and texture as above; weak fine and medium subangular and weak very fine granular structure; slightly hard, very friable, slightly sticky and slightly plastic; many fine roots; common very fine tubular and interstitial pores; many very fine earthy lumps that are difficult to rupture by rubbing; about 10 percent of dark reddish brown (2.5YR 3/4) material from below; common very fine shiny specks; extremely acid (pH 4.4); clear wavy boundary. (7 to 10 inches thick)

B21--12 to 20 inches; dark reddish brown (2.5YR 3/4) silty clay loam, dark red (2.5YR 3/6) dry; moderate very fine and fine subangular and angular blocky structure; very hard, friable, sticky and plastic; common fine roots; common fine and very fine tubular pores; few fine earthy lumps; few shiny specks; medium acid (pH 5.6); gradual smooth boundary. (6 to 8 inches thick)

B22--20 to 25 inches; dark reddish brown (2.5YR 3/4) silty clay loam, dark red (2.5YR 3/6) dry; moderate very fine and fine subangular and angular blocky structure; hard, firm, sticky and plastic; few fine roots; common very fine and fine tubular pores; patchy pressure faces on peds; few very fine earthy lumps; few very fine shiny specks; strongly acid (pH 5.3); gradual smooth boundary. (2 to 7 inches thick)

B23--25 to 32 inches; same color and texture as above; moderate very fine and fine subangular blocky structure; hard, firm, sticky and plastic; few fine roots; common fine tubular pores; weak continuous pressure faces on peds; few earthy lumps; few shiny specks; very strongly acid (pH 5.0); clear smooth boundary. (6 to 8 inches thick)

B24--32 to 38 inches; dark reddish brown (2.5YR 3/4) silty clay, red (2.5YR 5/8) dry; weak fine and very fine subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; few fine roots; common very fine, fine and medium pores; few thin patchy clay films; few very fine earthy lumps; few shiny specks; very strongly acid (pH 4.8); abrupt wavy boundary. (2 to 7 inches thick)

B25bt--38 to 60 inches; dark reddish brown (5YR 3/3) silty clay loam, dark reddish brown (5YR 3/4) moist; strong very fine and fine subangular and angular blocky structure; very hard, friable, sticky and plastic; compact in place; capped by a massive, banded, brittle pan 1/16 to 3/8 inch thick that has a smooth surface; few very fine tubular pores; dark red (10R 3/6) and red (10R 4/6) continuous clay films on about 50 percent of faces of peds; continuous strong pressure faces on all peds; many weathered stones and boulders that retain original rock structure; common light colored sand grains; very strongly acid (pH 4.7).

Type Location: Honolulu County, Hawaii; at the junction of Kunia Road and Farrington Highway 5.2 miles north on Kunia Road or 0.6 mile south of Kunia Camp, 50 feet west of the highway.

Range in Characteristics: The panlike layer at the top of the Bbt horizon is at depths ranging from 15 to 50 inches, but is normally at a depth of about 25 inches. Mean annual soil temperature is 71°F.

The A horizon has value and chroma of 2 or 3 moist and 3 or 4 dry.

The B horizon above the Bbt horizon has value of 2 or 3 and chroma of 4 through 6 when moist; when dry value is 3 through 5 and chroma is 4 through 8. The Bbt horizon is silty clay loam or silty clay. A black 1/4- to 1/2-inch thick layer of decomposed roots is commonly on top of the panlike layer. The amount of highly weathered rock fragments in the Bbt horizon varies within short distances, but it normally is between 30 and 40 percent by volume. The reaction of the B horizon ranges from medium acid to extremely acid.

Competing Series: These are the Haliimaile, Kunia, Kohala, Pohakupu series. Haliimaile and Kunia soils have kaolinitic mineralogy and Haliimaile soils have temperatures less than 72°F. Pohakupu soils do not have a panlike layer in the B horizon.

Kolekole Series

<u>Geographic Setting:</u> Kolekole soils are on uplands and have slopes of 1 to 25 percent. Elevation ranges from 500 to 1,200 feet. The soils formed in old gravelly alluvium mixed with volcanic ash. Annual rainfall is 35 to 50 inches. Mean annual temperature is about 71°F., average January temperature is 69°F., and average July temperature is 76°F.

<u>Geographically Associated Soils:</u> These are the Kunia, Mahana and Wahiawa soils. Mahana soils have ashy mineralogy in the control section, and they are very strongly acid throughout the B horizon. Wahiawa soils have patchy clay films in the lower part of the B2 horizon.

<u>Drainage and Permeability:</u> Well drained; medium runoff; moderately rapid permeability above the Bbt horizon and moderate below.

<u>Use and Vegetation:</u> Irrigated sugarcane and pineapple.

<u>Distribution and Extent:</u> Medial windward slopes of the Waianae Range on the island of Oahu. This series is about 3,200 acres in extent.

<u>Series Established:</u> Honolulu County, Hawaii. Soil Survey of the Territory of Hawaii, 1949.

National Cooperative Soil Survey
U.S.A.

HI0222

SOIL INTERPRETATIONS RECORD

MLRA(S): 163
REV. SW, 9-78
USTOXIC HUMITROPEPTS, FINE, OXIDIC, ISOHYPERTHERMIC

KOLEKOLE SERIES

THE KOLEKOLE SERIES CONSISTS OF WELL DRAINED SOILS ON UPLANDS. THESE SOILS FORMED IN OLD GRAVELLY ALLUVIUM MIXED WITH VOLCANIC ASH. TYPICALLY, THE SURFACE LAYER IS DARK REDDISH BROWN SILTY CLAY LOAM ABOUT 12 INCHES THICK. THE SUBSOIL, ABOUT 48 INCHES THICK, IS DARK REDDISH BROWN SILTY CLAY LOAM AND SILTY CLAY. A COMPACT PANLIKE LAYER TYPICALLY OCCURS AT A DEPTH OF 24 TO 40 INCHES. ELEVATIONS RANGE FROM 500 TO 1200 FEET. ANNUAL RAINFALL AMOUNTS TO 35 TO 50 INCHES. MEAN ANNUAL SOIL TEMPERATURE IS 71 F. SLOPES RANGE FROM 1 TO 25 PERCENT.

ESTIMATED SOIL PROPERTIES (A)

DEPTH (IN.)	USDA TEXTURE	UNIFIED	AASHTO	FRACT >3 IN (PCT)	PERCENT OF MATERIAL LESS THAN 3" PASSING SIEVE NO. 4	10	40	200	LIQUID LIMIT	PLAS-TICITY INDEX
0-12	SICL	ML-O	A-6, A-7	0	100	100	95-100	85-100	35-45	5-15
12-38	SICL, SIC	ML-C	A-6, A-7	0	100	100	95-100	85-100	35-45	5-15
38-60	SICL	ML-L	A-6, A-7	0-10	80-95	75-85	70-85	65-85	35-45	5-15

DEPTH (IN.)	CLAY (PCT)	MOIST BULK DENSITY (G/CM3)	PERMEA-BILITY (IN/HR)	AVAILABLE WATER CAPACITY (IN/IN)	SOIL REACTION (PH)	SALINITY (MMHOS/CM)	SHRINK-SWELL POTENTIAL	EROSION FACTORS K	T	WIND ERO. GROUP	ORGANIC MATTER (PCT)	CORROSIVITY STEEL	CONCRETE
0-12	35-40	1.00-1.20	2.0-6.0	0.09-0.11	4.5-5.5	-	LOW	.17	5	-	2-4	HIGH	HIGH
12-38	35-50	1.00-1.20	4.0-6.0	0.09-0.11	4.5-6.0	-	LOW	.17					
38-60	30-40	1.30-1.40	0.6-2.0	0.10-0.12	4.5-5.5	-	LOW	.17					

FLOODING FREQUENCY	DURATION	MONTHS	HIGH WATER TABLE DEPTH (FT)	KIND	MONTHS	CEMENTED PAN DEPTH (IN)	HARDNESS	BEDROCK DEPTH (IN)	HARDNESS	SUBSIDENCE INIT. (IN)	TOTAL (IN)	HYD GRP	POTENT'L FROST ACTION
NONE			>6.0			24-40	RIPPABLE	>60		-		B	-

SANITARY FACILITIES (A)

SEPTIC TANK ABSORPTION FIELDS	1-15%: SEVERE-CEMENTED PAN 15+%: SEVERE-CEMENTED PAN, SLOPE
SEWAGE LAGOON AREAS	1-7%: SEVERE-SEEPAGE, CEMENTED PAN 7+%: SEVERE-SEEPAGE, CEMENTED PAN, SLOPE
SANITARY LANDFILL (TRENCH)	SEVERE-CEMENTED PAN, SEEPAGE, TOO CLAYEY
SANITARY LANDFILL (AREA)	1-15%: SEVERE-SEEPAGE 15+%: SEVERE-SEEPAGE, SLOPE
DAILY COVER FOR LANDFILL	1-8%: FAIR-TOO CLAYEY 8-15%: FAIR-SLOPE, TOO CLAYEY 15+%: POOR-SLOPE

BUILDING SITE DEVELOPMENT (A)

SHALLOW EXCAVATIONS	1-8%: MODERATE-CEMENTED PAN 8-15%: MODERATE-SLOPE, CEMENTED PAN 15+%: SEVERE-SLOPE
DWELLINGS WITHOUT BASEMENTS	1-8%: SLIGHT 8-15%: MODERATE-SLOPE 15+%: SEVERE-SLOPE
DWELLINGS WITH BASEMENTS	1-8%: SLIGHT 8-15%: MODERATE-SLOPE 15+%: SEVERE-SLOPE
SMALL COMMERCIAL BUILDINGS	1-4%: SLIGHT 4-8%: MODERATE-SLOPE 8+%: SEVERE-SLOPE
LOCAL ROADS AND STREETS	1-8%: SLIGHT 8-15%: MODERATE-SLOPE 15+%: SEVERE-SLOPE
LAWNS, LANDSCAPING AND GOLF FAIRWAYS	1-8%: SLIGHT 8-15%: MODERATE-SLOPE 15+%: SEVERE-SLOPE

CONSTRUCTION MATERIAL (A)

ROADFILL	1-15%: GOOD 15-25%: FAIR-SLOPE
SAND	UNSUITED-EXCESS FINES
GRAVEL	UNSUITED-EXCESS FINES
TOPSOIL	1-8%: GOOD 8-15%: FAIR-SLOPE 15+%: POOR-SLOPE

WATER MANAGEMENT (A)

POND RESERVOIR AREA	1-8%: SEEPAGE 8+%: SLOPE, SEEPAGE
EMBANKMENTS DIKES AND LEVEES	FAVORABLE
EXCAVATED PONDS AQUIFER FED	NO WATER
DRAINAGE	1-15%: FAVORABLE 15+%: SLOPE
IRRIGATION	1-8%: CEMENTED PAN 8+%: SLOPE, CEMENTED PAN
TERRACES AND DIVERSIONS	1-15%: CEMENTED PAN 15+%: SLOPE, CEMENTED PAN
GRASSED WATERWAYS	1-8%: FAVORABLE 8+%: SLOPE

REGIONAL INTERPRETATIONS

Established Series
Rev.RCM/RXS
1/78

HELEMANO SERIES

The Helemano series consists of well drained soils that formed in alluvium and colluvium from basic igneous rock. Helemano soils are on uplands with slopes of 30 to 90 percent. Mean annual rainfall is about 45 inches and mean annual air temperature is about 71° F.

Taxonomic Class: Clayey, kaolinitic, isohyperthermic Tropeptic Haplustox.

Typical Pedon: Helemano silty clay - pasture. (Colors are for moist soils unless otherwise noted. All textures are "apparent field textures.")

Ap--0 to 10 inches; dark brown (2.5YR 3/4) dry and moist silty clay; moderate very fine and fine granular structure; hard, firm, sticky and plastic; many roots; many very fine interstitial pores; neutral (pH 6.6); abrupt smooth boundary. (6 to 10 inches thick)

B21--10 to 30 inches; dark reddish brown (2.5YR 3/4) silty clay, dark red (2.5YR 3/6) dry; moderate fine subangular blocky structure; hard, friable, sticky and plastic; common roots; common tubular pores; 15 to 25 percent soft strongly weathered pebbles and stones; neutral (pH 6.6); clear smooth boundary. (12 to 20 inches thick)

B22--30 to 41 inches; dark reddish brown (2.5YR 3/4) dry and moist silty clay; moderate fine and medium subangular blocky structure; hard, friable, sticky and plastic; few fine roots; common fine tubular pores; 15 to 25 percent soft strongly weathered pebbles and stones; neutral (pH 6.6); gradual smooth boundary. (8 to 12 inches thick)

B3--41 to 60 inches; dark red (10R 3/6) silty clay red (10R 4/6) dry; moderate fine and very fine subangular blocky structure; hard, friable, sticky and plastic; few very fine roots; common fine and medium tubular pores; 25 to 50 percent soft strongly weathered pebbles and stones; slightly acid (pH 6.5), (10 to 20 inches thick)

Type Location: Honolulu County, Hawaii--21° 27' 47" north latitude and 157° 59' 59" west longitude, near Waipio Acres? From the intersection of Kamehameha Highway and the road to Kipapa School, proceed south on Kam Highway 0.2 mile, turn northeast on road toward toward the Koolau Range. Proceed 1.35 miles, turn south toward Kipapa Gulch 0.7 mile. Site location north of the road 50 feet.

Range in Characteristics: The depth to highly weathered basalt is variable but ranges from 25 to more than 60 inches. Near the toe of slopes the solum is normally over 60 inches thick and commonly stony throughout. Mean annual soil temperature is about 72° F.

The A horizon has hue of 2.5YR or 5YR. Effervescence in the A horizon ranges from none to slight.

The B horizon has hue of 2.5YR or 10R, value of 2 through 4 and chroma of 2 through 6 when moist.

Competing Series: These are the Kahana, Lahaina, Niu and Wailuku series. Kahana soils have strong structure in the B horizon and effervesce with hydrogen peroxide in the control section. Lahaina soils have weak structure in the A horizon and effervesce with hydrogen peroxide throughout. Niu soils have weak structure in the A horizon and upper B horizon and effervesce with hydrogen peroxide in the control section. Wailuku soils have 5YR hue in the B horizon and effervesce with hydrogen peroxide throughout.

Geographic Setting: Helemano soils are on sides of V-shaped gulches at elevations of 500 to 1,200 feet. Slopes range from 30 to 90 percent. The slopes are convex and are from 100 to 500 feet in length. These soils formed in colluvium and alluvium weathered from basic igneous material of the Koolau and Waianae ranges. Annual rainfall is 30 to 60 inches. Average January temperature is about 69° F.; average July temperature is about 75° F. The mean annual temperature is about 72° F.

Geographically Associated Soils: These are the Leilehua, Manana, Molokai, Wahiawa soils and the competing Lahaina soils. Leilehua soils have an argillic horizon and are extremely acid throughout the solum. Manana soils have a thin panlike layer at depths of 15 to 50 inches and have an argillic horizon. Molokai soils have a torric moisture regime and have weak structure in the A horizon. Wahiawa soils effervesce with hydrogen peroxide throughout the profile and have thin patchy clay films in the lower part of the B2 horizon.

Drainage and Permeability: Well drained; rapid to very rapid runoff; moderately rapid permeability.

Use and Vegetation: Pasture, woodland and wildlife. Natural vegetation is mainly of guava (Psidium guajava), Java plum (Eugenia cumini), Christmasberry (Schinus terebinthifolius), koa haole (Leucaena glauca), Formosa koa (Acacia confusa) and bermudagrass (Cynodon dactylon).

Distribution and Extent: In the deep gulches and drainageways in the Wahiawa basin and foothills of the Koolau and Waianae mountains. This series is of moderate extent with an area of about 28,000 acres.

Series Established: Honolulu County, Island of Oahu, Hawaii, 1971.

National Cooperative Soil Survey
U. S. A.

HELEMANO SERIES HI0022

RECREATIONAL DEVELOPMENT (C)

CAMP AREAS	0-15%: SLIGHT 8-15%: MODERATE-SLOPE 15+%: SEVERE-SLOPE	PLAYGROUNDS	0-2%: MODERATE-CEMENTED PAN 2-6%: MODERATE-SLOPE,CEMENTED PAN 6+%: SEVERE-SLOPE
PICNIC AREAS	0-8%: SLIGHT 8-15%: MODERATE-SLOPE 15+%: SEVERE-SLOPE	PATHS AND TRAILS	0-15%: SLIGHT 15-25%: MODERATE-SLOPE

CAPABILITY AND YIELDS PER ACRE OF CROPS AND PASTURE (HIGH LEVEL MANAGEMENT) (C)

CLASS-DETERMINING PHASE	CAPABILITY NIRR	CAPABILITY IRR.	SUGARCANE (TONS) NIRR	SUGARCANE IRR.	PINEAPPLE (TONS) NIRR	PINEAPPLE IRR.	PINEAPPLE, RATOON (TONS) NIRR	IRR.	PASTURE (AUM) NIRR	IRR.	NIRR	IRR.	NIRR	IRR.	NIRR	IRR.
[illegible]	3E	3C														
[illegible]	3L	3E														
[illegible]	4E	4L														

WOODLAND SUITABILITY

CLASS-DETERMINING PHASE	ORD SYM	EROSION HAZARD	EQUIP. LIMIT	SEEDLING MORT'Y.	WINDTH. HAZARD	PLANT COMPET.	COMMON TREES	SITE INDEX	TREES TO PLANT
							NONE		

WINDBREAKS

CLASS-DETERMINING PHASE	SPECIES	HT	SPECIES	HT	SPECIES	HT	SPECIES	HT
ALL	CAJEPUT-TREE	[illegible]	PANAX	[illegible]	FORMOSA KOA	[illegible]	HORSETAIL CASUARINA	[illegible]
	SHALLCONE IRONWOOD	[illegible]	NORFOLK-ISLAND PINE	[illegible]	RED IRONBARK	[illegible]	BRUSHBOX	[illegible]

WILDLIFE HABITAT SUITABILITY (C)

CLASS-DETERMINING PHASE	GRAIN & SEED	GRASS & LEGUME	WILD HERB.	HARDWD TREES	CONIFER PLANTS	SHRUBS	WETLAND PLANTS	SHALLOW WATER	OPENLD WILDLF	WOODLD WILDLF	WETLAND WILDLF	RANGELD WILDLF
0-15%	GOOD	GOOD	GOOD	FAIR	-	GOOD	V. POOR	V. POOR	GOOD	FAIR	V. POOR	-
15+%	FAIR	GOOD	GOOD	FAIR	-	GOOD	V. POOR	V. POOR	GOOD	FAIR	V. POOR	-

POTENTIAL NATIVE PLANT COMMUNITY (RANGELAND OR FOREST UNDERSTORY VEGETATION)

COMMON PLANT NAME	PLANT SYMBOL (NLSPN)	PERCENTAGE COMPOSITION (DRY WEIGHT) BY CLASS DETERMINING PHASE: ALL				
GUAVA	PSGU					
LANTANA	LACA2					
BERMUDAGRASS	CYDA					
NATAL REDTOP	RHRE					
POTENTIAL PRODUCTION (LBS./AC. DRY WT): FAVORABLE YEARS						
NORMAL YEARS						
UNFAVORABLE YEARS						

FOOTNOTES

A SOIL REACTION IN THE SURFACE 12 INCHES OF SOILS CONTINUOUSLY USED FOR PINEAPPLE MAY BE AS LOW AS PH 4.0.
B GUIDE FOR INTERPRETING ENGINEERING USES OF SOILS, NOV. 1971, MODIFIED TO ACCOMMODATE SOILS OF HAWAII.
C BASED ON MODIFICATION OF GUIDE SHEETS IN SOILS MEMORANDUM 69, OCT. 1968, TO ACCOMMODATE SOILS OF HAWAII.
D CROP PERIOD FOR SUGARCANE IS 24 MONTHS; PINEAPPLE PLANT CROP IS 24 MONTHS, AND RATOON CROP IS 12.
E

HI0181

SOIL INTERPRETATIONS RECORD

MLRA(S): 158
REV. 3-77
TROPEPTIC HAPLUSTOX, CLAYEY, KAOLINITIC, ISOHYPERTHERMIC

MELEMANU SERIES

THE MELEMANU SERIES CONSISTS OF WELL-DRAINED SOILS ON ALLUVIAL FANS AND COLLUVIAL SLOPES ON SIDES OF GULCHES. THE SURFACE LAYER IS DARK REDDISH-BROWN SILTY CLAY ABOUT 10 INCHES THICK. THE SUBSOIL, ABOUT 50 INCHES THICK, IS A DARK REDDISH-BROWN AND DARK RED SILTY CLAY. ELEVATION RANGE FROM 500 TO 1200 FEET. THE ANNUAL RAINFALL DOMINANTLY AMOUNTS TO 30 TO 60 INCHES, BUT RANGES TO 75 INCHES AT THE HIGHEST ELEVATION. THE MEAN ANNUAL SOIL TEMPERATURE IS 73 F. SLOPES RANGE FROM 10 TO 35 PERCENT.

ESTIMATED SOIL PROPERTIES (A)

DEPTH (IN.)	USDA TEXTURE	UNIFIED	AASHTO	FRACT >3 IN (PCT)	PERCENT OF MATERIAL LESS THAN 3" PASSING SIEVE NO. 4	10	40	200	LIQUID LIMIT	PLAS-TICITY INDEX
0-60	SIC	MH-K	A-7	0-10					50-60	20-25

DEPTH (IN.)	CLAY (PCT)	MOIST BULK DENSITY (G/CM3)	PERMEA-BILITY (IN/HR)	AVAILABLE WATER CAPACITY (IN/IN)	SOIL REACTION (PH)	SALINITY (MMHOS/CM)	SHRINK-SWELL POTENTIAL	EROSION FACTORS K	T	WIND EROD. GROUP	ORGANIC MATTER (PCT)	CORROSIVITY STEEL	CONCRETE
0-60	-	0.7-1.0	0.6-2.0	0.11-0.13	5.6-6.5	-	LOW	.17	5	-	-	HIGH	MODERATE

FLOODING FREQUENCY	DURATION	MONTHS	HIGH WATER TABLE DEPTH (FT)	KIND	MONTHS	CEMENTED PAN DEPTH (IN)	HARDNESS	BEDROCK DEPTH (IN)	HARDNESS	SUBSIDENCE INIT. (IN)	TOTAL (IN)	HYD GRP	POTENT'L FROST ACTION
NONE			>6.0			-		>60		-		C	-

SANITARY FACILITIES (A)

SEPTIC TANK ABSORPTION FIELDS	SEVERE-SLOPE
SEWAGE LAGOON AREAS	SEVERE-SLOPE,SEEPAGE
SANITARY LANDFILL (TRENCH)	SEVERE-SLOPE,SEEPAGE
SANITARY LANDFILL (AREA)	SEVERE-SLOPE,SEEPAGE
DAILY COVER FOR LANDFILL	POOR-SLOPE

CONSTRUCTION MATERIAL (A)

ROADFILL	POOR-SLOPE
SAND	UNSUITED-EXCESS FINES
GRAVEL	UNSUITED-EXCESS FINES
TOPSOIL	POOR-SLOPE

BUILDING SITE DEVELOPMENT (A)

SHALLOW EXCAVATIONS	SEVERE-SLOPE
DWELLINGS WITHOUT BASEMENTS	SEVERE-SLOPE
DWELLINGS WITH BASEMENTS	
SMALL COMMERCIAL BUILDINGS	SEVERE-SLOPE
LOCAL ROADS AND STREETS	SEVERE-SLOPE
LAWNS, LANDSCAPING AND GOLF FAIRWAYS	SEVERE-SLOPE

WATER MANAGEMENT (A)

POND RESERVOIR AREA	SLOPE,SEEPAGE
EMBANKMENTS DIKES AND LEVEES	LOW STRENGTH
EXCAVATED PONDS AQUIFER FED	NO WATER
DRAINAGE	SLOPE
IRRIGATION	SLOPE
TERRACES AND DIVERSIONS	SLOPE
GRASSED WATERWAYS	SLOPE

REGIONAL INTERPRETATIONS

MELEMANU SERIES HI0181

RECREATIONAL DEVELOPMENT (A)

CAMP AREAS	SEVERE-SLOPE	PLAYGROUNDS	SEVERE-SLOPE
PICNIC AREAS	SEVERE-SLOPE	PATHS AND TRAILS	SEVERE-SLOPE

CAPABILITY AND YIELDS PER ACRE OF CROPS AND PASTURE (HIGH LEVEL MANAGEMENT)

CLASS-DETERMINING PHASE	CAPABILITY NIRR	CAPABILITY IRR.	PASTURE (AUM) NIRR	PASTURE (AUM) IRR.	NIRR	IRR.	NIRR	IRR.	NIRR	IRR.	NIRR	IRR.	NIRR	IRR.	NIRR	IRR.
ALL	7E		3.9													

WOODLAND SUITABILITY

CLASS-DETERMINING PHASE	ORD SYM	EROSION HAZARD	EQUIP. LIMIT	SEEDLING MORT'Y.	WINDTH. HAZARD	PLANT COMPET.	COMMON TREES	SITE INDX	TREES TO PLANT
ALL		SEVERE	SEVERE	MODERATE	SLIGHT	MODERATE	SALIGNA EUCALYPTUS BLACKBUTT EUCALYPTUS		SALIGNA EUCALYPTUS BLACKBUTT EUCALYPTUS NORFOLK-ISLAND PINE

WINDBREAKS

CLASS-DETERMINING PHASE	SPECIES	HT	SPECIES	HT	SPECIES	HT	SPECIES	HT
ALL	HORSETAIL CASUARINA PANAX	90 10	NORFOLK-ISLAND PINE	80	BRUSHBOX	50	CAJEPUT-TREE	50

WILDLIFE HABITAT SUITABILITY (C)

CLASS-DETERMINING PHASE	GRAIN & SEED	GRASS & LEGUME	WILD HERB.	HARDWD TREES	CONIFER PLANTS	SHRUBS	WETLAND PLANTS	SHALLOW WATER	OPENLD WILDLF	WOODLD WILDLF	WETLAND WILDLF	RANGELD WILDLF
ALL	POOR	FAIR	FAIR	FAIR	-	GOOD	V. POOR	V. POOR	FAIR	FAIR	V. POOR	-

POTENTIAL NATIVE PLANT COMMUNITY (RANGELAND OR FOREST UNDERSTORY VEGETATION)

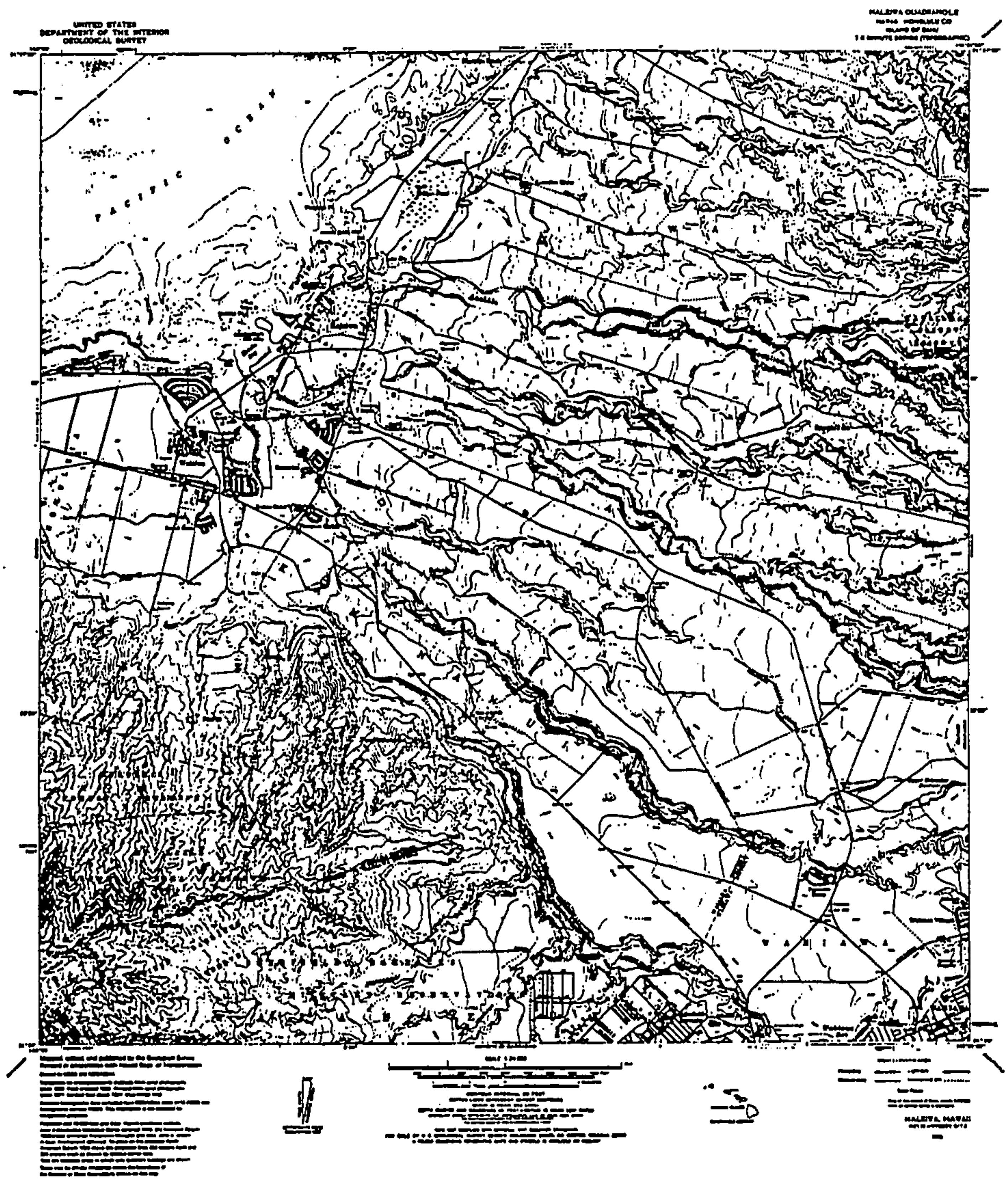
COMMON PLANT NAME	PLANT SYMBOL (NLSPN)	PERCENTAGE COMPOSITION (DRY WEIGHT) BY CLASS DETERMINING PHASE				
CHRISTMASBERRY	SCTE					
GUAVA	PSGU					
JAVA-PLUM	EUCU					
KOA-HAOLE	LEGL3					
POTENTIAL PRODUCTION (LBS./AC. DRY WT): FAVORABLE YEARS						
NORMAL YEARS						
UNFAVORABLE YEARS						

FOOTNOTES

A "GUIDE FOR INTERPRETING ENGINEERING USES OF SOILS," NOV. 1971, MODIFIED TO ACCOMMODATE SOILS OF HAWAII.
B BASED UPON MODIFICATION OF GUIDE SHEETS IN SOILS MEMORANDUM 69, OCT. 1968, TO ACCOMMODATE SOILS OF HAWAII.
C GUIDES IN SOILS MEMORANDUM 74, JAN. 1972, MODIFIED TO ACCOMMODATE SOILS OF HAWAII.

APPENDIX A

FIGURE A-2 TOPOGRAPHIC MAP OF THE AREA


UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
HALEIWA QUADRANGLE
PACIFIC OCEAN
HALEIWA, HAWAII

APPENDIX A

TABLE A-2 -- TABLES OF TOXICITY OF POTENTIAL PESTICIDES

Table 2. Description of acute and chronic toxicity test codes (with permission Murphy 1990).

Effect Code[1]	Test Description
	Acute Toxicity Tests
EC50	Median Effective Concentration. Used when an effect other than death is the observed endpoint.
ECxx	Effective Concentration to xx% of tested organisms.
	EC50AB - Abnormalities EC50BA - Byssal Attachment EC50BH - Behavior EC50BM - Biomass EC50CH - Chlorophyll EC50DT - Detachment EC50DV - Development EC50EQ - Equilibrium EC50EZ - Enzyme Activity EC50FC - Food Consumption EC50FR - Filtration Rate EC50GR - Growth EC50HA - Hatchability EC50IM - Immobilization EC50IN - Inhibition EC50IR - Irritation EC50NF - Nitrogen Fixation EC50OX - Oxygen Production EC50PG - Pigment Change EC50PH - Physiological Effect EC50PP - Population Size Reduction EC50PS - Photosynthesis Effect EC50RE - Reproduction EC50SW - Swimming EC50TE - Teratogenesis
ET50	Enzyme effect: Change in enzyme activity.
LC50	Median Lethal Concentration is the amount of a substance necessary to kill 50% of a population. Used only when death is the observed endpoint.
LCXX	Lethal concentration to xx% of tested organisms.

[1]Effect code used in toxicity table in Section 8.2. D=Delayed effect endpoint, indicated in the effect code field.

Table 2. Description of acute and chronic toxicity test codes (continued) (with permission Murphy 1990).

Effect Code	Test Description
	Acute Toxicity Tests
LD50	Median lethal dose or concentration is the amount of a substance necessary to kill 50% of a population when administered through injection or diet.
LDXX	Median lethal dose to xx% of tested organisms.
LET	Lethal: 100% mortality or 0% survival.
LT50	Lethal Threshold Concentration.
MOR	Mortality: Effects expressed as % death or % survival.
	Chronic Toxicity Tests
ABD	Abundance: Number of organisms within the same species changes.
ABN	Abnormalities: Physical malformation during developmental stages.
AVO	Avoidance: Avoidance or attraction to a chemical gradient.
BCF	Bioconcentration factor. Accumulation of a toxicant in the tissues of the test organism compared to the measured toxicant concentration in the water in which the organism was exposed;
	e.g., $BCF = \frac{\underline{\text{g/kg chemical in fish tissue}}}{\text{g/L chemical in } H_2O}$ (wet weight)
BEH	Behavior: Quantifiable change in activity.
BIO	Biochemical effect: Change in physiological processes.
BMS	Biomass: Change in the amount of living matter.
CEL	Cellular effect: Change in organelle structure.
CLN	Rate of colonization: Change in ability to colonize an uninhibited substrate under toxicant stress.

Table 2. Description of acute and chronic toxicity test codes (continued) (with permission Murphy 1990).

Effect Code	Test Description
	Chronic Toxicity Tests
CLR	Chlorophyll: Measurable change in chlorophyll content.
CYT	Cytogenetic effect: Changes in the RNA and DNA in the cell.
DRF	Drift: Change in number of larval aquatic insects to travel a given distance in a stream.
DVP	Development: Change in the ability to grow to a more mature life stage in time between life stages.
ENZ	Enzyme effect: Change in enzyme activity.
EQU	Equilibrium: Change in ability to maintain balance.
FCR	Change in food consumption rate.
FLT	Filtration rate: Change in rate of filtration by molluscs, crustaceans.
GRO	Measurable change in length and/or weight
HAT	Change in % hatch or time to hatch.
HEM	Change in hematological or various blood parameters.
HIS	Histological effect: Presence of physical damage to tissues.
HRM	Hormone effect: Change in hormone concentration.
LET	Lethal: 100% mortality or 0% survival including algicidal and herbicidal effects.
LOC	Locomotor behavior: Quantifiable change in direct movement or activity.
MOR	Mortality: Effect expressed as % death or % survival.
MOT	Motility: Change in the ability to move.
NFX	Nitrogen fixation: change in ability to fix nitrogen.

Table 2. Description of acute and chronic toxicity test codes

(continued) (with permission Murphy 1990).

Effect Code	Test Description
	Chronic Toxicity Tests
NOEL	No effect level for a given test.
OC	Oxygen consumption: Change in oxygen uptake of test organism or its tissues.
PATH	Pathological.
PRG	Change in population growth rate.
PHY	Physiological effects: Changes in the organic processes or functions of organs.
POP	Population: Change in number of species groups in a given community; species diversity.
PSE	Photosynthesis effect: Change in plant productivity.
REP	Change in male and/or female ability to reproduce.
RES	Respiration effect: Change in rate of ventilation or breathing activity.
RGN	Regeneration: Change in ability to regenerate a body part.
RSD	Residue: Used for tissue concentration when bio-concentration factor is not reported.
STR	Stress: Observed physiological tension in test organism.
TER	Teratogenesis: Quantifiable occurrence of abnormal offspring.
THL	Thermal effect: Change in tolerance to temperature change.
THR	Tumor occurrence: Presence of a mass of abnormal tissue.
VTE	Vertebral effect: Physical change in vertebral structure and/or composition leading to scoliosis, lordosis, bone composition.

Table 3. Toxicology of aquatic and terrestrial species. Chemical: 2,4-D Acid, CAS number: 94757

Class	Species	Effect	Duration (Days)	Concentration (ug/l)	Life Stage	Reference
ALGAE	Algae,phytoplankton,algal mat	ABD	3	0-68	NR	Inabinet (1979)
	Algae,phytoplankton,algal mat	CLR	90	0-68	NR	Inabinet (1979)
	Algae,phytoplankton,algal mat	POP	90	0-68	NR	Inabinet (1979)
	Algae,phytoplankton,algal mat	PSE	4 hr	1000	NR	Butler (1963)
	Blue-green algae (Agmenellum sp)	MOR	7	220000	NR	Elder et al. (1970)
	Blue-green algae (Anabaena variabilis)	EC50PP	2	>2200	NR	Hawxby et al. (1977)
	Blue-green algae (Anabaena variabilis)	EC50PS	NR	>2200	NR	Hawxby et al. (1977)
	Blue-green algae (Anabaena variabilis)	CEL	NR	>2200	NR	Hawxby et al. (1977)
	Blue-green algae (Anabaena flos-aquae)	CLR	NR	10000	NR	Chinnaswamy and Patel (1983)
	Blue-green algae (Anabaena cylindrica)	MOR	15	100000	NR	Venkatraman and Rajyalakshmi, B. (1972)
	Blue-green algae (Anabaena sp)	MOR	15	100000	NR	Venkatraman and Rajyalakshmi, B. (1972)
	Blue-green algae (Anabaena variabilis)	MOR	15	500000	NR	Venkatraman and Rajyalakshmi, B. (1972)
	Blue-green algae (Anabaena sp)	MOR	15	500000	NR	Venkatraman and Rajyalakshmi, B. (1972)
	Blue-green algae (Anabaena sp)	PGR	15		NR	Venkataraman and Rajyalakshmi (1971)
	Blue-green algae (Anacystis flos-aquae)	CEL	7	10000	NR	El-Ayouty et al. (1978)
	Blue-green algae (Anacystis flos-aquae)	CEL	7	18000	NR	El-Ayouty et al. (1978)
	Blue-green algae (Anacystis sp)	MOR	7	220000	NR	Elder et al. (1970)
	Blue-green algae (Anacystis nidulans)	MOR	15	100000	NR	Venkatraman and Rajyalakshmi, B. (1972)
	Blue-green algae (Anacystis aeruginosa)	PGR	1	250000	5 D LOG PHASE, (1-2)E+6 CELLS/ML	Fitzgerald et al. (1952)
	Blue-green algae (Anacystis nidulans)	PGR	7	50000	NR	Voight and Lynch (1974)
	Blue-green algae (Anacystis nidulans)	PGR	7	90000	NR	Voight and Lynch (1974)
	Blue-green algae (Anacystis nidulans)	PGR	15	200	NR	Venkataraman and Rajyalakshmi (1971)
	Blue-green algae (Anacystis aeruginosa)	PGR	21	2000	INITIAL CONC 125000 CELLS/ML	Palmer and Maloney (1955)
	Blue-green algae (Anacystis nidulans)	PGR	NR	80000	NR	Voight and Lynch (1974)
	Blue-green algae (Aulosira fertilissima)	MOR	15	100000	NR	Venkatraman and Rajyalakshmi, B. (1972)
	Blue-green algae (Aulosira fertilissima)	PGR	15	200	NR	Venkataraman and Rajyalakshmi (1971)
	Blue-green algae (Cylindrospermum sp)	MOR	7	220000	NR	Elder et al. (1970)
	Blue-green algae (Cylindrospermum licheniforme)	PGR	3	2000	INITIAL CONC 125000 CELLS/ML	Palmer and Maloney (1955)
	Blue-green algae (Lyngbya sp)	EC50PP	1	>2200	EXPONENTIAL PHASE	Hawxby et al. (1977)
	Blue-green algae (Lyngbya sp)	EC50PS	NR	>2200	EXPONENTIAL PHASE	Hawxby et al. (1977)
	Blue-green algae (Lyngbya sp)	CEL	NR	>2200	EXPONENTIAL PHASE	Hawxby et al. (1977)
	Blue-green algae (Microcoleus sp)	MOR	7	220000	NR	Elder et al. (1970)
	Blue-green algae (Nostoc sp)	MOR	7	220000	NR	Elder et al. (1970)
	Blue-green algae (Nostoc sp)	MOR	15	5000	NR	Venkatraman and Rajyalakshmi, B. (1972)
	Blue-green algae (Nostoc sp)	MOR	15	50000	NR	Venkatraman and

Class	Species	Effect	Duration (Days)	Concentration (µg/l)	Life Stage	Reference
						Rajyalakshmi, B. (1972)
	Blue-green algae (Nostoc calcicola)	MOR	15	100000	NR	Venkatraman and Rajyalakshmi, B. (1972)
	Blue-green algae (Nostoc sp)	MOR	15	100000	NR	Venkatraman and Rajyalakshmi, B. (1972)
	Blue-green algae (Nostoc sp)	PGR	15		NR	Venkataraman and Rajyalakshmi (1971)
	Blue-green algae (Oscillatoria amphibia)	CEL	7	10000	NR	El-Ayouty et al. (1978)

Table 3. (continued) Toxicology of aquatic and terrestrial species. Chemical: 2,4-D Acid, CAS number: 94757

Class	Species	Effect	Duration (Days)	Concentration (µg/l)	Life Stage	Reference
	Blue-green algae (Oscillatoria amphibia)	CEL	7	18000	NR	El-Ayouty et al. (1978)
	Blue-green algae (Oscillatoria sp)	MOR	7	220000	NR	Elder et al. (1970)
	Blue-green algae (Tolypothrix tenuis)	MOR	15	100000	NR	Venkatraman and Rajyalakshmi, B. (1972)
	Blue-green algae (Tolypothrix tenuis)	PGR	15	200	NR	Venkataraman and Rajyalakshmi (1971)
	Coccolithophorid (Coccolithus sp)	MOR	7	220000	NR	Elder et al. (1970)
	Cuvie, tangleweed	GRO	NR	100000	GAMETOPHYTE	Hopkin and Kain (1978)
	Cuvie, tangleweed	GRO	NR	100000	SPOROPHYTE	Hopkin and Kain (1978)
	Cuvie, tangleweed	PGR	28	1000	ZOOSPORES	Hopkins and Kain (1971)
	Cuvie, tangleweed	PSE	NR	1000000	MATURE FROND TISSUE	Hopkin and Kain (1978)
	Diatom (Gomphonema parvulum)	PGR	21	2000	INITIAL CONC 125000 CELLS/ML	Palmer and Maloney (1955)
	Diatom (Navicula sp)	MOR	7	220000	NR	Elder et al. (1970)
	Diatom (Nitzschia palea)	PGR	3	2000	INITIAL CONC 125000 CELLS/ML	Palmer and Maloney (1955)
	Diatom (Phaeodactylum tricornutum)	EC50OX	1.5 hr	60000	LOG PHASE	Walsh (1972)
	Diatom (Phaeodactylum tricornutum)	PGR	10	50000	LOG PHASE	Walsh (1972)
	Diatom (Phaeodactylum sp)	PSE	NR	10000	NR	Walsh et al. (1970)
	Flagellate euglenoid (Euglena sp)	MOR	7	220000	NR	Elder et al. (1970)
	Flagellate euglenoid (Euglena gracilis)	MOT	3	220000	NR	Elder et al. (1970)
	Flagellate euglenoid (Euglena gracilis)	PGR	1	100000	1 WK	Poorman (1973)
	Flagellate euglenoid (Euglena gracilis)	PGR	7	100000	1 WK	Poorman (1973)
	Flagellate euglenoid (Euglena gracilis)	RSD	6 hr	10-1000	NR	Valentine and Bingham (1974)
	Green algae (Ankistrodesmus sp)	PGR	14	110000	NR	Lembi et al. (1975)
	Green algae (Bracteacoccus cinnaberinus)	PGR	2-10	40000-70000	NR	Voight and Lynch (1974)
	Green algae (Bracteacoccus cinnaberinus)	PGR	NR	100000	NR	Voight and Lynch (1974)
	Green algae (Chlamydomonas reinhardtii)	EC50GR	5	320000-560000	500000 CELLS/ML	Benijts-Claus and Persoone (1975)
	Green algae (Chlamydomonas eugametos)	PGR	4	200000	2ND D OF LOG PHASE	Vance and Smith (1969)
	Green algae (Chlamydomonas reinhardtii)	PGR	5	300000	500000 CELLS/ML	Benijts-Claus and Persoone (1975)
	Green algae (Chlamydomonas reinhardtii)	RSD	6 hr	10-1000	NR	Valentine and Bingham (1974)
	Green algae (Chlorococcum sp)	EC50OX	1.5 hr	60000	LOG PHASE	Walsh (1972)
	Green algae (Chlorella pyrenoidosa)	EC50PP	1	>2200	EXPONENTIAL PHASE	Hawxby et al. (1977)
	Green algae (Chlorococcum sp)	EC50PP	1	>2200	EXPONENTIAL PHASE	Hawxby et al. (1977)
	Green algae (Chlorella pyrenoidosa)	EC50PS	NR	>2200	EXPONENTIAL PHASE	Hawxby et al. (1977)
	Green algae (Chlorococcum sp)	EC50PS	NR	>2200	EXPONENTIAL PHASE	Hawxby et al. (1977)
	Green algae (Chlorella pyrenoidosa)	CEL	NR	>2200	EXPONENTIAL PHASE	Hawxby et al. (1977)
	Green algae (Chlorococcum sp)	CEL	NR	>2200	EXPONENTIAL PHASE	Hawxby et al. (1977)
	Green algae (Chlorella pyrenoidosa)	CLR	3	50000	NR	Huang and Gloyna (1968)
	Green algae (Chlorella pyrenoidosa)	PGR	1.67	1000000	NR	Tomisek et al. (1957)
	Green algae (Chlorella pyrenoidosa)	PGR	4	200000	2ND D OF LOG PHASE	Vance and Smith (1969)
	Green algae (Chlorococcum sp)	PGR	10	50000	LOG PHASE	Walsh (1972)
	Green algae (Chlorella variegata)	PGR	21	2000	INITIAL CONC 125000 CELLS/ML	Palmer and Maloney (1955)
	Green algae (Chlorella pyrenoidosa)	PSE	1 hr	442000	2 WK CULTURE	Wedding et al. (1954)
	Green algae (Chlorella pyrenoidosa)	PSE	>2 hr	0.00302	3 D CULTURE,20 MG DRY WT	Erickson et al. (1955)

	Green algae (Chlorella sp)	PSE	NR	10000	NR	Walsh et al. (1970)
	Green algae (Chlorococcum sp)	PSE	NR	10000	NR	Walsh et al. (1970)
	Green algae (Chlorella pyrenoidosa)	RSD	6 hr	10-1000	NR	Valentine and Bingham (1974)
	Green algae (Coelastrum microporum)	PGR	2-10	5000-50000	NR	Voight and Lynch (1974)
	Green algae (Coelastrum microporum)	PGR	2-10	55000-65000	NR	Voight and Lynch (1974)
	Green algae (Coelastrum microporum)	PGR	7	1800	NR	El-Ayouty et al. (1978)
	Green algae (Coelastrum microporum)	PGR	7	3200	NR	El-Ayouty et al. (1978)

Table 3. (continued) Toxicology of aquatic and terrestrial species. Chemical: 2,4-D Acid, CAS number: 94757

Class	Species	Effect	Duration (Days)	Concentration (µg/l)	Life Stage	Reference
	Green algae (Coelastrum microporum)	PGR	NR	100000	NR	Voight and Lynch (1974)
	Green algae (Dunaliella tertiolecta)	EC50OX	1.5 hr	50000	LOG PHASE	Walsh (1972)
	Green algae (Dunaliella bioculata)	PGR	2	100	LOG PHASE	Felix et al. (1988)
	Green algae (Dunaliella tertiolecta)	PGR	10	75000	LOG PHASE	Walsh (1972)
	Green algae (Dunaliella sp)	PSE	NR	10000	NR	Walsh et al. (1970)
	Green algae (Enteromorpha linza)	BCF	1	25	GERMLINGS	Sikka et al. (1976)
	Green algae (Enteromorpha linza)	PSE	21	220000	GERMLINGS	Sikka et al. (1976)
	Green algae (Hydrodictyon sp)	NOR	7	220000	NR	Elder et al. (1970)
	Green algae (Nannochloris sp)	PSE	NR	10000	NR	Walsh et al. (1970)
	Green algae (Pandorina sp)	NOR	7	220000	NR	Elder et al. (1970)
	Green algae (Pediastrum sp)	ABD	14	22000	NR	Elder et al. (1970)
	Green algae (Pediastrum sp)	PGR	14	110000	NR	Lembi et al. (1975)
	Green algae (Pithophora sp)	NOR	7	220000	NR	Elder et al. (1970)
	Green algae (Platymonas sp)	PSE	NR	10000	NR	Walsh et al. (1970)
	Green algae (Scenedesmus sp)	EC50GR	5	870000-1000000	500000 CELLS/ML	Benijts-Claus and Persoone (1975)
	Green algae (Scenedesmus obliquus)	BCF	NR	11.05	NR	Bohm and Muller (1976)
	Green algae (Scenedesmus opoliensis)	CEL	7	5600	NR	El-Ayouty et al. (1978)
	Green algae (Scenedesmus opoliensis)	CEL	7	10000	NR	El-Ayouty et al. (1978)
	Green algae (Scenedesmus quadricauda)	PGR	4	200000	2ND D OF LOG PHASE	Vance and Smith (1969)
	Green algae (Scenedesmus sp)	PGR	5	300000	500000 CELLS/ML	Benijts-Claus and Persoone (1975)
	Green algae (Scenedesmus sp)	PGR	14	110000	NR	Lembi et al. (1975)
	Green algae (Scenedesmus obliquus)	PGR	21	2000	INITIAL CONC 125000 CELLS/ML	Palmer and Maloney (1955)
	Green algae (Scenedesmus quadricauda)	PSE	2	1000	NR	Stadnyk et al. (1971)
	Green algae (Scenedesmus quadricauda)	PSE	4	1000	NR	Stadnyk et al. (1971)
	Green algae (Scenedesmus quadricauda)	PSE	6	100	NR	Stadnyk et al. (1971)
	Green algae (Scenedesmus quadricauda)	PSE	8	100	NR	Stadnyk et al. (1971)
	Green algae (Scenedesmus quadricauda)	PSE	10	1000	NR	Stadnyk et al. (1971)
	Green algae (Scenedesmus obliquus)	RSD	4.5 hr	100-1000	1000000 CELLS/ML	Ellgehausen et al. (1980)
	Green algae (Scenedesmus quadricauda)	RSD	6 hr	10-1000	NR	Valentine and Bingham (1974)
	Green algae (Selenastrum capricornutum)	EC50	NR	12900	NR	Miller et al. (1985)
	Green algae (Selenastrum capricornutum)	EC50	NR	95800	NR	Miller et al. (1985)
	Green algae (Spirogyra sp)	NOR	7	220000	NR	Elder et al. (1970)
	Green algae (Ulva lactuca)	BCF	1	25	FIELD THALLI	Sikka et al. (1976)
	Green algae (Ulva lactuca)	PSE	7	220000	FIELD THALLI	Sikka et al. (1976)
	Green algae (Volvox sp)	NOR	7	220000	NR	Elder et al. (1970)
	Green algae (Zygnema sp)	NOR	7	220000	NR	Elder et al. (1970)
	Haptophyte (Isochrysis galbana)	EC50OX	1.5 hr	60000	LOG PHASE	Walsh (1972)
	Haptophyte (Isochrysis galbana)	PGR	10	50000	LOG PHASE	Walsh (1972)
	Haptophyte (Isochrysis sp)	PSE	NR	10000	NR	Walsh et al. (1970)
	Haptophyte (Pavlova sp)	PSE	NR	10000	NR	Walsh et al. (1970)
	Haptophyte (Pleurochrysis sp)	NOR	7	220000	NR	Elder et al. (1970)
	Red algae (Champia parvula)	GRO	11-14	21600	TETRASPOROPHYTES	Thursby et al. (1985)
	Red algae (Champia parvula)	REP	11-14	100000	TETRASPOROPHYTES	Thursby et al. (1985)
	Red algae (Rhodymenia pseudopalmata)	BCF	1	25	LAB THALLI	Sikka et al. (1976)

	Red algae (Rhodymenia pseudopalmata)	PSE	21	220000	LAB THALLI	Sikka et al. (1976)
AMPHIBIA	Common indian toad	LC50	1	13770	LARVAE	Vardia et al. (1984)
	Common indian toad	LC50	2	9030	LARVAE	Vardia et al. (1984)
	Common indian toad	LC50	4	8050	LARVAE	Vardia et al. (1984)
	Frog (Rana temporaria)	STR-D	2	50000	TADPOLE	Cooke (1972)

Table 3. (continued) Toxicology of aquatic and terrestrial species. Chemical: 2,4-D Acid, CAS number: 94757

Class	Species	Effect	Duration (Days)	Concentration (µg/l)	Life Stage	Reference
ANNELIDA	Annelid worm class	ABD	21	44	NR	Marshall and Rutschsky (1974)
	Leech class	ABD	7	44	NR	Marshall and Rutschsky (1974)
	Oligochaete (Lumbriculus variegatus)	LC50	7	122200	NR	Bailey and Liu (1980)
	Oligochaete (Lumbriculus variegatus)	LC50	8	122200	NR	Bailey and Liu (1980)
AQUATIC INVERTEBRATE	Invertebrates	ABD	3	22.4	NR	Hooper (1953)
ARACHNIDA	Water mite (Hydracarina)	ABD	35	44	NR	Marshall and Rutschsky (1974)
CHONDRICHT	Spiny dogfish	MOR	3	20	NR	Guarino et al. (1976)
CNIDARIA	Hydra	ABN	3.75	4000	ADULT	Kudla (1984)
CRUSTACEA	Blue crab	EC50EQ	1	2900	JUVENILE	Butler (1963)
	Blue crab	EC50EQ	2	2900	JUVENILE	Butler (1963)
	Brown shrimp	EC50EQ	1	550	ADULT	Butler (1963)
	Brown shrimp	EC50EQ	2	550	ADULT	Butler (1963)
	Calanoid copepod (Eudiaptomus gracilis)	LC50	4	144100	NR	Presing and Ponyi (1986)
	Calanoid copepod (Spicodiaptomus chilospinus)	LC50	1	2400	ADULT, 2.2-2.8 MM	Kader et al. (1976)
	Calanoid copepod (Spicodiaptomus chilospinus)	LC50	2	1850	ADULT, 2.2-2.8 MM	Kader et al. (1976)
	Crayfish family	ABD	21	44	NR	Marshall and Rutschsky (1974)
	Cyclopoid copepod (Acanthocyclops vernalis)	EC50IM	2	37420	0-4 H,NAUPLII	Robertson and Bunting (1976)
	Cyclopoid copepod (Acanthocyclops vernalis)	EC50IM	4	8720	0-4 H,NAUPLII	Robertson and Bunting (1976)
	Cyclopoid copepod (Mesocyclops leuckarti)	MOR	30	50000	NR	George et al. (1982)
	Dungeness or edible crab	DVP	1	100000	PRE ZOEAE	Caldwell et al. (1979)
	Dungeness or edible crab	DVP	50	1000	1ST STAGE ZOEAE	Caldwell et al. (1979)
	Dungeness or edible crab	MOR	80	590	JUVENILES, 3RD INSTAR	Caldwell et al. (1979)
	Dungeness or edible crab	MOR	85	10000	ADULT, 80-100 MM	Caldwell et al. (1979)
	Grass shrimp (Palaemonetes pugio)	AVO	0.5 hr	1000	10-40 MM	Hansen et al. (1973)
	Red swamp crayfish	LC50	4	1389000	JUVENILE, 0.4 G, 25-35 MM	Cheah et al. (1980)
	Scud (Gammarus fasciatus)	LC50	2	3200	EARLY INSTAR	Sanders (1970a)
	Water flea (Daphnia magna)	EC50	NR	13100	NR	Miller et al. (1985)
	Water flea (Daphnia magna)	EC50	NR	>240000	NR	Miller et al. (1985)
	Water flea (Daphnia magna)	EC50IM	1.08	>100000	1ST INSTAR	Crosby and Tucker (1966)
	Water flea (Daphnia pulex)	EC50IM	2	3200	1ST INSTAR	Sanders and Cope (1966)
	Water flea (Daphnia magna)	EC50IM	2	>100000	EARLY INSTAR	Sanders (1970a)
	Water flea (Daphnia magna)	LC50	1	180000	NR	Benijts-Claus and Persoone (1975)
	Water flea (Daphnia magna)	LC50	1	225000	NR	Benijts-Claus and

						Persoone (1975)
	Water flea (Daphnia magna)	LC50	1	235000	NR	Benijts-Claus and Persoone (1975)
	Water flea (Daphnia magna)	LC50	1	240000	NR	Benijts-Claus and Persoone (1975)
	Water flea (Daphnia magna)	LC50	1	>100000	NEONATE	Alexander et al. (1985)
	Water flea (Daphnia magna)	LC50	2	25000	NEONATE	Alexander et al. (1985)
	Water flea (Daphnia magna)	LC50	2	36400	NEONATE	Alexander et al. (1985)

Table 3. (continued) Toxicology of aquatic and terrestrial species. Chemical: 2,4-D Acid, CAS number: 94757

Class	Species	Effect	Duration (Days)	Concentration (µg/l)	Life Stage	Reference
	Water flea (Daphnia magna)	LC50	2	135000	NR	Benijts-Claus and Persoone (1975)
	Water flea (Daphnia magna)	LC50	2	90000-120000	NR	Benijts-Claus and Persoone (1975)
	Water flea (Daphnia magna)	LC50	2	195000-220000	NR	Benijts-Claus and Persoone (1975)
	Water flea (Daphnia magna)	LC50	21	1000	NR	Benijts-Claus and Persoone (1975)
	Water flea (Daphnia magna)	LC50	21	100000	NR	Benijts-Claus and Persoone (1975)
	Water flea (Daphnia lumholzi)	LT50	0.88	20000	NR	George et al. (1982)
	Water flea (Daphnia lumholzi)	LT50	1.58	10000	NR	George et al. (1982)
	Water flea (Daphnia lumholzi)	LET	1.29	20000	NR	George et al. (1982)
	Water flea (Daphnia lumholzi)	LET	2.96	10000	NR	George et al. (1982)
	Water flea (Daphnia magna)	RSD	2	100-1000	1 MG/ML	Ellgehausen et al. (1980)
	Water flea (Simocephalus serrulatus)	EC50IM	2	4900	1ST INSTAR	Sanders and Cope (1966)
FISH	American eel	LC50	1	427200	YOUNG OF THE YEAR	Rehwoldt et al. (1977)
	American eel	LC50	2	390200	YOUNG OF THE YEAR	Rehwoldt et al. (1977)
	American eel	LC50	4	300600	YOUNG OF THE YEAR	Rehwoldt et al. (1977)
	Banded killifish	LC50	1	306200	YOUNG OF THE YEAR	Rehwoldt et al. (1977)
	Banded killifish	LC50	2	261100	YOUNG OF THE YEAR	Rehwoldt et al. (1977)
	Banded killifish	LC50	4	26700	YOUNG OF THE YEAR	Rehwoldt et al. (1977)
	Banded tetra	MOR	2	600	NR	Rodrigues et al. (1980)
	Banded tetra	MOR	2	900	NR	Rodrigues et al. (1980)
	Banded tetra	MOR	2	1350	NR	Rodrigues et al. (1980)
	Banded tetra	MOR	2	2020	NR	Rodrigues et al. (1980)
	Banded tetra	MOR	2	3030	NR	Rodrigues et al. (1980)
	Bluegill	LC50	1	8000	FINGERLING, 2.5-7.6 CM	Hughes and Davis (1963)
	Bluegill	LC50	1	305000	19.5 MM, 0.15 G	Alexander et al. (1985)
	Bluegill	LC50	2	8000	FINGERLING, 2.5-7.6 CM	Hughes and Davis (1963)
	Bluegill	LC50	2	290000	19.5 MM, 0.15 G	Alexander et al. (1985)
	Bluegill	LC50	3	263000	19.5 MM, 0.15 G	Alexander et al. (1985)
	Bluegill	LC50	4	263000	19.5 MM, 0.15 G	Alexander et al. (1985)
	Bluegill	LD50	7	1000000	6.4-10.2 CM, 5 G	Harrisson and Rees (1946)
	Bluegill	LET	1	5000	FRY	Hiltibran (1967)
	Bluegill	MOR	7	100000	FINGERLING, 6.2 CM	King and Penfound (1946)
	Bluegill	RSD	1	125-312	NR	Schultz and Harman (1974)
	Bluegill	RSD	14	25-617	NR	Schultz and Harman (1974)
	Bluegill	STR	1	5000	FINGERLING, <= 10 CM	Applegate et al. (1957)
	Brown bullhead	LD50	7	2000000	12.7-15.2 CM,8.5 G	Harrisson and Rees (1946)
	Brown bullhead	LET	7	3000000	12.7-15.2 CM, 85 G	Harrisson and Rees (1946)
	Brown bullhead	MOR	7	1000000	12.7-15.2 CM, 85 G	Harrisson and Rees (1946)
	Brown bullhead	MOR	7	2000000	12.7-15.2 CM, 85 G	Harrisson and Rees (1946)
	Brown bullhead	MOR	7	2500000	12.7-15.2 CM, 85 G	Harrisson and Rees (1946)
	Channel catfish	MOR	2	10000	1 Y, 14 G, 12 CM, FINGERLINGS	Mccorkle et al. (1977)
	Channel catfish	RSD	1	125-312	NR	Schultz and Harman (1974)

Class	Species	Effect	Duration (Days)	Concentration (µg/l)	Life Stage	Reference
	Channel catfish	RSD	4	100-1000	1-2 G	Ellgehausen et al. (1980)
	Channel catfish	RSD	5	1000	3-4 G,50-75 MM	Rodgers and Stalling (1972)
	Channel catfish	RSD	14	25-617	NR	Schultz and Harman (1974)
	Chum salmon	MOR	4	10000	FRY	Meehan et al. (1974)
	Chum salmon	MOR	4	50000	FRY	Meehan et al. (1974)
	Class - bony fishes	RSD	60	3.9	YOUNG - ADULT FROM 4 FAMILIES	Frank et al. (1987)
	Coho salmon,silver salmon	BCF	3	200	FRY	Sears and Meehan (1971)

Table 3. (continued) Toxicology of aquatic and terrestrial species. Chemical: 2,4-D Acid, CAS number: 94757

Class	Species	Effect	Duration (Days)	Concentration (µg/l)	Life Stage	Reference
	Coho salmon,silver salmon	BCF	NR	430000	6-18 MO, 8.9-25.5 G	Walsh and Ribelin (1973)
	Coho salmon,silver salmon	MOR	4	10000	FRY	Meehan et al. (1974)
	Coho salmon,silver salmon	MOR	4	10000	FINGERLING	Meehan et al. (1974)
	Coho salmon,silver salmon	MOR	4	50000	FRY	Meehan et al. (1974)
	Coho salmon,silver salmon	MOR	4	50000	FINGERLING	Meehan et al. (1974)
	Coho salmon,silver salmon	MOR	6	200000	YEARLING	Lorz et al. (1979)
	Common, mirror, colored, carp	LC100	0.67	3200000	EGGS,27 H	Kamler et al. (1974)
	Common, mirror, colored, carp	LC100	2 hr	3200000	LARVAE,2 H	Kamler et al. (1974)
	Common, mirror, colored, carp	LC50	1	5930	6.52(5.97-6.97)CM,3.52(3.43-3.67)G	Vardia and Durve (1981b)
	Common, mirror, colored, carp	LC50	1	20000	6.52(5.97-6.97)CM,3.52(3.43-3.67)G	Vardia and Durve (1981b)
	Common, mirror, colored, carp	LC50	1	35720	6.52(5.97-6.97)CM,3.52(3.43-3.67)G	Vardia and Durve (1981b)
	Common, mirror, colored, carp	LC50	1	35720	1.01-3.63 G	Vardia and Durve (1981a)
	Common, mirror, colored, carp	LC50	1	38720	6.52(5.97-6.97)CM,3.52(3.43-3.67)G	Vardia and Durve (1981b)
	Common, mirror, colored, carp	LC50	1	45000	6.52(5.97-6.97)CM,3.52(3.43-3.67)G	Vardia and Durve (1981b)
	Common, mirror, colored, carp	LC50	1	175200	YOUNG OF THE YEAR	Rehwoldt et al. (1977)
	Common, mirror, colored, carp	LC50	2	5800	6.52(5.97-6.97)CM,3.52(3.43-3.67)G	Vardia and Durve (1981b)
	Common, mirror, colored, carp	LC50	2	18400	6.52(5.97-6.97)CM,3.52(3.43-3.67)G	Vardia and Durve (1981b)
	Common, mirror, colored, carp	LC50	2	21300	6.52(5.97-6.97)CM,3.52(3.43-3.67)G	Vardia and Durve (1981b)
	Common, mirror, colored, carp	LC50	2	21300	1.01-3.63 G	Vardia and Durve (1981a)
	Common, mirror, colored, carp	LC50	2	35380	6.52(5.97-6.97)CM,3.52(3.43-3.67)G	Vardia and Durve (1981b)
	Common, mirror, colored, carp	LC50	2	35720	6.52(5.97-6.97)CM,3.52(3.43-3.67)G	Vardia and Durve (1981b)
	Common, mirror, colored, carp	LC50	2	42500	6.52(5.97-6.97)CM,3.52(3.43-3.67)G	Vardia and Durve (1981b)
	Common, mirror, colored, carp	LC50	2	100200	YOUNG OF THE YEAR	Rehwoldt et al. (1977)
	Common, mirror, colored, carp	LC50	4	5100	6.52(5.97-6.97)CM,3.52(3.43-3.67)G	Vardia and Durve (1981b)
	Common, mirror, colored, carp	LC50	4	15300	6.52(5.97-6.97)CM,3.52(3.43-3.67)G	Vardia and Durve (1981b)
	Common, mirror, colored, carp	LC50	4	20000	6.52(5.97-6.97)CM,3.52(3.43-3.67)G	Vardia and Durve (1981b)
	Common, mirror, colored, carp	LC50	4	20000	1.01-3.63 G	Vardia and Durve (1981a)
	Common, mirror, colored, carp	LC50	4	24150	6.52(5.97-6.97)CM,3.52(3.43-3.67)G	Vardia and Durve (1981b)
	Common, mirror, colored, carp	LC50	4	31250	6.52(5.97-6.97)CM,3.52(3.43-3.67)G	Vardia and Durve (1981b)
	Common, mirror, colored, carp	LC50	4	35000	6.52(5.97-6.97)CM,3.52(3.43-3.67)G	Vardia and Durve (1981b)
	Common, mirror, colored, carp	LC50	4	96500	YOUNG OF THE YEAR	Rehwoldt et al. (1977)
	Common, mirror, colored, carp	OVP	34	50000	EGG	Kamler et al. (1974)
	Common, mirror, colored, carp	MOR	1	100000	EGGS, 27 H	[illegible] et al. (1974)
	Common, mirror, colored, carp	MOR	2	800000	LARVAE, 3 H	Kamler et al. (1974)
	Common, mirror, colored, carp	MOR	2	1600000	LARVAE,3 H	Kamler et al. (1974)
	Common, mirror, colored, carp	MOR	8.3	50000	EMBRYO	Kamler (1973)
	Common, mirror, colored, carp	MOT	1	200000	EGGS,27 H	Kamler et al. (1974)
	Common, mirror, colored, carp	OC	9	50000	EGG	Kamler et al. (1974)
	Common, mirror, colored, carp	PHY	10	5000	FERTILIZED EGGS	Kamler (1972)
	Cutthroat trout	LC50	4	64000	0.3 G	Johnson and Finley (1980)
	Cyprinid fish (Rasbora neilgherriensis)	LC50	1	7800	1.01-3.63 G	Vardia and Durve (1981a)
	Cyprinid fish (Rasbora neilgherriensis)	LC50	2	6800	1.01-3.63 G	Vardia and Durve (1981a)
	Cyprinid fish (Rasbora neilgherriensis)	LC50	4	5600	1.01-3.63 G	Vardia and Durve (1981a)
	Dolly varden	MOR	4	50000	FINGERLING	Meehan et al. (1974)
	Fathead minnow	LC50	1	344000	20.4 MM, 0.14 G	Alexander et al. (1985)
	Fathead minnow	LC50	2	325000	20.4 MM, 0.14 G	Alexander et al. (1985)
	Fathead minnow	LC50	3	325000	20.4 MM, 0.14 G	Alexander et al. (1985)

	Fathead minnow	LC50	4	263000	20.4 MM, 0.14 G	Alexander et al. (1985)
	Fish (Labeo boga)	LC50	1	6700	1.01-3.63 G	Vardia and Durve (1981a)
	Fish (Labeo boga)	LC50	2	3800	1.01-3.63 G	Vardia and Durve (1981a)
	Fish (Labeo boga)	LC50	4	3800	1.01-3.63 G	Vardia and Durve (1981a)
	Goldfish	LC50	4	>187000	EGGS, 4 D POSTHATCH	Birge et al. (1979)
	Goldfish	LC50	4	>201000	EGGS, 4 D POSTHATCH	Birge et al. (1979)
	Goldfish	LC50	8	119100	EGGS, 4 D POSTHATCH	Birge et al. (1979)
	Goldfish	LC50	8	133100	EGGS, 4 D POSTHATCH	Birge et al. (1979)

Table 3. (continued) Toxicology of aquatic and terrestrial species. Chemical: 2,4-D Acid, CAS number: 94757

Class	Species	Effect	Duration (Days)	Concentration (ug/l)	Life Stage	Reference
	Green sunfish	HAT	8	5000	FERTILIZED EGGS	Hiltibran (1967)
	Green sunfish	MOR	1.71	110000	50-150 G	Sargent et al. (1970)
	Green sunfish	MOR	1.71	110000	50-150 G	Sergeant et al. (1971)
	Guppy	LC50	1	10210	1.7 CM, 0.10 G	Vardia and Durve (1984)
	Guppy	LC50	1	76700	NR	Rehwoldt et al. (1977)
	Guppy	LC50	2	9616	1.7 CM, 0.10 G	Vardia and Durve (1984)
	Guppy	LC50	2	81200	NR	Rehwoldt et al. (1977)
	Guppy	LC50	4	8356	1.7 CM, 0.10 G	Vardia and Durve (1984)
	Guppy	LC50	4	70700	NR	Rehwoldt et al. (1977)
	Harlequinfish, red rasbora	LC50	1	3950000	1.3-3 CM	Alabaster (1969)
	Harlequinfish, red rasbora	LC50	1	7000000	1.3-3 CM	Alabaster (1969)
	Harlequinfish, red rasbora	LC50	2	3100000	1.3-3 CM	Alabaster (1969)
	Killifish, topminnow family	LD50	7	2000000	3.8-6.4 CM,1.5 G	Harrisson and Rees (1946)
	Killifish, topminnow family	LET	7	2500000	3.8-6.4 CM, 1.5 G	Harrisson and Rees (1946)
	Killifish, topminnow family	MOR	7	100000	3.8-6.4 CM, 1.5 G	Harrisson and Rees (1946)
	Killifish, topminnow family	MOR	7	1000000	3.8-6.4 CM,1.5 G	Harrisson and Rees (1946)
	Killifish, topminnow family	MOR	7	1500000	3.8-6.4 CM, 1.5 G	Harrisson and Rees (1946)
	Killifish, topminnow family	MOR	7	2000000	3.8-6.4 CM, 1.5 G	Harrisson and Rees (1946)
	Lake trout, siscowet	LC50	4	45000	0.3 G	Johnson and Finley (1980)
	Lake trout, siscowet	BCF	NR	430000	6-18 MO, 8.9-25.5 G	Walsh and Ribelin (1973)
	Largemouth bass	LC50	3.5	160700	EGGS, 4 D POSTHATCH	Birge et al. (1979)
	Largemouth bass	LC50	3.5	165400	EGGS, 4 D POSTHATCH	Birge et al. (1979)
	Largemouth bass	LC50	7.5	81600	EGGS, 4 D POSTHATCH	Birge et al. (1979)
	Largemouth bass	LC50	7.5	108600	EGGS, 4 D POSTHATCH	Birge et al. (1979)
	Largemouth bass	MOR	7	100000	FINGERLING, 7.8 CM	King and Penfound (1946)
	Largemouth bass	RSD	1	125-312	NR	Schultz and Harman (1974)
	Largemouth bass	RSD	14	25-617	NR	Schultz and Harman (1974)
	Longnose killifish	LC50	1	3500	JUVENILE	Butler (1963)
	Longnose killifish	LC50	2	3000	JUVENILE	Butler (1963)
	Medaka, high-eyes	LC50	1	110000	NR	Shim and Self (1973)
	Medaka, high-eyes	MOR	3	14.0	NR	Shim and Self (1973)
	Medaka, high-eyes	MOR	3	28.0	NR	Shim and Self (1973)
	Northern squawfish	MOR	1	10000	5-10 CM	MacPhee (1969)
	Oikawa	LC50	1	140000	NR	Shim and Self (1973)
	Oikawa	MOR	3	14.0	NR	Shim and Self (1973)
	Oikawa	MOR	3	28.0	NR	Shim and Self (1973)
	Pink salmon	LET	4	50000	FRY	Meehan et al. (1974)
	Pink salmon	MOR	4	1000	FRY	Meehan et al. (1974)
	Pink salmon	MOR	4	5000	FRY	Meehan et al. (1974)
	Pink salmon	MOR	4	10000	FRY	Meehan et al. (1974)
	Pumpkinseed	LC50	1	120000	YOUNG OF THE YEAR	Rehwoldt et al. (1977)
	Pumpkinseed	LC50	2	118300	YOUNG OF THE YEAR	Rehwoldt et al. (1977)
	Pumpkinseed	LC50	4	94600	YOUNG OF THE YEAR	Rehwoldt et al. (1977)
	Pumpkinseed	LET	7	1500000	6.4-10.2 CM, 5 G	Harrisson and Rees (1946)
	Pumpkinseed	MOR	7	10000	6.4-10.2 CM, 5 G	Harrisson and Rees (1946)
	Pumpkinseed	MOR	7	100000	6.4-10.2 CM,5 G	Harrisson and Rees (1946)
	Pumpkinseed	MOR	7	500000	6.4-10.2 CM, 5 G	Harrisson and Rees (1946)

Class	Species	Effect	Duration (Days)	Concentration (µg/l)	Life Stage	Reference
	Pumpkinseed	MOR	7	1000000	6.4-10.2 CM, 5 G --	Harrisson and Rees (1946)
	Rainbow trout,donaldson trout	LC50	1	3000	UNDER-YEARLING	Alabaster (1969)
	Rainbow trout,donaldson trout	LC50	1	358000	27.7 MM, 0.34 G	Alexander et al. (1985)
	Rainbow trout,donaldson trout	LC50	1	3400000	UNDER-YEARLING	Alabaster (1969)
	Rainbow trout,donaldson trout	LC50	1	7000000	1.3-3 CM	Alabaster (1969)
	Rainbow trout,donaldson trout	LC50	2	2200	UNDER-YEARLING	Alabaster (1969)
	Rainbow trout,donaldson trout	LC50	2	358000	27.7 MM, 0.34 G	Alexander et al. (1985)
	Rainbow trout,donaldson trout	LC50	2	2600000	UNDER-YEARLING	Alabaster (1969)

Table 3. (continued) Toxicology of aquatic and terrestrial species. Chemical: 2,4-D Acid, CAS number: 94757

Class	Species	Effect	Duration (Days)	Concentration (µg/l)	Life Stage	Reference
	Rainbow trout,donaldson trout	LC50	2	4800000	1.3-3 CM	Alabaster (1969)
	Rainbow trout,donaldson trout	LC50	3	358000	27.7 MM, 0.34 G	Alexander et al. (1985)
	Rainbow trout,donaldson trout	LC50	4	358000	27.7 MM, 0.34 G	Alexander et al. (1985)
	Rainbow trout,donaldson trout	LC50	23	4200	EGGS, 4 D POSTHATCH	Birge et al. (1979)
	Rainbow trout,donaldson trout	LC50	23	11000	EGGS, 4 D POSTHATCH	Birge et al. (1979)
	Rainbow trout,donaldson trout	LC50	27	4200	EGGS, 4 D POSTHATCH	Birge et al. (1979)
	Rainbow trout,donaldson trout	LC50	27	11000	EGGS, 4 D POSTHATCH	Birge et al. (1979)
	Rainbow trout,donaldson trout	ENZ	NR	20000	YEARLING	Davis et al. (1972)
	Rainbow trout,donaldson trout	MOR	4	50000	FINGERLING	Meehan et al. (1974)
	Rainbow trout,donaldson trout	RSD	1-24 hr	0.1-10	125-175 G, 20-28 CM	Carpenter and Eaton (1983)
	Rainbow trout,donaldson trout	RSD	5	1000	3-4 G,50-75 MM	Rodgers and Stalling (1972)
	Rainbow trout,donaldson trout	STR	1	5000	FINGERLING, <= 10 CM	Applegate et al. (1957)
	Rainbow trout,donaldson trout	STR	6	1000000	FINGERLING, 3.5-9.1 G	Doe et al. (1988)
	Red breasted bream	LET	2	8000	NR	Rodrigues et al. (1980)
	Red breasted bream	MOR	2	4000	NR	Rodrigues et al. (1980)
	Sea lamprey	STR	1	5000	LARVAE, 8-13 CM	Applegate et al. (1957)
	Sheepshead minnow	AVO	NR	100	20-40 MM	Hansen (1970)
	Sockeye salmon	MOR	4	10000	SMOLT	Meehan et al. (1974)
	Sockeye salmon	MOR	4	50000	SMOLT	Meehan et al. (1974)
	Striped bass	LC50	1	85600	YOUNG OF THE YEAR	Rehwoldt et al. (1977)
	Striped bass	LC50	2	70200	YOUNG OF THE YEAR	Rehwoldt et al. (1977)
	Striped bass	LC50	4	70100	YOUNG OF THE YEAR	Rehwoldt et al. (1977)
	Tooth carp	LC50	2	207.80	NR	Boumaiza et al. (1979)
	Tooth carp	LC50	4	242.22	NR	Boumaiza et al. (1979)
	Two spotted,tic tac toe barb	LC50	1	1600	MATURE, 2.85 CM, 614 MG	Verma et al. (1984b)
	Two spotted,tic tac toe barb	HIS	1	1000	MATURE, 2.85 CM, 614 MG	Verma et al. (1984b)
	White mullet	LC50	1	1500	JUVENILE	Butler (1963)
	White mullet	LC50	2	1500	JUVENILE	Butler (1963)
	White mullet	GRO	2	50000	JUVENILE	Butler (1963)
	White perch	LC50	1	55300	YOUNG OF THE YEAR	Rehwoldt et al. (1977)
	White perch	LC50	2	48200	YOUNG OF THE YEAR	Rehwoldt et al. (1977)
	White perch	LC50	4	40000	YOUNG OF THE YEAR	Rehwoldt et al. (1977)
	Winter flounder	BCF	1 hr	2000	NR	Pritchard and James (1979)
	Zebra danio, zebrafish	LC50	1	180000	NR	Benijts-Claus and Persoone (1975)
	Zebra danio, zebrafish	LC50	2	160000	NR	Benijts-Claus and Persoone (1975)
	Zebra danio, zebrafish	LC50	4	160000	NR	Benijts-Claus and Persoone (1975)
INSECT	Biting midge family	ABD	7	44	NR	Marshall and Rutschsky (1974)
	Damselfly family	ABD	21	44	NR	Marshall and Rutschsky (1974)

	Dragonfly family (Gomphidae)	ABO	35	44	NR	Marshall and Rutschsky (1974)
	Dragonfly family (Libellulidae)	ABO	7	44	NR	Marshall and Rutschsky (1974)
	Mayfly (Hexagenia sp)	ABO	21	44	NR	Marshall and Rutschsky (1974)
	Mayfly family	ABO	35	44	NR	Marshall and Rutschsky (1974)

Table 3. (continued) Toxicology of aquatic and terrestrial species. Chemical: 2,4-D Acid, CAS number: 94757

Class	Species	Effect	Duration (Days)	Concentration (µg/l)	Life Stage	Reference
	Midge family	ABO	7	44	NR	Marshall and Rutschsky (1974)
	Mosquito (Aedes aegypti)	MOR	1	10000	LARVAE, 3RD INSTAR	Lichtenstein et al. (1973)
	Mosquito (Culex tritaeniorhynchus)	LC50	1	91800	LARVAE	Shim and Self (1973)
	Springtail beetle	ABO	7	44	NR	Marshall and Rutschsky (1974)
	Stonefly (Pteronarcys californica)	LC50	1	8500	NYMPH	Cope (1965)
	Stonefly (Pteronarcys californica)	LC50	1	56000	30-35 MM	Sanders and Cope (1968)
	Stonefly (Pteronarcys californica)	LC50	2	1800	NYMPH	Cope (1965)
	Stonefly (Pteronarcys californica)	LC50	2	44000	30-35 MM	Sanders and Cope (1968)
	Stonefly (Pteronarcys californica)	LC50	4	1600	NYMPH	Cope (1965)
	Stonefly (Pteronarcys californica)	LC50	4	15000	30-35 MM	Sanders and Cope (1968)
	Water scavenger beetle family	ABO	35	44	NR	Marshall and Rutschsky (1974)
	Water strider family	ABO	7	44	NR	Marshall and Rutschsky (1974)
MULLUSCA	American or virginia oyster	GRO	4	2000	2.5-5.1 CM	Butler (1963)
	Bivalve, clam, mussel class	ABO	35	44	NR	Marshall and Rutschsky (1974)
	Common bay mussel,blue mussel	EC50BA	4	262000	ADULT,3-4 CM	Liu and Lee (1975)
	Common bay mussel,blue mussel	EC50DV	2	211700	EGGS	Liu and Lee (1975)
	Common bay mussel,blue mussel	LC50	4	259000	ADULT,3-4 CM	Liu and Lee (1975)
	Common bay mussel,blue mussel	DVP	40	176000	29-30 D, LARVAE	Liu and Lee (1975)
	Common bay mussel,blue mussel	GRO	20	45700	LARVAE	Liu and Lee (1975)
	Common bay mussel,blue mussel	GRO	20	91400	LARVAE	Liu and Lee (1975)
	Pouch snail family	ABO	21	44	NR	Marshall and Rutschsky (1974)
PLATYHELMI	Planarian, flatworm	ABO	7	44	NR	Marshall and Rutschsky (1974)
PROTOZOA	Ciliate (Colpidium campylum)	PGR	1.79	>10000	> 96 H	Dive et al. (1980)
	Ciliate (Paramecium aurelia)	MOR	1.5 hr	1000	10000 CELLS/L	Joshi and Misra (1986)
	Ciliate (Paramecium aurelia)	MOR	1.5 hr	5000	10000 CELLS/L	Joshi and Misra (1986)
	Ciliate (Stylonychia mytilus)	LC50	3	104000	NR	Benijts-Claus and Persoone (1975)
	Ciliate (Stylonychia mytilus)	LC50	3	485000	NR	Benijts-Claus and Persoone (1975)
ROTIFERA	Rotifer (Brachionus calyciflorus)	LT50	1	5000	NR	George et al. (1982)
	Rotifer (Brachionus calyciflorus)	LET	1.29	5000	NR	George et al. (1982)
TRACHEOPHYT	Duckweed (Lemna perpusilla)	GRO	11	10	NR	Schott and Worthley (1974)
	Duckweed (Lemna perpusilla)	GRO	11	100	NR	Schott and Worthley

Class	Species	Effect	Duration (Days)	Concentration (ug/l)	Life Stage	Reference
						(1974)
	Duckweed (Lemna minor)	PHY	2	200	FROND	O'Brien and Prendeville (1979)
	Duckweed (Lemna minor)	PHY	4	200	FROND	O'Brien and Prendeville (1979)
	Parrot's-feather	GRO	14	200	1 WK	Sutton and Bingham (1970)
	Parrot's-feather	GRO	14	220	2 WK	Sutton and Bingham (1970)
	Parrot's-feather	GRO	14	550	2 WK	Sutton and Bingham (1970)

Table 3. (continued) Toxicology of aquatic and terrestrial species. Chemical: 2,4-D Acid, CAS number: 94757

Class	Species	Effect	Duration (Days)	Concentration (ug/l)	Life Stage	Reference
	Parrot's-feather	GRO	14	2000	1 WK	Sutton and Bingham (1970)
	Parrot's-feather	PHY	14	20	1 WK	Sutton and Bingham (1970)
	Parrot's-feather	PHY	14	200	1 WK	Sutton and Bingham (1970)
	Parrot's-feather	PHY	14	220	2 WK	Sutton and Bingham (1970)
	Parrot's-feather	PHY	14	550	2 WK	Sutton and Bingham (1970)
	Water-meal	LET	12-30	1000000	NR	Worthley and Schott (1972)
BIRD	Japanese quail	LD50	14	668.00 MG/KG	60 D	Hudson et al. (1984)
	Japanese quail	LO REP	6	250.00 MG/KG	ADULT	Haegele and Tucker (1974)
	Japanese quail	LO SIGNS	6	250.00 MG/KG	ADULT	Haegele and Tucker (1974)
	Mallard duck	LO REP	6	1500.00 MG/KG	ADULT	Haegele and Tucker (1974)
	Pheasant	NO REP	NR	150.00 R	ADULT	Solomon et al. (1973)
	Pigeon	LD50	14	668.00 MG/KG		Dahlgren and Linder (1971)
	Ring-necked pheasant	LD50	14	472.00 MG/KG	90-120 D	Hudson et al. (1984)
MAMMAL	Deer mouse	NO POP	NR	3.00 LB/AC	MULT	Johnson and Hansen (1969)
	Deer mouse	NO REP	NR	3.00 LB/AC	MULT	Johnson and Hansen (1969)
	Least chipmunk	LO POP	NR	2.00 LB/AC	MULT	Johnson and Hansen (1969)
	Least chipmunk	NO REP	NR	2.00 LB/AC	MULT	Johnson and Hansen (1969)
	Montane vole	LO POP	NR	2.00 LB/AC	MULT	Johnson and Hansen (1969)
	Montane vole	LO REP	NR	2.00 LB/AC	MULT	Johnson and Hansen (1969)
	Mouse (Mus sp.)	LO PHY	7	100.00 MG/KG	56-84 D	Jenssen and Renberg (1976)
	Mouse (Mus sp.)	LO PHY	7	100.00 MG/KG	84 D	Jenssen and Renberg (1976)
	Northern pocket gopher	LO POP	NR	2.00 LB/AC	MULT	Johnson and Hansen (1969)
	Rat	LO GRO	NR	50.00 MG/KG	ADULT	Khera and McKinley (1972)
	Rat	LO GRO	NR	150.00 MG/KG	ADULT	Khera and McKinley (1972)
	Rat	LO REP	NR	100.00 MG/KG	ADULT	Khera and McKinley (1972)
	Rat	NO GRO	NR	25.00 MG/KG	ADULT	Khera and McKinley (1972)
	Rat	NO GRO	NR	100.00 MG/KG	ADULT	Khera and McKinley (1972)
	Rat	NO REP	NR	50.00 MG/KG	ADULT	Khera and McKinley (1972)

Table 4. Toxicology of aquatic and terrestrial species. Chemical: 2,4-D Butyl ester, CAS number: 1929733

Class	Species	Effect	Duration (Days)	Concentration (ug/l)	Life Stage	Reference
ALGAE	Algae,phytoplankton,algal mat	PGR	4 hr	1000	NR	Butler (1964)
	Diatom (Phaeodactylum tricornutum)	EC50CX	1.5 hr	200000	LOG PHASE	Walsh (1972)
	Diatom (Phaeodactylum tricornutum)	PGR	10	150000	LOG PHASE	Walsh (1972)
	Green algae (Chlorococcum sp)	EC50CX	1.5 hr	100000	LOG PHASE	Walsh (1972)
	Green algae (Chlorococcum sp)	PGR	10	75000	LOG PHASE	Walsh (1972)

	Green algae (Dunaliella tertiolecta)	EC50GX	1.5 hr	100000	LOG PHASE	Walsh (1972)
	Green algae (Dunaliella tertiolecta)	PGR	10	75000	LOG PHASE	Walsh (1972)
	Green algae division	PGR	14	4000	NR	Butler et al. (1975)
	Green algae division	PGR	14	<1000	NR	Butler et al. (1975)
	Haptophyte (Isochrysis galbana)	EC50GX	1.5 hr	100000	LOG PHASE	Walsh (1972)
	Haptophyte (Isochrysis galbana)	PGR	10	75000	LOG PHASE	Walsh (1972)

Table 4. (continued) Toxicology of aquatic and terrestrial species. Chemical: 2,4-D Butyl ester, CAS number: 1929733

Class	Species	Effect	Duration (Days)	Concentration (µg/l)	Life Stage	Reference
AQUATIC	Invertebrates	POP	338	1000	BENTHIC	Stephenson and Mackie (1986)
INVERTEBRATE						
CRUSTACEA	Aquatic sowbug (Asellus brevicaudus)	LC50	2	3200	EARLY INSTAR	Sanders (1970a)
	Aquatic sowbug (Asellus brevicaudus)	LC50	4	2600	MATURE	Johnson and Finley (1980)
	Blue crab	MOR	21		SMALL	Rawls (1977)
	Crayfish (Orconectes nais)	LC50	2	>100000	EARLY INSTAR	Sanders (1970a)
	Grass shrimp (Palaemonetes kadiakensis)	LC50	2	1400	EARLY INSTAR	Sanders (1970a)
	Grass shrimp (Palaemonetes pugio)	MOR	21		SMALL	Rawls (1977)
	Harpacticoid copepod	LC50	4	3100	0.6 - 0.8 MM	Linden et al. (1979)
	Ostracod (Cypridopsis vidua)	EC50IM	2	1800	EARLY INSTAR	Sanders (1970a)
	Ostracod (Cypridopsis vidua)	EC50IM	2	2200	MATURE	Johnson and Finley (1980)
	Pink shrimp (america)	MOR	2	1000	ADULT	Butler (1964)
	Scud (Gammarus lacustris)	LC50	1	1400	2 MO OLD	Sanders (1969)
	Scud (Gammarus fasciatus)	LC50	1	6500	EARLY INSTAR	Sanders (1970a)
	Scud (Gammarus lacustris)	LC50	2	760	2 MO OLD	Sanders (1969)
	Scud (Gammarus fasciatus)	LC50	2	5900	EARLY INSTAR	Sanders (1970a)
	Scud (Gammarus fasciatus)	LC50	2	5900	EARLY INSTAR	Sanders (1970a)
	Scud (Gammarus lacustris)	LC50	4	440	2 MO OLD	Sanders (1969)
	Scud (Gammarus fasciatus)	LC50	4	5900	EARLY INSTAR	Sanders (1970a)
	Scud (Gammarus fasciatus)	LC50	4	6100	MATURE	Johnson and Finley (1980)
	Water flea (Daphnia magna)	EC50IM	2	5600	EARLY INSTAR	Sanders (1970a)
	Water flea (Daphnia magna)	EC50IM	2	6400	1ST INSTAR	Johnson and Finley (1980)
	Water flea (Daphnia pulex)	OC	0.25-0.	3000	MATURE	Sigmon (1979b)
FISH	Black bullhead	LC50	1	8700	125 MM, 15 G	Inglis and Davis (1972)
	Black bullhead	LC50	1	8800	125 MM, 15 G	Inglis and Davis (1972)
	Black bullhead	LC50	2	7100	125 MM, 15 GM	Inglis and Davis (1972)
	Black bullhead	LC50	2	7700	125 MM, 15 GM	Inglis and Davis (1972)
	Black bullhead	LC50	6 hr	8900	125 MM, 15 G	Inglis and Davis (1972)
	Black bullhead	LC50	6 hr	10600	125 MM, 15 G	Inglis and Davis (1972)
	Black bullhead	LC50	6 hr	11200	125 MM, 15 G	Inglis and Davis (1972)
	Bleak	LC50	4	3200-3700	8 CM	Linden et al. (1979)
	Bluegill	LC50	0.5	2000	40 MM, 0.75 GM	Inglis and Davis (1972)
	Bluegill	LC50	0.5	2020	40 MM, 0.75 GM	Inglis and Davis (1972)
	Bluegill	LC50	0.5	2120	40 MM, 0.75 GM	Inglis and Davis (1972)
	Bluegill	LC50	1	1460	40 MM, 0.75 GM	Inglis and Davis (1972)
	Bluegill	LC50	1	1540	40 MM, 0.75 GM	Inglis and Davis (1972)
	Bluegill	LC50	1	1680	40 MM, 0.75 GM	Inglis and Davis (1972)
	Bluegill	LC50	1	1710	40 MM, 0.75 GM	Inglis and Davis (1972)
	Bluegill	LC50	1	·1740	40 MM, 0.75GM	Inglis and Davis (1972)
	Bluegill	LC50	1	1980	40 MM, 0.75 GM	Inglis and Davis (1972)
	Bluegill	LC50	1	2100	FINGERLING,2.5-7.6 CM	Hughes and Davis (1963)
	Bluegill	LC50	1	2100	NR	Hughes and Davis (1962)
	Bluegill	LC50	1	36500	NR	Hughes and Davis (1962)

	Bluegill	LC50	1	43400	NR	Hughes and Davis (1962)
	Bluegill	LC50	2	1380	40 MM, 0.75 GM	Inglis and Davis (1972)
	Bluegill	LC50	2	1470	40 MM, 0.75 GM	Inglis and Davis (1972)
	Bluegill	LC50	2	1510	40 MM, 0.75 GM	Inglis and Davis (1972)
	Bluegill	LC50	2	2100	FINGERLING,2.5-7.6 CM	Hughes and Davis (1963)
	Bluegill	LC50	2	2100	NR	Hughes and Davis (1962)
	Bluegill	LC50	2	34500	NR	Hughes and Davis (1962)
	Bluegill	LC50	2	41400	NR	Hughes and Davis (1962)

Table 4. (continued) Toxicology of aquatic and terrestrial species. Chemical: 2,4-D Butyl ester, CAS number: 1929733

Class	Species	Effect	Duration (Days)	Concentration (ug/l)	Life Stage	Reference
	Bluegill	LC50	4	1200	1.4 G	Johnson and Finley (1980)
	Bluegill	LC50	6 hr	2030	40 MM, 0.75 GM	Inglis and Davis (1972)
	Bluegill	LC50	6 hr	2090	40 MM, 0.75 GM	Inglis and Davis (1972)
	Bluegill	LC50	6 hr	2160	40 MM, 0.75 GM	Inglis and Davis (1972)
	Bluegill	LC50	6 hr	2500	40 MM, 0.75 GM	Inglis and Davis (1972)
	Bluegill	LC50	6 hr	2500	40 MM, 0.75 GM	Inglis and Davis (1972)
	Bluegill	LC50	6 hr	2650	40 MM, 0.75 GM	Inglis and Davis (1972)
	Bluegill	BCF	1	770	3-4 G, 50-75 MM	Rodgers and Stalling (1972)
	Bluegill	BCF	1	770	3-4 G, 50-75 MM	Rodgers and Stalling (1972)
	Bluegill	BCF	1 hr	530	3-4 G, 50-75 MM	Rodgers and Stalling (1972)
	Bluegill	BCF	1 hr	530	3-4 G, 50-75 MM	Rodgers and Stalling (1972)
	Bluegill	BCF	2 hr	680	3-4 G, 50-75 MM	Rodgers and Stalling (1972)
	Bluegill	BCF	2 hr	680	3-4 G, 50-75 MM	Rodgers and Stalling (1972)
	Bluegill	BCF	3 hr	650	3-4 G, 50-75 MM	Rodgers and Stalling (1972)
	Bluegill	BCF	3 hr	650	3-4 G, 50-75 MM	Rodgers and Stalling (1972)
	Bluegill	BCF	4 hr	620	3-4 G, 50-75 MM	Rodgers and Stalling (1972)
	Bluegill	BCF	4 hr	620	3-4 G, 50-75 MM	Rodgers and Stalling (1972)
	Bluegill	BCF	6 hr	760	3-4 G, 50-75 MM	Rodgers and Stalling (1972)
	Bluegill	BCF	6 hr	760	3-4 G, 50-75 MM	Rodgers and Stalling (1972)
	Bluegill	MOR	NR	6000	SMALL	Hiltibran (1969)
	Bluegill	OC	0.5-1 h	3000	0.28-23.30 G	Sigmon (1979a)
	Bluegill	OC	0.5-1 h	3000	0.28-23.30 G	Sigmon (1979a)
	Bluegill	OC	0.5-1 h	3000	0.28-23.30 G	Sigmon (1979a)
	Bluegill	OC	NR	54	SMALL	Hiltibran (1969)
	Bluegill	OC	NR	540000	SMALL	Hiltibran (1969)
	Bluegill	RSD	1	<1-37	NR	Smith and Isom (1967)
	Channel catfish	BCF	1	770	3-4 G, 50-75 MM	Rodgers and Stalling (1972)
	Channel catfish	BCF	1	770	3-4 G, 50-75 MM	Rodgers and Stalling (1972)
	Channel catfish	BCF	1 hr	530	3-4 G, 50-75 MM	Rodgers and Stalling (1972)
	Channel catfish	BCF	1 hr	530	3-4 G, 50-75 MM	Rodgers and Stalling (1972)
	Channel catfish	BCF	2 hr	680	3-4 G, 50-75 MM	Rodgers and Stalling

Class	Species	Effect	Duration (Days)	Concentration (µg/l)	Life Stage	Reference
	Channel catfish	BCF	2 hr	680	3-4 G, 50-75 MM	Rodgers and Stalling (1972)
	Channel catfish	BCF	3 hr	650	3-4 G, 50-75 MM	Rodgers and Stalling (1972)
	Channel catfish	BCF	3 hr	650	3-4 G, 50-75 MM	Rodgers and Stalling (1972)
	Channel catfish	BCF	4 hr	620	3-4 G, 50-75 MM	Rodgers and Stalling (1972)

Table 4. (continued) Toxicology of aquatic and terrestrial species. Chemical: 2,4-D Butyl ester, CAS number: 1929733

Class	Species	Effect	Duration (Days)	Concentration (µg/l)	Life Stage	Reference
	Channel catfish	BCF	4 hr	620	3-4 G, 50-75 MM	Rodgers and Stalling (1972)
	Channel catfish	BCF	6 hr	760	3-4 G, 50-75 MM	Rodgers and Stalling (1972)
	Channel catfish	BCF	6 hr	760	3-4 G, 50-75 MM	Rodgers and Stalling (1972)
	Chinook salmon	LC50	4	303	FRY, 37 MM, 0.44 G	Finlayson and Verrue (1985)
	Chinook salmon	LC50	4	327	FRY, 3.8 MM, 0.38 G	Finlayson and Verrue (1985)
	Chinook salmon	LC50	4	332	SMOLT, 111 MM, 15.4 G	Finlayson and Verrue (1985)
	Chinook salmon	LC50	4	418	SMOLT, 109 MM, 14.6 G	Finlayson and Verrue (1985)
	Chinook salmon	GRO	86	40	FRY, 36 D POST-HAT	Finlayson and Verrue (1985)
	Chinook salmon	GRO	86	60	FRY, 36 D POST-HAT	Finlayson and Verrue (1985)
	Chinook salmon	MOR	86	40	ALEVIN TO FRY	Finlayson and Verrue (1985)
	Chinook salmon	MOR	86	60	ALEVIN TO FRY	Finlayson and Verrue (1985)
	Chinook salmon	MOR	86	118	EMBRYO	Finlayson and Verrue (1985)
	Fathead minnow	LC50	4	3300	0.9 G	Johnson and Finley (1980)
	Fathead minnow	MOR	14	310	EGG TO FRY	Mount and Stephan (1967)
	Fathead minnow	MOR	300	310	2.5 CM	Mount and Stephan (1967)
	Goldfish	LC50	0.5	3950	41 MM, 1.25 G	Inglis and Davis (1972)
	Goldfish	LC50	0.5	4500	41 MM, 1.25 CM	Inglis and Davis (1972)
	Goldfish	LC50	0.5	4350	41 MM, 1.25 G	Inglis and Davis (1972)
	Goldfish	LC50	1	3630	41 MM, 1.25 CM	Inglis and Davis (1972)
	Goldfish	LC50	1	3900	41 MM, 1.25 CM	Inglis and Davis (1972)
	Goldfish	LC50	1	4100	41 MM, 1.25 CM	Inglis and Davis (1972)
	Goldfish	LC50	2	2650	41 MM, 1.25 CM	Inglis and Davis (1972)
	Goldfish	LC50	2	2720	41 MM, 1.25 CM	Inglis and Davis (1972)
	Goldfish	LC50	2	3620	41 MM, 1.25 CM	Inglis and Davis (1972)
	Goldfish	LC50	6 hr	5000	41 MM, 1.25 CM	Inglis and Davis (1972)
	Goldfish	LC50	6 hr	5170	41 MM, 1.25 CM	Inglis and Davis (1972)
	Goldfish	LC50	6 hr	5780	41 MM, 1.25 CM	Inglis and Davis (1972)
	Green sunfish	LET	1 hr	110000	50-150 G	Sergeant et al. (1971)
	Green sunfish	MOR	1 hr	110000	50-150 G	Sargent et al. (1970)
	Harlequinfish, red rasbora	LC50	1	1000	1.3-3 CM	Alabaster (1969)
	Harlequinfish, red rasbora	LC50	2	1000	1.3-3 CM	Alabaster (1969)
	Longnose killifish	LC50	1	5000	JUVENILE	Butler (1963)
	Longnose killifish	LC50	2	5000	JUVENILE	Butler (1963)
	Mosquitofish (Gambusia affinis)	LC50	1	7000	NR	Hansen et al. (1972)

Mosquitofish (Gambusia affinis)	AVO	1 hr	1000	20-45 MM	Hansen et al. (1972)
Mummichog	MOR	21		NR	Rawls (1977)
Rainbow trout,donaldson trout	LC50	0.5	1940	46 MM, 0.67 G	Inglis and Davis (1972)
Rainbow trout,donaldson trout	LC50	0.5	1960	46 MM, 0.67 GM	Inglis and Davis (1972)
Rainbow trout,donaldson trout	LC50	0.5	1980	46 MM, 0.67 GM	Inglis and Davis (1972)
Rainbow trout,donaldson trout	LC50	1	1520	46 MM, 0.67 G	Inglis and Davis (1972)
Rainbow trout,donaldson trout	LC50	1	1560	46 MM, 0.67 GM	Inglis and Davis (1972)
Rainbow trout,donaldson trout	LC50	1	1560	46 MM, 0.67 GM	Inglis and Davis (1972)
Rainbow trout,donaldson trout	LC50	2	1460	46 MM, 0.67 G	Inglis and Davis (1972)

Table 4. (continued) Toxicology of aquatic and terrestrial species. Chemical: 2,4-D Butyl ester, CAS number: 1929733

Class	Species	Effect	Duration (Days)	Concentration (µg/l)	Life Stage	Reference
	Rainbow trout,donaldson trout	LC50	2	1500	46 MM, 0.67 G	Inglis and Davis (1972)
	Rainbow trout,donaldson trout	LC50	2	1550	46 MM, 0.67 G	Inglis and Davis (1972)
	Rainbow trout,donaldson trout	LC50	4	452	SMOLT, 81 MM, 7.8 G	Finlayson and Verrue (1985)
	Rainbow trout,donaldson trout	LC50	4	484	SMOLT, 85 MM, 6.4 G	Finlayson and Verrue (1985)
	Rainbow trout,donaldson trout	LC50	4	512	FRY, 24 MM, 0.11 G	Finlayson and Verrue (1985)
	Rainbow trout,donaldson trout	LC50	4	525	FRY, 23 MM, 0.10 G	Finlayson and Verrue (1985)
	Rainbow trout,donaldson trout	LC50	4	1206	SMOLT, 82 MM, 7.8 G	Finlayson and Verrue (1985)
	Rainbow trout,donaldson trout	LC50	4	3689	SMOLT, 80 MM, 7.6 G	Finlayson and Verrue (1985)
	Rainbow trout,donaldson trout	LC50	6 hr	2810	46 MM, 0.67 GM	Inglis and Davis (1972)
	Rainbow trout,donaldson trout	LC50	6 hr	3200	46 MM, 0.67 GM	Inglis and Davis (1972)
	Rainbow trout,donaldson trout	LC50	6 hr	3440	46 MM, 0.67 GM	Inglis and Davis (1972)
	Rainbow trout,donaldson trout	MOR	1	14000	YEARLING, 15-27 CM	Dodson and Mayfield (1979a)
	Sheepshead minnow	AVO	0.5 hr	100	20-40 MM	Hansen (1969)
	Two spotted,tic tac toe barb	HEM	1	1000	2.85 CM, 614.06 MG	Chouhan et al. (1983)
INSECT	Alderfly family	ABD	21	44	NR	Marshall and Rutschsky (1974)
	Caddisfly family	ABD	360	<1-37	NR	Smith and Isom (1967)
	Cranefly family	ABD	35	44	NR	Marshall and Rutschsky (1974)
	Crawling water beetle family	ABD	21	44	NR	Marshall and Rutschsky (1974)
	Dragonfly suborder	ABD	360	<1-37	NR	Smith and Isom (1967)
	Horsefly family	ABD	35	44	NR	Marshall and Rutschsky (1974)
	Mayfly (Caenis sp)	ABD	360	<1-37	NR	Smith and Isom (1967)
	Mayfly (Hexagenia sp)	ABD	360	<1-157	NR	Smith and Isom (1967)
	Mayfly (Hexagenia sp)	ABD	360	<1-37	NR	Smith and Isom (1967)
	Midge (Chironomus sp)	DVP	11	3000	LARVAE	Sigmon (1979c)
	Midge (Chironomus sp)	DVP	13	3000	LARVAE	Sigmon (1979c)
	Midge (Chironomus sp)	DVP	NR	3000	LARVAE	Sigmon (1979c)
	Midge (Chironomus sp)	DVP	NR	3000	LARVAE	Sigmon (1979c)
	Midge (Chironomus sp)	DVP	NR	3000	LARVAE	Sigmon (1979c)
	Midge (Chironomus sp)	DVP	NR	3000	LARVAE	Sigmon (1979c)
	Midge (Chironomus sp)	DVP	NR	3000	LARVAE	Sigmon (1979c)
	Midge (Chironomus sp)	DVP	NR	1000-3000	LARVAE	Sigmon (1979c)
	Midge (Chironomus sp)	DVP	NR	1000-3000	LARVAE	Sigmon (1979c)
	Midge (Chironomus sp)	MOR	NR	3000	LARVAE	Sigmon (1979c)
	Midge (Chironomus sp)	MOR	NR	3000	LARVAE	Sigmon (1979c)
	Midge (Chironomus sp)	MOR	NR	1000-3000	LARVAE	Sigmon (1979c)

	Mosquito (Anopheles quadrimaculatus)	MOR	NR	100	3RD & 4TH INSTAR LARVAE	Smith and Isom (1967)
	Riffle beetle family	ABD	360	<1-37	NR	Smith and Isom (1967)
	Stonefly (Pteronarcys californica)	LC50	1	8500	30-35 MM	Sanders and Cope (1968)
	Stonefly (Pteronarcys californica)	LC50	2	1800	30-35 MM	Sanders and Cope (1968)
	Stonefly (Pteronarcys californica)	LC50	4	1600	30-35 MM	Sanders and Cope (1968)
MULLUSCA	American or virginia oyster	EC50DV	2	8000	EGGS, 2 CELL STAGE	Davis and Hidu (1979)
	American or virginia oyster	EC50GR	4	3750	2.5-5.1 CM	Butler (1963)

Table 4. (continued) Toxicology of aquatic and terrestrial species. Chemical: 2,4-D Butyl ester, CAS number: 1929733

Class	Species	Effect	Duration (Days)	Concentration (µg/l)	Life Stage	Reference
	American or virginia oyster	LC50	12	740	2 D LARVAE	Davis and Hidu (1979)
	American or virginia oyster	GRO	12	25	2 D LARVAE	Davis and Hidu (1979)
	American or virginia oyster	GRO	21		6.25 CM	Rawls (1977)
	American or virginia oyster	GRO	66		6.25 CM	Rawls (1977)
	Hooked mussel	MOR	21		SMALL	Rawls (1977)
	Mollusk phylum	ABD	30	<1-37	NR	Smith and Isom (1967)
	Mussel (Elliptio crassidens)	RSD	1	<1-37	NR	Smith and Isom (1967)
TRACHEOPHY	Creeping bentgrass	MOR	NR	2000	NR	Hiltibran and Turgeon (1977)
	Pondweed (Potamogeton perfoliatus)	STR	21		NR	Rawls (1977)
	Vascular plants	RSD	0-88	<115.5	AQUATIC MACROPHYTES	Carpentier et al. (1988)
	Water-celery, tapegrass	MOR	39	10	NR	Quinn et al. (1977)
	Water-celery, tapegrass	MOR	46	10	NR	Quinn et al. (1977)
	Water-milfoil (Myriophyllum spicatum)	CLR	7		NR	Rawls (1977)
	Water-milfoil (Myriophyllum spicatum)	MOR	14		NR	Haven (1963)
	Water-milfoil (Myriophyllum spicatum)	MOR	14	10	NR	Quinn et al. (1977)
	Water-milfoil (Myriophyllum spicatum)	MOR	21		NR	Rawls (1977)
	Water-milfoil (Myriophyllum spicatum)	MOR	22	10	NR	Quinn et al. (1977)
	Water-milfoil (Myriophyllum spicatum)	MOR	30	44	NR	Marshall and Rutschsky (1974)
	Water-milfoil (Myriophyllum spicatum)	MOR	116		NR	Rawls (1977)
	Water-milfoil (Myriophyllum spicatum)	RSD	1	<1-37	NR	Smith and Isom (1967)
	Waterweed (Elodea canadensis)	MOR	13	10	NR	Quinn et al. (1977)
	Waterweed (Elodea canadensis)	MOR	35	10	NR	Quinn et al. (1977)
	Widgeon-grass	STR	21		NR	Rawls (1977)
BIRD	Bobwhite quail	LC50	8	>5000		Heath et al. (1972)
	Japanese quail	LC50	8	>5000		Heath et al. (1972)
	Mallard duck	LC50	8	>5000		Heath et al. (1972)
	Ring-necked pheasant	LC50	8	>5000		Heath et al. (1972)
INVERTEBRATE	Honey bee	LO SIGNS	NR	1.00 LB/AC	ADULT	Moffett and Morton (1972)
	Honey bee	NO MOR	NR	1.00 LB/AC	ADULT	Moffett and Morton (1972)
	Honey bee	NO MOR	NR	1.00 LB/AC	ADULT	Moffett and Morton (1972)
MAMMAL	Guinea pig	LD50	NR	848		USDA Forest Service (1984)
	Mouse	LD50	NR	380		USDA Forest Service (1984)
	Rabbit	LD50	NR	424		USDA Forest Service (1984)
	Rat	LD50	NR	620		USDA Forest Service (1984)

Table 5. Toxicology of aquatic and terrestrial species. Chemical: 2,4-D Ester, CAS number: 25168267

Class	Species	Effect	Duration (Days)	Concentration (ug/l)	Life Stage	Reference
INVERTEBRATE	Honey bee	LO MOR	NR	4.00 LB/AC	MULT	Moffett and Morton (1972)
	Honey bee	NO MOR	NR	4.00 LB/AC	MULT	Moffett and Morton (1972)

Table 5. (continued) Toxicology of aquatic and terrestrial species. Chemical: 2,4-D Ester, CAS number: 25168267

Class	Species	Effect	Duration (Days)	Concentration (ug/l)	Life Stage	Reference
MAMMAL	Rat	LO REP	NR	150.00 MG/KG	ADULT	Khera and McKinley (1972)
	Rat	NO REP	NR	50.00 MG/KG	ADULT	Khera and McKinley (1972)

Table 6. Toxicology of aquatic and terrestrial species. Chemical: 2,4-D Ester, CAS number: 64047354

Class	Species	Effect	Duration (Days)	Concentration (ug/l)	Life Stage	Reference
MAMMAL	Rat	LO REP	NR	150.00 MG/KG	ADULT	Khera and McKinley (1972)
	Rat	NO REP	NR	50.00 MG/KG	ADULT	Khera and McKinley (1972)

Table 7. Toxicology of aquatic and terrestrial species. Chemical: 2,4-D PGBE, CAS number: 1320189

Class	Species	Effect	Duration (Days)	Concentration (ug/l)	Life Stage	Reference
ALGAE	Algae,phytoplankton,algal mat	PGR	4 hr	1000	NR	Butler (1964)
	Stonewort (Chara sp)	MOR	196	0-8000	NR	Cope et al. (1970)
CRUSTACEA	Aquatic sowbug (Asellus brevicaudus)	LC50	2	2200	EARLY INSTAR	Sanders (1970a)
	Crayfish (Orconectes nais)	LC50	2	>100000	EARLY INSTAR	Sanders (1970a)
	Grass shrimp (Palaemonetes kadiakensis)	LC50	2	2700	EARLY INSTAR	Sanders (1970a)
	Grass shrimp (Palaemonetes kadiakensis)	LC50	4	400	MATURE	Johnson and Finley (1980)
	Ostracod (Cypridopsis vidua)	EC50IM	2	320	EARLY INSTAR	Sanders (1970a)
	Ostracod (Cypridopsis vidua)	EC50IM	2	400	MATURE	Johnson and Finley (1980)
	Pink shrimp (america)	MOR	2	1000	ADULT	Butler (1964)
	Scud (Gammarus lacustris)	LC50	1	2100	2 MO	Sanders (1969)
	Scud (Gammarus fasciatus)	LC50	1	4100	EARLY INSTAR	Sanders (1970a)
	Scud (Gammarus lacustris)	LC50	2	1800	2 MO	Sanders (1969)
	Scud (Gammarus fasciatus)	LC50	2	2600	EARLY INSTAR	Sanders (1970a)
	Scud (Gammarus fasciatus)	LC50	2	2600	EARLY INSTAR	Sanders (1970a)
	Scud (Gammarus lacustris)	LC50	4	1600	2 MO	Sanders (1969)
	Scud (Gammarus fasciatus)	LC50	4	2500	EARLY INSTAR	Sanders (1970a)
	Scud (Gammarus fasciatus)	LC50	4	2900	MATURE	Johnson and Finley (1980)
	Water flea (Daphnia magna)	EC50IM	2	100	EARLY INSTAR	Sanders (1970a)
	Water flea (Daphnia magna)	EC50IM	2	1200	1ST INSTAR	Johnson and Finley (1980)
	Water flea (Simocephalus serrulatus)	EC50IM	2	4900	1ST INSTAR	Johnson and Finley (1980)
FISH	Bluegill	LC50	0.5	1280	40 MM, 0.75 G	Inglis and Davis (1972)
	Bluegill	LC50	0.5	1340	40 MM, 0.75 G	Inglis and Davis (1972)
	Bluegill	LC50	0.5	1430	40 MM, 0.75 G	Inglis and Davis (1972)
	Bluegill	LC50	1	1020	40 MM, 0.75 G	Inglis and Davis (1972)
	Bluegill	LC50	1	1150	40 MM, 0.75 G	Inglis and Davis (1972)

	Bluegill	LC50	1	1200	40 MM, 0.75 G	Inglis and Davis (1972)
	Bluegill	LC50	1	2100	FINGERLING, 2.5-7.6 CM	Hughes and Davis (1963)
	Bluegill	LC50	1	2100	NR	Hughes and Davis (1962)
	Bluegill	LC50	1	9300	NR	Hughes and Davis (1962)
	Bluegill	LC50	2	990	40 MM, 0.75 G	Inglis and Davis (1972)
	Bluegill	LC50	2	1030	40 MM, 0.75 G	Inglis and Davis (1972)
	Bluegill	LC50	2	1180	40 MM, 0.75 G	Inglis and Davis (1972)

Table 7. (continued) Toxicology of aquatic and terrestrial species. Chemical: 2,4-D PGBE, CAS number: 1320189

Class	Species	Effect	Duration (Days)	Concentration (µg/l)	Life Stage	Reference
	Bluegill	LC50	2	2100	FINGERLING, 2.5-7.6 CM	Hughes and Davis (1963)
	Bluegill	LC50	2	2100	NR	Hughes and Davis (1962)
	Bluegill	LC50	2	9300	NR	Hughes and Davis (1962)
	Bluegill	LC50	4	600	1.0 G	Johnson and Finley (1980)
	Bluegill	LC50	6 hr	1960	40 MM, 0.75 G	Inglis and Davis (1972)
	Bluegill	LC50	6 hr	2080	40 MM, 0.75 G	Inglis and Davis (1972)
	Bluegill	LC50	6 hr	2140	40 MM, 0.75 G	Inglis and Davis (1972)
	Bluegill	LET	2	1000	FRY	Hiltibran (1967)
	Bluegill	MOR	12	2000	SMALL	Hiltibran (1967)
	Bluegill	MOR	NR	2000	SMALL	Hiltibran (1969)
	Bluegill	OC	NR	64	SMALL	Hiltibran (1969)
	Bluegill	REP	196	100-4000	80-110 MM	Cope et al. (1970)
	Central stoneroller	HAT	8	25000	FERTILIZED EGGS	Hiltibran (1967)
	Chinook salmon	LC50	4	170	SMOLT, 109 MM, 14.6 G	Finlayson and Verrue (1985)
	Chinook salmon	LC50	4	311	SMOLT, 111 MM, 15.4 G	Finlayson and Verrue (1985)
	Coho salmon,silver salmon	LET	4	5000	FINGERLING	Meehan et al. (1974)
	Coho salmon,silver salmon	MOR	4	1000	FINGERLING	Meehan et al. (1974)
	Cutthroat trout	LC50	4	490	FINGERLING, 0.34-1.1 G	Woodward and Mayer (1978)
	Cutthroat trout	LC50	4	770	FINGERLING, 0.4-0.8 G	Woodward (1982)
	Cutthroat trout	LC50	4	780	FINGERLING, 0.34-1.1 G	Woodward and Mayer (1978)
	Cutthroat trout	LC50	4	860	FINGERLING, 0.34-1.1 G	Woodward and Mayer (1978)
	Cutthroat trout	LC50	4	930	FINGERLING, 0.34-1.1 G	Woodward and Mayer (1978)
	Cutthroat trout	LC50	4	930	FINGERLING, 0.34-1.1 G	Woodward and Mayer (1978)
	Cutthroat trout	LC50	4	1000	1.0 G	Johnson and Finley (1980)
	Cutthroat trout	LC50	4	1000	FINGERLING, 0.34-1.1 G	Woodward and Mayer (1978)
	Cutthroat trout	LC50	4	1000	FINGERLING, 0.34-1.1 G	Woodward and Mayer (1978)
	Cutthroat trout	LC50	4	1030	FINGERLING, 0.34-1.1 G	Woodward and Mayer (1978)
	Cutthroat trout	LC50	4	1220	FINGERLING, 0.34-1.1 G	Woodward and Mayer (1978)
	Cutthroat trout	GRO	60	124	FRY	Woodward and Mayer (1978)
	Cutthroat trout	LET	4	500	ALEVIN	Woodward and Mayer (1978)
	Cutthroat trout	MOR	60	31	ALEVIN	Woodward and Mayer (1978)
	Cutthroat trout	MOR	60	60	ALEVIN	Woodward and Mayer (1978)
	Green sunfish	HAT	8	1000	FERTILIZED EGGS	Hiltibran (1967)
	Green sunfish	LET	5	1000	FRY	Hiltibran (1967)
	Lake chubsucker	LET	5	1000	FRY	Hiltibran (1967)
	Lake trout, siscowet	LC50	4	630	FINGERLING, 0.34-1.1 G	Woodward and Mayer (1978)
	Lake trout, siscowet	LC50	4	700	FINGERLING, 0.34-1.1 G	Woodward and Mayer (1978)
	Lake trout, siscowet	LC50	4	840	FINGERLING, 0.34-1.1 G	Woodward and Mayer (1978)
	Lake trout, siscowet	LC50	4	1000	FINGERLING, 0.34-1.1 G	Woodward and Mayer (1978)
	Lake trout, siscowet	LC50	4	1050	FINGERLING, 0.34-1.1 G	Woodward and Mayer (1978)
	Lake trout, siscowet	LC50	4	1075	FINGERLING, 0.34-1.1 G	Woodward and Mayer (1978)
	Lake trout, siscowet	LC50	4	1100	0.6 G	Johnson and Finley (1980)
	Lake trout, siscowet	LC50	4	1125	FINGERLING, 0.34-1.1 G	Woodward and Mayer (1978)
	Lake trout, siscowet	LC50	4	1150	FINGERLING, 0.34-1.1 G	Woodward and Mayer (1978)
	Lake trout, siscowet	LC50	4	1200	FINGERLING, 0.34-1.1 G	Woodward and Mayer (1978)

Lake trout, siscowet	DVP	60	100	ALEVIN	Woodward and Mayer (1978)
Lake trout, siscowet	GRO	60	100	FRY	Woodward and Mayer (1978)
Lake trout, siscowet	MOR	60	52	FRY, ALEVIN	Woodward and Mayer (1978)
Lake trout, siscowet	MOR	60	100	FRY, ALEVIN	Woodward and Mayer (1978)
Longnose killifish	LC50	1	5000	JUVENILE	Butler (1963)
Longnose killifish	LC50	2	4500	JUVENILE	Butler (1963)
Rainbow trout,donaldson trout	LC50	4	304	FRY, 24 MM, 0.11 G	Finleyson and Verrue (1985)

Table 7. (continued) Toxicology of aquatic and terrestrial species. Chemical: 2,4-D PGBE, CAS number: 1320189

Class	Species	Effect	Duration (Days)	Concentration (µg/l)	Life Stage	Reference
	Rainbow trout,donaldson trout	LC50	4	329	SMOLT, 81 MM, 7.8 G	Finlayson and Verrue (1985)
	Rainbow trout,donaldson trout	LC50	4	354	FRY, 23 MM, 0.10 G	Finlayson and Verrue (1985)
	Rainbow trout,donaldson trout	LC50	4	355	SMOLT, 85 MM, 6.4 G	Finlayson and Verrue (1985)
	Rainbow trout,donaldson trout	LC50	4	1000	1.5 G	Johnson and Finley (1980)
	Smallmouth bass	LET	5	1000	FRY	Hiltibran (1967)
INSECT	Stonefly (Pteronarcella badia)	LC50	4	2400	NAIAD	Johnson and Finley (1980)
	Stonefly (Pteronarcys californica)	LC50	4	2600	2ND YR CLASS	Johnson and Finley (1980)
TRACHEOPHY	Pondweed (Potamogeton sp)	MOR	196	0-8000	NR	Cope et al. (1970)
	Water nymph	MOR	196	0-8000	NR	Cope et al. (1970)

Table 8. Toxicology of aquatic and terrestrial species. Chemical: 2,4-D Sodium salt, CAS number: 2702729

Class	Species	Effect	Duration (Days)	Concentration (µg/l)	Life Stage	Reference
ALGAE	Blue-green algae (Anabaenopsis raciborskii)	CYT	0.33	1000000	NR	Das and Singh (1977)
	Blue-green algae (Anabaena aphanizomendoides)	CYT	0.33	1000000	NR	Das and Singh (1977)
	Blue-green algae (Anabaena spiroides)	CYT	0.33	1000000	NR	Das and Singh (1977)
	Blue-green algae (Anacystis flos-aquae)	CYT	0.33	1000000	NR	Das and Singh (1977)
	Blue-green algae (Cylindrospermum sp)	MOR	8	900000	INIT CONC 1500 FILAMENTS PER ML,/	Singh (1974)
	Blue-green algae (Cylindrospermum sp)	PGR	1	1000000	INIT CONC 4.5E+5 CELLS/ML,/	Singh (1974)
	Blue-green algae (Cylindrospermum sp)	PGR	8	100000	INIT CONC 1500 FILAMENTS PER ML,/	Singh (1974)
	Blue-green algae (Cylindrospermum sp)	PGR	8	150000	INIT CONC 4.5E+5 CELLS/ML,/	Singh (1974)
	Blue-green algae (Cylindrospermum sp)	PGR	8	800000	INIT CONC 4.5E+5 CELLS/ML,/	Singh (1974)
	Blue-green algae (Cylindrospermum sp)	PGR	8	800000	INIT CONC 1500 FILAMENTS PER ML,/	Singh (1974)
	Green algae (Chlorella pyrenoidosa)	BIO	0.75	110000	NR	Bertagnolli and Nadakavukaren (1974)
	Green algae (Chlorella pyrenoidosa)	CEL	6 hr	1215000	5 D CULTURES	Bertagnolli and NaCakavukaren (1970)
	Green algae (Chlorella pyrenoidosa)	CLR	3	5000000	NR	Huang and Gloyne (1968)
	Green algae (Chlorella pyrenoidosa)	ENZ	0.75	1100000	NR	Bertagnolli and Nadakavukaren (1974)
	Green algae (Chlorella pyrenoidosa)	OC	0.75	110000	NR	Bertagnolli and Nadakavukaren (1974)
	Green algae (Chlorella pyrenoidosa)	PGR	0.75	1100000	NR	Bertagnolli and Nadakavukaren (1974)
	Green algae (Chlorella pyrenoidosa)	PSE	0.75	110000	NR	Bertagnolli and Nadakavukaren (1974)
AMPHIBIA	Frog (Bufo bufo japonicus)	LC50	1	>40000	NR	Nishiuchi (1980a)
	Frog (Bufo bufo japonicus)	LC50	1	>40000	NR	Nishiuchi (1980a)
	Frog (Bufo bufo japonicus)	LC50	1	>40000	NR	Nishiuchi (1980a)
	Frog (Bufo bufo japonicus)	LC50	1	>40000	NR	Nishiuchi (1980a)
	Frog (Bufo bufo japonicus)	LC50	1	>40000	NR	Nishiuchi (1980a)
	Frog (Bufo bufo japonicus)	LC50	1	>40000	NR	Nishiuchi (1980a)
	Frog (Bufo bufo japonicus)	LC50	2	>40000	TADPOLE	Hashimoto and Nishiuchi (1981)
	Frog (Rana temporaria)	DVP	1	1000	TADPOLE	Buslovich and Borushko (1976)

Table 8. (continued) Toxicology of aquatic and terrestrial species. Chemical: 2,4-D Sodium salt, CAS number: 2702729

Class	Species	Effect	Duration (Days)	Concentration (µg/l)	Life Stage	Reference
BRYOPHYTA	Floating moss	MOR	6	5000	NR	Titova (1978)
CRUSTACEA	Aquatic sowbug (Asellus aquaticus)	EC50IM	1	1070000	NR	Zimakowska-Gnoinska (1977)
	Aquatic sowbug (Asellus aquaticus)	EC50IM	2	530000	NR	Zimakowska-Gnoinska (1977)
	Calanoid copepod (Eudiaptomus gracilis)	LC50	4	68600	NR	Presing and Ponyi (1986)
	Calanoid copepod (Eudiaptomus gracilis)	LC50	4	75200	NR	Presing and Ponyi (1986)
	Calanoid copepod (Eudiaptomus gracilis)	LC50	4	81900	NR	Presing and Ponyi (1986)
	Calanoid copepod (Eudiaptomus gracilis)	LC50	4	90900	NR	Presing and Ponyi (1986)
	Calanoid copepod (Eudiaptomus gracilis)	LC50	4	173400	NR	Presing and Ponyi (1986)
	Calanoid copepod (Eudiaptomus gracilioides)	MOR	1	2430000	NAUPLIUS,COPEPODIDS I-V,ADULT	Wierzbicka (1974)
	Calanoid copepod (Eudiaptomus gracilis)	REP	21	2500	NR	Presing and Ponyi (1986)
	Cyclopoid copepod (Cyclops strenuus)	MOR	1	2430000	NAUPLIUS,COPEPODIDS I-V,ADULT	Wierzbicka (1974)
	Cyclopoid copepod (Cyclops bohater)	MOR	4	2430000	COPEPODID V	Wierzbicka (1974)
	Cyclopoid copepod (Cyclops vicinus vicinus)	MOR	4	3650000	COPEPODID IV	Wierzbicka (1974)
	Cyclopoid copepod (Cyclops vicinus kikuchii)	MOR	4	3650000	COPEPODID IV	Wierzbicka (1974)
	Cyclopoid copepod (Cyclops strenuus)	MOR	4	3650000	COPEPODID IV	Wierzbicka (1974)
	Freshwater prawn (Macrobrachium dayanum)	LC50	1	2474000	46-55 MM	Omkar and Shukla (1984)
	Freshwater prawn (Macrobrachium naso)	LC50	1	2644000	65-75 MM	Omkar and Shukla (1984)
	Freshwater prawn (Macrobrachium dayanum)	LC50	2	2381000	46-55 MM	Omkar and Shukla (1984)
	Freshwater prawn (Macrobrachium naso)	LC50	2	2536000	65-75 MM	Omkar and Shukla (1984)
	Freshwater prawn (Macrobrachium dayanum)	LC50	3	2333000	46-55 MM	Omkar and Shukla (1984)
	Freshwater prawn (Macrobrachium naso)	LC50	3	2435000	65-75 MM	Omkar and Shukla (1984)
	Freshwater prawn (Macrobrachium dayanum)	LC50	4	2275000	46-55 MM	Omkar and Shukla (1984)
	Freshwater prawn (Macrobrachium naso)	LC50	4	2397000	65-75 MM	Omkar and Shukla (1984)
	Prawn	LC50	1	2224	NR	Shukla and Omkar (1983a)
	Prawn	LC50	1	2267	NR	Shukla and Omkar (1983a)
	Prawn	LC50	1	2309	NR	Shukla and Omkar (1983a)
	Prawn	LC50	1	2342	NR	Shukla and Omkar (1983a)
	Water flea (Daphnia pulex)	LC50	3 hr	>40000	NR	Hashimoto and Nishiuchi (1981)
	Water flea (Daphnia magna)	MOR	6	50000	NR	Matlak (1972)
	Water flea (Moina macrocopa)	LC50	3 hr	>40000	NR	Hashimoto and Nishiuchi (1981)
	Water flea (Simocephalus vetulus)	LT50	4	1700000	1.5 MM	Kaniewska-Prus (1975)
	Water flea (Simocephalus vetulus)	LET	4	564000	1.5 MM	Kaniewska-Prus (1975)
	Water flea (Simocephalus vetulus)	MOR	0.5	610000-1200000	MATURE FEMALE, 50-70 UG DRY WT	Klekowski and Zvirgzds (1971)
	Water flea (Simocephalus vetulus)	MOR	6 hr	3600000	MATURE FEMALE, 50-70 UG DRY WT	Klekowski and Zvirgzds (1971)
	Water flea (Simocephalus vetulus)	OC	4	282000	1.5 MM	Kaniewska-Prus (1975)
	Water flea (Simocephalus vetulus)	RES	3 hr	1800000	MATURE FEMALE, 50-70 UG DRY WT	Klekowski and Zvirgzds (1971)
FISH	Bleak	LC50	0.5	111200	LARVAE,>55 H,2 MG	Biro (1979)
	Bleak	LC50	0.5	159400	EMBRYO 16-30 H,<4 MG	Biro (1979)

	Bleak	LC50	1	70600	LARVAE,>55 H,2 MG	Biro (1979)
	Bleak	LC50	1	129000	EMBRYO 16-30 H,<4 MG	Biro (1979)
	Bleak	LC50	1.5	62100	LARVAE,>55 H,2 MG	Biro (1979)
	Bleak	LC50	1.5	63900	EMBRYO 16-30 H,<4 MG	Biro (1979)
	Bleak	LC50	2	12900	EMBRYO 16-30 H,<4 MG	Biro (1979)
	Bleak	LC50	2	51600	LARVAE,>55 H,2 MG	Biro (1979)
	Bluegill	BIO	NR	37	SMALL	Hiltibran (1969)

Table 8. (continued) Toxicology of aquatic and terrestrial species. Chemical: 2,4-D Sodium salt, CAS number: 2702729

Class	Species	Effect	Duration (Days)	Concentration (µg/l)	Life Stage	Reference
	Bluegill	MOR	12	100000	SMALL	Hiltibran (1967)
	Bluegill	MOR	NR	100000	SMALL	Hiltibran (1969)
	Common, mirror, colored, carp	LC50	2	>40000	NR	Hashimoto and Nishiuchi (1981)
	Common, mirror, colored, carp	GRO	10	5000	EGGS	Matlak (1972)
	Common, mirror, colored, carp	GRO	10	50000	EGGS	Matlak (1972)
	Common, mirror, colored, carp	LET	2	3200000	LARVAE, 3 H	Kamler et al. (1974)
	Common, mirror, colored, carp	LET	2 hr	3200000	EGGS, 27 H	Kamler et al. (1974)
	Common, mirror, colored, carp	MOR	1	200000	EGGS, 27 H	Kamler et al. (1974)
	Common, mirror, colored, carp	MOR	2	1600000	LARVAE, 3 H	Kamler et al. (1974)
	Common, mirror, colored, carp	MOT	1	400000	EGGS,27 H	Kamler et al. (1974)
	Goldfish	LC50	2	>40000	NR	Hashimoto and Nishiuchi (1981)
	Guppy	LC50	1	2971000	1.7 CM, 0.10 G	Vardia and Durve (1984)
	Guppy	LC50	2	2348000	1.7 CM, 0.10 G	Vardia and Durve (1984)
	Guppy	LC50	4	1418000	1.7 CM, 0.10 G	Vardia and Durve (1984)
	Harlequinfish, red rasbora	LC50	1	1160000	1.3-3 CM	Alabaster (1969)
	Loach (Misgurnus fossilis)	LC90	0.42	3645000	EGG	Klekowski et al. (1977)
	Loach (Misgurnus fossilis)	OC	0.42	3645000	EGG	Klekowski et al. (1977)
	Loach (Misgurnus fossilis)	OC	6 hr	3645000	EGG	Klekowski et al. (1977)
	Medaka, high-eyes	LC50	2	>40000	NR	Hashimoto and Nishiuchi (1981)
	Medaka, high-eyes	AVO	NR	177	NR	Hidaka et al. (1984)
	Oriental weatherfish	LC50	2	>40000	NR	Hashimoto and Nishiuchi (1981)
INSECT	Mayfly (Cloeon dipterum)	LC50	2	>40000	LARVAE	Hashimoto and Nishiuchi (1981)
MOLLUSCA	American or virginia oyster	EC50DV	2	20440	EGGS, 2 CELL STAGE	Davis and Hidu (1979)
	American or virginia oyster	LC50	12	64290	2 D, LARVAE	Davis and Hidu (1979)
	American or virginia oyster	GRO	12	25	2 D, LARVAE	Davis and Hidu (1979)
	Bladder snail	LC50	2	>100000	NR	Hashimoto and Nishiuchi (1981)
	Marsh snail	LC50	2	>100000	NR	Hashimoto and Nishiuchi (1981)
	Snail (Indoplanorbis exustus)	LC50	2	>100000	NR	Hashimoto and Nishiuchi (1981)
	Swan mussel	EC50PH	0.5 hr	0.25 G/L	LARVAE	Varanka (1979)
	Swan mussel	EC50PH	0.5 hr	7 G/L	LARVAE	Varanka (1979)
TRACHEOPHY	Coon-tail	MOR	>6	5000	UPPER LEAFY PARTS, 10 CM	Titova (1978)
	Duckweed (Lemna minor)	MOR	>6	5000	NR	Titova (1978)
	Water-milfoil (Myriophyllum spicatum)	MOR	>6	5000	UPPER LEAFY PARTS, 10 CM	Titova (1978)
	Waterweed (Elodea canadensis)	MOR	6	5000	UPPER LEAFY PARTS, 10 CM	Titova (1978)

Table 9. Toxicology of aquatic and terrestrial species. Chemical: 2,4-D, Amine, CAS number: 2008391

Class	Species	Effect	Duration (Days)	Concentration (µg/l)	Life Stage	Reference
BIRD	Mallard duck	LD50	NR	2000		Tucker and Crabtree (1970).
	Mallard duck	LD50	NR	>2025		Hudson et al. (1984)
INVERTEBRATE	Honey bee	NO MOR	NR	1.00 LB/AC	ADULT	Moffett and Morton (1972)
	Honey bee	NO MOR	NR	4.00 LB/AC	MULT	Moffett and Morton (1972)

Table 13. Toxicology of aquatic and terrestrial species. Chemical: Bendiocarb, CAS number: 22781233

Class	Species	Effect	Duration (Days)	Concentration (µg/l)	Life Stage	Reference
CRUSTACEA	Red swamp crayfish	LC50	4	5550	IMMATURE, 25-40 MM	Holck and Meek (1987)
	Red swamp crayfish	LC50	4	5550	IMMATURE, 25-40 MM	Holck and Meek (1987)
INSECT	Mosquito (Aedes punctor)	LC50	1	88.7	LARVAE,4TH INSTAR	Rettich (1977)
	Mosquito (Aedes punctor)	LC50	1	88.7	LARVAE,4TH INSTAR	Rettich (1977)
	Mosquito (Aedes cantans)	LC50	1	175.1	LARVAE,4TH INSTAR	Rettich (1977)
	Mosquito (Aedes cantans)	LC50	1	175.1	LARVAE,4TH INSTAR	Rettich (1977)
	Mosquito (Anopheles quadrimaculatus)	LC50	1	81	FOURTH INSTAR	Holck and Meek (1987)
	Mosquito (Anopheles quadrimaculatus)	LC50	1	81	FOURTH INSTAR	Holck and Meek (1987)
	Mosquito (Anopheles stephensi)	LC50	1	1700	4TH INSTAR LARVA,/	Scott and Georghiou (1986)
	Mosquito (Anopheles stephensi)	LC50	1	1700	4TH INSTAR LARVA,/	Scott and Georghiou (1986)
	Mosquito (Culex pipiens pipiens)	LC50	1	57.0	LARVAE,4TH INSTAR	Rettich (1977)
	Mosquito (Culex pipiens pipiens)	LC50	1	57.0	LARVAE,4TH INSTAR	Rettich (1977)
	Mosquito (Culex pipiens molestus)	LC50	1	96.5	LARVAE,4TH INSTAR	Rettich (1977)
	Mosquito (Culex pipiens molestus)	LC50	1	96.5	LARVAE,4TH INSTAR	Rettich (1977)
	Mosquito (Culiseta annulata)	LC50	1	178.2	LARVAE,4TH INSTAR	Rettich (1977)
	Mosquito (Culiseta annulata)	LC50	1	178.2	LARVAE,4TH INSTAR	Rettich (1977)
MAMMAL	Rat	LD50		40-179 MG/KG		Farm Chemicals Handbook (1990)

Table 15. Toxicology of aquatic and terrestrial species. Chemical: Benomyl, CAS number: 17804352

Class	Species	Effect	Duration (Days)	Concentration (µg/l)	Life Stage	Reference
ALGAE	Algae,phytoplankton,algal mat	PSE	4 hr	100000	NR	Somashekar and Sreenath (1984)
FISH	Bluegill	LC50	4	850	0.9 G	Johnson and Finley (1980)
	Bluegill	LC50	4	1200	0.6 G	Johnson and Finley (1980)
	Bluegill	LC50	4	1300	FRY, 0.2 G	Palawski and Knowles (1986)
	Channel catfish	LC50	4	5.6	YOLK SAC FRY	Johnson and Finley (1980)
	Channel catfish	LC50	4	6	YOLK SAC FRY	Palawski and Knowles (1986)
	Channel catfish	LC50	4	12	SWIM-UP FRY	Johnson and Finley (1980)
	Channel catfish	LC50	4	12	SWIM-UP FRY	Palawski and Knowles (1986)
	Channel catfish	LC50	4	24	FRY, 0.2 G	Palawski and Knowles (1986)
	Channel catfish	LC50	4	28	1.2 G	Johnson and Finley (1980)
	Channel catfish	LC50	4	29	1.2 G	Johnson and Finley (1980)
	Channel catfish	LC50	4	29	FINGERLING	Johnson and Finley (1980)
	Channel catfish	LC50	4	29	FINGERLING, 1.2 G	Palawski and Knowles (1986)
	Channel catfish	LC50	4	42	FINGERLING	Palawski and Knowles (1986)

Table 15. (continued) Toxicology of aquatic and terrestrial species. Chemical: Benomyl, CAS number: 17804352

Class	Species	Effect	Duration (Days)	Concentration (µg/l)	Life Stage	Reference
	Channel catfish	LC50	4	43	FINGERLING	Palawski and Knowles (1986)
	Channel catfish	LC50	4	44	FINGERLING	Palawski and Knowles (1986)
	Channel catfish	LC50	4	47	FINGERLING	Palawski and Knowles (1986)
	Channel catfish	LC50	4	56	FINGERLING	Palawski and Knowles (1986)
	Channel catfish	LC50	4	76	FINGERLING	Palawski and Knowles (1986)
	Channel catfish	LC50	4	120	FINGERLING	Palawski and Knowles (1986)
	Channel catfish	LC50	4	720	FINGERLING	Palawski and Knowles (1986)
	Fathead minnow	LC50	4	1900	0.5 G	Johnson and Finley (1980)
	Fathead minnow	LC50	4	2200	0.9 G	Johnson and Finley (1980)
	Rainbow trout,donaldson trout	LC5C	4	120	FRY, 0.2 G	Palawski and Knowles (1986)
	Rainbow trout,donaldson trout	LC50	4	160	SWIM-UP FRY	Palawski and Knowles (1986)
	Rainbow trout,donaldson trout	LC50	4	160	FINGERLING	Palawski and Knowles (1986)
	Rainbow trout,donaldson trout	LC50	4	170	1.2 G	Johnson and Finley (1980)
	Rainbow trout,donaldson trout	LC50	4	170	FINGERLING, 1.2 G	Palawski and Knowles (1986)
	Rainbow trout,donaldson trout	LC50	4	170	FINGERLING	Palawski and Knowles (1986)
	Rainbow trout,donaldson trout	LC50	4	190	FINGERLING	Palawski and Knowles (1986)
	Rainbow trout,donaldson trout	LC50	4	200	FINGERLING	Palawski and Knowles (1986)
	Rainbow trout,donaldson trout	LC50	4	230	FINGERLING	Palawski and Knowles (1986)
	Rainbow trout,donaldson trout	LC50	4	280	YOLK SAC FRY	Palawski and Knowles (1986)
	Rainbow trout,donaldson trout	LC50	4	280	FINGERLING	Palawski and Knowles (1986)
	Rainbow trout,donaldson trout	LC50	4	310	1.0 G	Johnson and Finley (1980)
	Rainbow trout,donaldson trout	LC50	4	600	FINGERLING	Palawski and Knowles (1986)
	Rainbow trout,donaldson trout	LC50	4	850	FINGERLING	Palawski and Knowles (1986)
INVERTEBRATE	Earthworm	LO AVO	2	0.87 UG/C		Stringer and Wright (1973)
	Earthworm	LO AVO	12	0.87 UG		Stringer and Wright (1976)

Class	Species	Effect	Duration (Days)	Concentration (ug/l)	Life Stage	Reference
	Earthworm	LO AVO	21	0.87 UG		Stringer and Wright (1976)
	Earthworm	LO AVO	27	0.00 %		Stringer and Wright (1973)
	Earthworm	LO AVO	49	560.00 G/HA		Keogh and Whitehead (1975)
	Earthworm	LO AVO	NR	0.80 UG/C	ADULT	Wright (1977)
	Earthworm	LO MOR	14	1.55 KG/HA		Stringer and Wright (1973)

Table 15. (continued) Toxicology of aquatic and terrestrial species. Chemical: Benomyl, CAS number: 17804352

Class	Species	Effect	Duration (Days)	Concentration (ug/l)	Life Stage	Reference
	Earthworm	LO MOR	21	0.87 UG		Stringer adn Wright (1976)
	Earthworm	LO MOR	27	0.05 %		Stringer and Wright (1973)
	Earthworm	LO MOR	NR	0.05 %	ADULT	Wright (1977)
	Earthworm	LO MOR	NR	1.55 KG/HA	ADULT	Wright (1977)
	Earthworm	LO POP	21	7.80 KG/HA	MULT	Tomlin and Gore (1974)
	Earthworm	LO POP	NR	0.28 KG/HA	MULT	Wright (1977)
	Earthworm	LO POP	NR	0.28 KG/HA	MULT	Wright (1977)
	Earthworm	LO POP	NR	0.28 KG/HA	MULT	Wright (1977)
	Earthworm	LO POP	NR	0.28 KG/HA	MULT	Wright (1977)
	Earthworm	LO POP	NR	0.28 KG/HA	MULT	Wright (1977)
	Earthworm	LO POP	NR	0.28 KG/HA	MULT	Wright (1977)
	Earthworm	LO POP	NR	0.28 KG/HA	MULT	Wright (1977)
	Earthworm	LO POP	NR	0.28 KG/HA	MULT	Wright (1977)
	Earthworm	LO POP	NR	0.28 KG/HA	YNG	Wright (1977)
	Earthworm	LO POP	NR	0.28 KG/HA	YNG	Wright (1977)
	Earthworm	LO POP	NR	0.28 KG/HA	MULT	Wright (1977)
	Earthworm	LO POP	NR	0.28 KG/HA	MULT	Wright (1977)
	Earthworm	LO POP	NR	0.28 KG/HA	MULT	Wright (1977)
	Earthworm	LO POP	NR	0.28 KG/HA	MULT	Wright (1977)
	Earthworm	LO POP	NR	0.28 KG/HA	MULT	Wright (1977)
	Earthworm	LO POP	NR	0.28 KG/HA	MULT	Wright (1977)
	Earthworm	LO POP	NR	0.28 KG/HA	MULT	Wright (1977)
	Earthworm	LO POP	NR	0.28 KG/HA .		Stringer and Wright (1973)
	Earthworm	LO POP	370	0.025 %		Cook and Swait (1975)
	Earthworm	LO POP	825	18.00 G/SQ		Black and Neely (1975)
	Earthworm	LO SIGNS	27	0.05 %		Stringer and Wright (1973)
	Earthworm	NO AVO	2	0.43 UG/C		Stringer and Wright (1973)
	Earthworm	NO AVO	2	7.00 UG/C		Stringer and Wright (1973)
	Earthworm	NO AVO	12	0.43 UG		Stringer adn Wright (1976)
	Earthworm	NO MOR	27	0.005 %		Stringer and Wright (1973)
	Earthworm	NO SIGNS	27	0.005 %		Stringer and Wright (1973)

Table 16. Toxicology of aquatic and terrestrial species. Chemical: Bensulide, CAS number: 741582

Class	Species	Effect	Duration (Days)	Concentration (µg/l)	Life Stage	Reference
ALGAE	Green algae (Chlamydomonas eugametos)	PGR	2	400	INIT CONC 100000 CELLS/ML	Ness (1980)
	Green algae (Chlamydomonas eugametos)	PGR	2	4000	INIT CONC 100000 CELLS/ML	Ness (1980)
CRUSTACEA	Scud (Gammarus fasciatus)	LC50	1	7600	EARLY INSTAR	Sanders (1970a)
	Scud (Gammarus fasciatus)	LC50	2	3300	EARLY INSTAR	Sanders (1970a)
	Scud (Gammarus fasciatus)	LC50	4	1400	EARLY INSTAR	Sanders (1970a)
	Scud (Gammarus fasciatus)	LC50	4	1400	MATURE	Johnson and Finley (1980)
FISH	Bluegill	LC50	1	970	1.04 G	Cope (1965)
	Bluegill	LC50	2	810	1.04 G	Cope (1965)
	Bluegill	LC50	4	800	0.2 G	Johnson and Finley (1980)
	Bluegill	LC50	4	810	1.04 G	Cope (1965)
	Channel catfish	LC50	4	379	1 Y, 14 G, 12 CM, FINGERLINGS	Mccorkle et al. (1977)
	Rainbow trout,donaldson trout	LC50	1	960	1.62 G	Cope (1965)
	Rainbow trout,donaldson trout	LC50	2	730	1.62 G	Cope (1965)
	Rainbow trout,donaldson trout	LC50	4	700	1.6 G	Johnson and Finley (1980)
	Rainbow trout,donaldson trout	LC50	4	720	1.62 G	Cope (1965)
TRACHEOPHYT	Duckweed (Lemna perpusilla)	NOR	7	100000	NR	Nishiuchi (1974)
MAMMAL	Rat	LD50		241-1470 MG/KG		Farm Chemicals Handbook (1990)

Table 19. Toxicology of aquatic and terrestrial species. Chemical: Chlorothalonil, CAS number: 1897456

Class	Species	Effect	Duration (Days)	Concentration (µg/l)	Life Stage	Reference
ALGAE	Algae,phytoplankton,algal mat	BCF	14	20	AUFWUCHS	Davies (1988)
AMPHIBIA	Frog (Bufo bufo japonicus)	LC50	2	160	TADPOLE	Hashimoto and Nishiuchi (1981)
CRUSTACEA	Dungeness or edible crab	EC50SW	2	170	FIRST STAGE ZOEAE	Armstrong et al. (1976)
	Dungeness or edible crab	EC50SW	4	<100	FIRST STAGE ZOEAE	Armstrong et al. (1976)
	Dungeness or edible crab	LC50	2	560	FIRST STAGE ZOEAE	Armstrong et al. (1976)
	Dungeness or edible crab	LC50	4	140	FIRST STAGE ZOEAE	Armstrong et al. (1976)
	Water flea (Daphnia pulex)	LC50	3 hr	7800	NR	Hashimoto and Nishiuchi (1981)
	Water flea (Daphnia pulex)	LC50	3 hr	7800	NR	Nishiuchi and Hashimoto (1975)
	Water flea (Moina macrocopa)	LC50	3 hr	>10000	NR	Hashimoto and Nishiuchi (1981)
	Water flea (Moina macrocopa)	LC50	3 hr	>10000	NR	Nishiuchi and Hashimoto (1975)
FISH	Common, mirror, colored, carp	LC50	2	110	NR	Hashimoto and Nishiuchi (1981)
	Common, mirror, colored, carp	LC50	2	110	NR	Nishiuchi and Hashimoto (1975)
	Golden galaxias	BCF	14	20	NR	Davies (1988)
	Goldfish	LC50	2	170	NR	Hashimoto and Nishiuchi (1981)
	Goldfish	LC50	2	170	NR	Nishiuchi and Hashimoto (1975)
	Medaka, high-eyes	LC50	2	88	NR	Hashimoto and Nishiuchi (1981)
	Medaka, high-eyes	LC50	2	88	NR	Nishiuchi and Hashimoto (1975)
	Oriental weatherfish	LC50	2	150	NR	Hashimoto and Nishiuchi (1981)
	Rainbow trout,donaldson trout	LC50	4	7.6	9.5(6-12) G	Davies (1987)
	Rainbow trout,donaldson trout	LC50	4	10.5	9.5(6-12) G	Davies (1987)
	Rainbow trout,donaldson trout	LC50	4	13.6	9.5(6-12) G	Davies (1987)

Table 19. (continued) Toxicology of aquatic and terrestrial species. Chemical: Chlorothalonil, CAS number: 1897456

Class	Species	Effect	Duration (Days)	Concentration (µg/l)	Life Stage	Reference
	Rainbow trout,donaldson trout	LC50	4	17.1	9.5(6-12) G	Davies (1987)
	Rainbow trout,donaldson trout	BIO	2	50	9.5(6-12) G	Davies (1987)
	Rainbow trout,donaldson trout	HEM	1	>20	9.5(6-12) G	Davies (1987)
	Rainbow trout,donaldson trout	HIS	24	2.0	9.5(6-12) G	Davies (1987)
	Rainbow trout,donaldson trout	RES	2 hr	30	9.5(6-12) G	Davies (1987)
INSECT	Mayfly (Cloeon dipterum)	LC50	2	1800	LARVAE	Hashimoto and Nishiuchi (1981)
MULLUSCA	Bladder snail	LC50	2	37000	NR	Hashimoto and Nishiuchi (1981)
	Bladder snail	LC50	2	37000	NR	Nishiuchi and Yoshida (1972)
	Marsh snail	LC50	2	9000	NR	Hashimoto and Nishiuchi (1981)
	Marsh snail	LC50	2	9000	NR	Nishiuchi and Yoshida (1972)
	Mud snail	LC50	2	30000	NR	Nishiuchi and Yoshida (1972)
	Snail (Indoplanorbis exustus)	LC50	2	15000	NR	Hashimoto and Nishiuchi (1981)
	Snail (Indoplanorbis exustus)	LC50	2	15000	NR	Nishiuchi and Yoshida (1972)
MAMMAL	Rat	LC50	1 hr	.31 MG/L		Farm Chemicals Handbook (1990)
	Rat	LD50		>10000 MG/KG		Farm Chemicals Handbook (1990)

Table 20. Toxicology of aquatic and terrestrial species. Chemical: Chlorpyriphos, CAS number: 2921882

Class	Species	Effect	Duration (Days)	Concentration (µg/l)	Life Stage	Reference
ALGAE	Algae,phytoplankton,algal mat	ABD	30	10	NR	Hughes et al. (1980)
	Algae,phytoplankton,algal mat	ABD	74	7.2	NR	Hurlbert et al. (1972)
	Algae,phytoplankton,algal mat	ABD	74	72	NR	Hurlbert et al. (1972)
	Algae,phytoplankton,algal mat	PGR	NR	4	NR	Butcher et al. (1975)
	Algae,phytoplankton,algal mat	POP	80	4	NR	Butcher et al. (1977)
	Algae,phytoplankton,algal mat	POP	80	10	NR	Butcher et al. (1977)
	Algae,phytoplankton,algal mat	POP	80	1000	NR	Butcher et al. (1977)
	Blue-green algae (Anabaena sp)	ABD	74	72	NR	Hurlbert et al. (1972)
	Blue-green algae (Anabaena sp)	BCFD	1	1000	NR	Lal and Singh (1987a)
	Blue-green algae (Anabaena sp)	BCFD	1	5000	NR	Lal and Singh (1987a)
	Blue-green algae (Anabaena sp)	BCFD	1	10000	NR	Lal and Singh (1987a)

	Blue-green algae (Anabaena sp)	BCFD	2	1000	NR	Lal and Singh (1987a)
	Blue-green algae (Anabaena sp)	BCFD	2	5000	NR	Lal and Singh (1987a)
	Blue-green algae (Anabaena sp)	BCFD	2	10000	NR	Lal and Singh (1987a)
	Blue-green algae (Anabaena sp)	BCFD	3	1000	NR	Lal and Singh (1987a)
	Blue-green algae (Anabaena sp)	BCFD	3	5000	NR	Lal and Singh (1987a)
	Blue-green algae (Anabaena sp)	BCFD	3	10000	NR	Lal and Singh (1987a)
	Blue-green algae (Anabaena sp)	BCFD	4	1000	NR	Lal and Singh (1987a)
	Blue-green algae (Anabaena sp)	BCFD	4	5000	NR	Lal and Singh (1987a)
						Lal and Singh (1987a)

Table 20. (continued) Toxicology of aquatic and terrestrial species. Chemical: Chlorpyriphos, CAS number: 2921882

Class	Species	Effect	Duration (Days)	Concentration (µg/l)	Life Stage	Reference
	Blue-green algae (Anabaena sp)	BCFD	4	10000	NR	Lal and Singh (1987a)
	Blue-green algae (Anabaena sp)	BCFD	5	1000	NR	Lal and Singh (1987a)
	Blue-green algae (Anabaena sp)	BCFD	5	5000	NR	Lal and Singh (1987a)
	Blue-green algae (Anabaena sp)	BCFD	5	10000	NR	Lal and Singh (1987a)
	Blue-green algae (Aulosira fertilissima)	BCFD	1	1000	NR	Lal and Singh (1987a)
	Blue-green algae (Aulosira fertilissima)	BCFD	1	5000	NR	Lal and Singh (1987a)
	Blue-green algae (Aulosira fertilissima)	BCFD	1	10000	NR	Lal and Singh (1987a)
	Blue-green algae (Aulosira fertilissima)	BCFD	2	1000	NR	Lal and Singh (1987a)
	Blue-green algae (Aulosira fertilissima)	BCFD	2	5000	NR	Lal and Singh (1987a)
	Blue-green algae (Aulosira fertilissima)	BCFD	2	10000	NR	Lal and Singh (1987a)
	Blue-green algae (Aulosira fertilissima)	BCFD	3	1000	NR	Lal and Singh (1987a)
	Blue-green algae (Aulosira fertilissima)	BCFD	3	5000	NR	Lal and Singh (1987a)
	Blue-green algae (Aulosira fertilissima)	BCFD	3	10000	NR	Lal and Singh (1987a)
	Blue-green algae (Aulosira fertilissima)	BCFD	4	1000	NR	Lal and Singh (1987a)
	Blue-green algae (Aulosira fertilissima)	BCFD	4	5000	NR	Lal and Singh (1987a)
	Blue-green algae (Aulosira fertilissima)	BCFD	4	10000	NR	Lal and Singh (1987a)
	Blue-green algae (Aulosira fertilissima)	BCFD	5	1000	NR	Lal and Singh (1987a)
	Blue-green algae (Aulosira fertilissima)	BCFD	5	5000	NR	Lal and Singh (1987a)
	Blue-green algae (Aulosira fertilissima)	BCFD	5	10000	NR	Lal and Singh (1987a)
	Chrysophyte	ABD	17	1.2	NR	Brown and Chow (1974)
	Diatom (Amphiprora sp)	PGR	4	10000	NR	Maly and Ruber (1983)
	Diatom (Skeletonema costatum)	EC50PP	2	1200	INIT CONC 40000 CELLS/ML	Walsh (1983)
	Diatom class	POP	42	250	NR	Nelson et al. (1976)
	Diatom class	POP	84	500	NR	Nelson et al. (1976)
	Diatoms, chrysophyte division	ABD	74	7.2	NR	Hurlbert et al. (1972)
	Diatoms, chrysophyte division	PGR	10	400	NR	Roberts and Miller (1970)
	Dinoflagellate (Ceratium sp)	ABD	17	240	NR	Brown et al. (1976)
	Dinoflagellate (Glenodinium sp)	ABD	17	1.2	NR	Brown and Chow (1974)
	Dinoflagellate (Gonyaulax sp)	PGR	4	10000	NR	Maly and Ruber (1983)
	Green algae (Ankistrodesmus falcatum)	ABD	6	200	NR	Brown and Chow (1974)
	Green algae (Ankistrodesmus falcatum)	ABD	9	1.2	NR	Brown et al. (1976)
	Green algae (Ankistrodesmus falcatum)	ABD	17	1.2	NR	Brown and Chow (1974)
	Green algae (Ankistrodesmus spiralis)	ABD	17	1.2	NR	Brown and Chow (1974)
	Green algae (Ankistrodesmus falcatum)	PGR	6	100	NR	Brown and Chow (1974)
	Green algae (Chlorella vulgaris)	ABD	6	10	NR	Brown and Chow (1974)
	Green algae (Chlorella vulgaris)	ABD	6	100	NR	Brown and Chow (1974)
	Green algae (Chlorococcum sp)	PGR	4	10000	NR	Maly and Ruber (1983)
	Green algae (Chlorella vulgaris)	PGR	6	1.0	NR	Brown and Chow (1974)
	Green algae (Schroederia setigera)	ABD	74	72	NR	Hurlbert et al. (1972)
	Green algae (Tetraedron sp)	ABD	9	1.2	NR	Brown et al. (1976)
	Green algae (Tetraedron sp)	ABD	17	1.2	NR	Brown et al. (1976)
AMPHIBIA	Western toad	TKL	1	30	19.8(15-28) MM	Johnson and Prine (1976)
ANNELIDA	Oligochaete (Branchiura sowerbyi)	LET	3	1500	NR	Naqvi (1973)
	Oligochaete (Branchiura sowerbyi)	LET	3	1500	NR	Naqvi (1973)
	Oligochaete (Branchiura sowerbyi)	MOR	3	1500	NR	Naqvi (1973)
	Oligochaete (Branchiura sowerbyi)	MOR	90	1500	NR	Naqvi (1973)
	Oligochaete family	ABD	21	7.4	NR	Ali and Mulla (1978b)
AQUATIC INVERTEBRATE	Invertebrates	ABD	28	0.16-17.3	MICROINVERTEBRATES	Siefert (1987)
	Invertebrates	ABD	28	0.16-17.3	MACROINVERTEBRATES	Siefert (1987)
CNIDARIA	Hydra (Hydra sp)	MOR	2	100	NR	Hughes (1977)

Table 20. (continued) Toxicology of aquatic and terrestrial species. Chemical: Chlorpyriphos, CAS number: 2921882 .

Class	Species	Effect	Duration (Days)	Concentration (µg/l)	Life Stage	Reference
CRUSTACEA	Calanoid copepod (Diaptomus sp)	ABD	21	7.4	NR	Ali and Mulla (1978b)
	Calanoid copepod (Diaptomus pallidus)	ABD	74	7.2	NAUPLII	Hurlbert et al. (1972)
	Calanoid copepod (Diaptomus pallidus)	ABD	74	7.2	COPEPODIDS	Hurlbert et al. (1972)
	Calanoid copepod (Diaptomus pallidus)	ABD	74	72	COPEPODID	Hurlbert et al. (1972)
	Calanoid copepod (Diaptomus sp)	MOR	2	100	NR	Hughes (1977)
	Copepod order	LC50	2	2.13	NR	Siefert (1987)
	Copepod order	LC50	3	0.94	NR	Siefert (1987)
	Copepod order	ABD	20	10	NAUPLII	Hughes et al. (1980)
	Copepod order	ABD	74	7.2	NAUPLII	Hurlbert et al. (1972)
	Copepod order	STR	2	6.1-15.9	NR	Siefert (1987)
	Copepod suborder	ABD	40	10	COPEPODIDS	Hughes et al. (1980)
	Crayfish (Orconectes immunis)	LC50	4	6	1.8 G	Phipps and Holcombe (1985)
	Crustacean class	ABD	7	0.056-0.112	NR	Frank and Sjogren (1978)
	Cyclopoid copepod (Acanthocyclops vernalis)	ABD	28	0.011	NR	Hurlbert et al. (1970)
	Cyclopoid copepod (Acanthocyclops vernalis)	ABD	74	7.2	NAUPLII	Hurlbert et al. (1972)
	Cyclopoid copepod (Acanthocyclops vernalis)	ABD	74	7.2	COPEPODIDS	Hurlbert et al. (1972)
	Cyclopoid copepod (Acanthocyclops vernalis)	ABD	74	72	COPEPODIDS	Hurlbert et al. (1972)
	Cyclopoid copepod (Acanthocyclops vernalis)	MOR	28	0.011	NR	Hurlbert et al. (1970)
	Cyclopoid copepod (Cyclops sp)	ABD	21	7.4	NR	Ali and Mulla (1978b)
	Cyclopoid copepod (Macrocyclops albidus)	MOR	1	1	NR	Johnson (1978a)
	Cyclopoid copepod (Macrocyclops albidus)	MOR	1	5	NR	Johnson (1978a)
	Cyclopoid copepod (Macrocyclops albidus)	MOR	1	10	NR	Johnson (1978a)
	Cyclopoid copepod (Macrocyclops albidus)	MOR	1	25	NR	Johnson (1978a)
	Fairy shrimp order	LC50	0.4583	0.39	NR	Siefert (1987)
	Fairy shrimp order	LC50	5 hr	0.67	NR	Siefert (1987)
	Grass shrimp (Palaemonetes pugio)	AVO	0.50	1	10-40 MM	Hansen et al. (1973)
	Opossum shrimp (Mysidopsis bahia)	LC50	4	0.035	NEWLY HAT, <= 24 H	Schimmel et al. (1983)
	Ostracod (Cyprinotus sp)	ABD	7	3	NR	Ali and Mulla (1978b)
	Ostracod (Cyprinotus sp)	ABD	28	7.4	NR	Ali and Mulla (1978b)
	Ostracod,seed shrimp subclass	LET	2	100	NR	Hughes (1977)
	Ostracod,seed shrimp subclass	MOR	2	1	NR	Hughes (1977)
	Ostracod,seed shrimp subclass	MOR	4	6.93	NR	Siefert (1987)
	Red swamp crayfish	LET	3.5 hr	3720	10.6 G	Naqvi (1973)
	Scud (Gammarus fasciatus)	LC10	1	0.8	NR	Thayer and Ruber (1976)
	Scud (Gammarus lacustris)	LC50	1	0.76	2 MONTH OLD	Sanders (1969)
	Scud (Gammarus fasciatus)	LC50	1	5.6	NR	Sanders (1972)
	Scud (Gammarus pseudolimnaeus)	LC50	2	0.33	NR	Siefert (1987)
	Scud (Gammarus lacustris)	LC50	2	0.40	2 MONTH OLD	Sanders (1969)
	Scud (Gammarus pseudolimnaeus)	LC50	3	0.19	NR	Siefert (1987)
	Scud (Gammarus lacustris)	LC50	4	0.11	2 MONTH OLD	Sanders (1969)
	Scud (Gammarus lacustris)	LC50	4	0.11	MATURE	Johnson and Finley (1980)
	Scud (Gammarus pseudolimnaeus)	LC50	4	0.18	NR	Siefert (1987)
	Scud (Gammarus fasciatus)	LC50	4	0.32	NR	Sanders (1972)
	Scud (Gammarus fasciatus)	DRF	1	0.8	NR	Thayer and Ruber (1976)
	Scud (Gammarus fasciatus)	DRF	1	0.8	NR	Thayer and Ruber (1976)
	Scud (Hyalella azteca)	LC50	1	0.68	NR	Siefert (1987)
	Scud (Hyalella azteca)	LC50	2	0.29	NR	Siefert (1987)
	Scud (Hyalella azteca)	LC50	3	0.18	NR	Siefert (1987)
	Scud (Hyalella azteca)	LC50	4	0.14	NR	Siefert (1987)
	Scud (Hyalella azteca)	ABD	14	3	NR	Ali and Mulla (1978b)
	Scud (Hyalella azteca)	ABD	21	7.4	NR	Ali and Mulla (1978b)
	Water flea (Ceriodaphnia reticulata)	LET	0.75	2.6	NR	Siefert (1987)
	Water flea (Daphnia pulex)	LC50	0.75	0.24	NR	Siefert (1987)

Table 20. (continued) Toxicology of aquatic and terrestrial species. Chemical: Chlorpyriphos, CAS number: 2921882

Class	Species	Effect	Duration (Days)	Concentration (µg/l)	Life Stage	Reference
	Water flea (Daphnia pulex)	LC50	1	0.17	NR	Siefert (1987)
	Water flea (Daphnia magna)	LC50	1	0.4	FEMALE	Roberts and Miller (1971)
	Water flea (Daphnia pulex)	LC50	3	0.12	NR	Siefert (1987)
	Water flea (Daphnia sp)	LC50	4 hr	0.88	NR	Siefert (1987)
	Water flea (Daphnia sp)	ABD	7	7.4	NR	Ali and Mulla (1978b)
	Water flea (Daphnia magna)	LET	1	1.3	FEMALE	Roberts and Miller (1971)
	Water flea (Daphnia sp)	LET	6 hr	100	NR	Hughes (1977)
	Water flea (Daphnia magna)	MOR	1	0.4	FEMALE	Roberts and Miller (1971)
	Water flea (Daphnia sp)	MOR	6 hr	1	NR	Hughes (1977)
	Water flea (Moina rectrirostris)	ABD	3	0.06	LARVAE	Mulla and Khasawinah (1969)
	Water flea (Moina rectrirostris)	ABD	3	0.06	LARVAE	Mulla and Khasawinah (1969)
	Water flea (Moina micrura)	ABD	74	7.2	NR	Hurlbert et al. (1972)
	Water flea (Moina micrura)	ABD	74	72	NR	Hurlbert et al. (1972)
	Water flea (Moina micrura)	LET	28	0.011	NR	Hurlbert et al. (1970)
	Water flea (Moina micrura)	MOR	28	0.011	NR	Hurlbert et al. (1970)
	Water flea order	ABD	1	10	NR	Hughes et al. (1980)
	Water flea order	LET	NR	0.88	NR	Siefert (1987)
	White river crayfish	LC50	4	2	0.7 G	Carter and Graves (1972)
FISH	Atlantic salmon	BEH	1	100-250	1 G, 3.0-4.0 CM, JUVENILE	Peterson (1976)
	Atlantic salmon	MOR	1	250	1 G, 3.0-4.0 CM, JUVENILE	Peterson (1976)
	Atlantic silverside	LC50	4	1.7	EMBRYO, > 48 H	Schimmel et al. (1983)
	Banded tetra	LET	2	80	NR	Rodrigues et al. (1980)
	Banded tetra	MOR	2	7	NR	Rodrigues et al. (1980)
	Banded tetra	MOR	2	14	NR	Rodrigues et al. (1980)
	Banded tetra	MOR	2	25	NR	Rodrigues et al. (1980)
	Banded tetra	MOR	2	45	NR	Rodrigues et al. (1980)
	Banded tetra	MOR	2	50	NR	Rodrigues et al. (1980)
	Banded tetra	MOR	2	70	NR	Rodrigues et al. (1980)
	Barb	LC50	1	0.8	NR	Scirocchi and Erme (1980)
	Bluegill	LC50	4	2.4	0.6 G	Johnson and Finley (1980)
	Bluegill	LC50	4	10	0.8 G	Phipps and Holcombe (1985)
	Bluegill	LC50	4	30	0.5 G	Carter and Graves (1972)
	Bluegill	BCF	1	2.38	14.1 G ; 8.6 CM	Macek et al. (1972)
	Bluegill	BCF	1	6.4	JUVENILE	Siefert (1987)
	Bluegill	BCF	1	0.995	14.1 G ; 8.6 CM	Macek et al. (1972)
	Bluegill	BCF	3	1.73	14.1 G, 8.6 CM	Macek et al. (1972)
	Bluegill	BCF	3	4.5	JUVENILE	Siefert (1987)
	Bluegill	BCF	3	0.305	14.1 G ; 8.6 CM	Macek et al. (1972)
	Bluegill	BCF	7	0.20	14.1 G ; 8.6 CM	Macek et al. (1972)
	Bluegill	BCF	7	0.39	JUVENILE	Siefert (1987)
	Bluegill	BCF	7	1.08	14.1 G ; 8.6 CM	Macek et al. (1972)
	Bluegill	BCF	7	1.76	JUVENILE	Siefert (1987)
	Bluegill	BCF	14	0.23	JUVENILE	Siefert (1987)
	Bluegill	BCF	14	0.77	JUVENILE	Siefert (1987)
	Bluegill	BCF	28	0.15	14.1 G ; 8.6 CM	Macek et al. (1972)
	Bluegill	BCF	28	0.165	14.1 G ; 8.6 CM	Macek et al. (1972)
	Bluegill	BCF	35	1.66	14.1 G ; 8.6 CM	Macek et al. (1972)
	Bluegill	BCF	35	0.595	14.1 G ; 8.6 CM	Macek et al. (1972)
	Bluegill	BCF	37	0.38	14.1 G ; 8.6 CM	Macek et al. (1972)
	Bluegill	BCF	37	1.02	14.1 G ; 8.6 CM	Macek et al. (1972)
	Bluegill	BCF	49	0.04	14.1 G ; 8.6 CM	Macek et al. (1972)

Table 20. (continued) Toxicology of aquatic and terrestrial species. Chemical: Chlorpyriphos, CAS number: 2921882

Class	Species	Effect	Duration (Days)	Concentration (ug/l)	Life Stage	Reference
	Bluegill	BCF	49	0.06	14.1 G ; 8.6 CM	Macek et al. (1972)
	Bluegill	STR	28	0.16-17.3	JUVENILE	Siefert (1987)
	Channel catfish	LC50	1	160	10.0 G	Carter and Graves (1972)
	Channel catfish	LC50	3	806	7.9 G	Phipps and Holcombe (1985)
	Channel catfish	LC50	4	280	0.8 G	Johnson and Finley (1980)
	Channel catfish	LC50	4	806	7.9 G	Phipps and Holcombe (1985)
	Common, mirror, colored, carp	LC50	0.5	123	132 MM, 31.5 G	El-Refai et al. (1976)
	Common, mirror, colored, carp	LC50	0.5	430	49 MM, 1.75 G	El-Refai et al. (1976)
	Common, mirror, colored, carp	LC50	1	81	132 MM, 31.5 G	El-Refai et al. (1976)
	Common, mirror, colored, carp	LC50	1	310	49 MM, 1.75 G	El-Refai et al. (1976)
	Common, mirror, colored, carp	LC50	2	59	132 MM, 31.5 G	El-Refai et al. (1976)
	Common, mirror, colored, carp	LC50	2	280	49 MM, 1.75 G	El-Refai et al. (1976)
	Crucian carp	LC50	NR	14	NR	Jirasek et al. (1978)
	Cutthroat trout	LC50	4	18	1.4 G	Johnson and Finley (1980)
	Fathead minnow	EC50AB	4	54.9	< 24 H LARVAE	Jarvinen et al. (1988)
	Fathead minnow	LC50	1	320.0	31-32 D, 0.1 G	Holcombe et al. (1982)
	Fathead minnow	LC50	2	248.0	31-32 D, 0.1 G	Holcombe et al. (1982)
	Fathead minnow	LC50	3	220.0	31-32 D, 0.1 G	Holcombe et al. (1982)
	Fathead minnow	LC50	4	120	NEWLY HAT LARVAE	Jarvinen and Tanner (1982)
	Fathead minnow	LC50	4	122.2	< 24 H LARVAE	Jarvinen et al. (1988)
	Fathead minnow	LC50	4	130	NEWLY HAT LARVAE	Jarvinen and Tanner (1982)
	Fathead minnow	LC50	4	140	NEWLY HAT LARVAE	Jarvinen and Tanner (1982)
	Fathead minnow	LC50	4	170	NEWLY HAT LARVAE	Jarvinen and Tanner (1982)
	Fathead minnow	LC50	4	200	32 D, 0.0 MM, 0.000 G	Geiger et al. (1988)
	Fathead minnow	LC50	4	203.0	31-32 D, 0.1 G	Holcombe et al. (1982)
	Fathead minnow	LC50	4	506	44 D, 0.0 MM, 0.000 G	Geiger et al. (1988)
	Fathead minnow	LC50	4	542	0.5 G	Phipps and Holcombe (1985)
	Fathead minnow	ABN	30	1.29	< 24 H LARVAE	Jarvinen et al. (1988)
	Fathead minnow	ABN	30	2.10	< 24 H LARVAE	Jarvinen et al. (1988)
	Fathead minnow	ABN	NR	2.68	< 24 H, LARVAE	Jarvinen et al. (1983)
	Fathead minnow	BMS	NR	0.12	< 24 H, LARVAE	Jarvinen et al. (1983)
	Fathead minnow	ENZ	60	0.27	< 24 H, LARVAE	Jarvinen et al. (1983)
	Fathead minnow	GRO	7	3.7	NEWLY HAT, < 24 H	Norberg and Mount (1985)
	Fathead minnow	GRO	7	7.4	NEWLY HAT, < 24 H	Norberg and Mount (1985)
	Fathead minnow	GRO	30	2.68	< 24 H, LARVAE	Jarvinen et al. (1983)
	Fathead minnow	GRO	30	3.88	< 24 H LARVAE	Jarvinen et al. (1988)
	Fathead minnow	GRO	30	7.08	< 24 H LARVAE	Jarvinen et al. (1988)
	Fathead minnow	GRO	32	1.6	EMBRYO	Jarvinen and Tanner (1982)
	Fathead minnow	GRO	32	2.2	EMBRYO	Jarvinen and Tanner (1982)
	Fathead minnow	GRO	32	3.2	EMBRYO	Jarvinen and Tanner (1982)
	Fathead minnow	GRO	32	4.8	EMBRYO	Jarvinen and Tanner (1982)
	Fathead minnow	GRO	60	1.21	< 24 H, LARVAE	Jarvinen et al. (1983)
	Fathead minnow	GRO	NR	0.12	< 24 H, LARVAE	Jarvinen et al. (1983)
	Fathead minnow	MOR	30	2.68	< 24 H, LARVAE	Jarvinen et al. (1983)

Table 20. (continued) Toxicology of aquatic and terrestrial species. Chemical: Chlorpyriphos, CAS number: 2921882

Class	Species	Effect	Duration (Days)	Concentration (µg/l)	Life Stage	Reference
	Fathead minnow	MOR	30	7.08	< 24 H LARVAE	Jarvinen et al. (1988)
	Fathead minnow	MOR	32	2.2	EMBRYO	Jarvinen and Tanner (1982)
	Fathead minnow	MOR	32	3.2	EMBRYO	Jarvinen and Tanner (1982)
	Fathead minnow	MOR	32	4.8	EMBRYO	Jarvinen and Tanner (1982)
	Fathead minnow	MOR	32	5.7	EMBRYO	Jarvinen and Tanner (1982)
	Fathead minnow	MOR	NR	0.12	< 24 H, LARVAE	Jarvinen et al. (1983)
	Fathead minnow	MOR	NR	0.27	< 24 H, LARVAE	Jarvinen et al. (1983)
	Fathead minnow	MOR	NR	0.63	< 24 H, LARVAE	Jarvinen et al. (1983)
	Fathead minnow	MOR	NR	1.21	< 24 H, LARVAE	Jarvinen et al. (1983)
	Fathead minnow	MOR	NR	2.68	< 24 H, LARVAE	Jarvinen et al. (1983)
	Fathead minnow	REP	NR	0.63	< 24 H, LARVAE	Jarvinen et al. (1983)
	Fathead minnow	REP	NR	2.68	< 24 H, LARVAE	Jarvinen et al. (1983)
	Fathead minnow	REP	136	0.12	< 24 H, LARVAE	Jarvinen et al. (1983)
	Golden shiner	MOR	6 hr	0.1 kg/ha	NR	Mount et al. (1970)
	Goldfish	LC50	4	>806	10.7 G	Phipps and Holcombe (1985)
	Green sunfish	LC50	1	110	1.8 G,5.7 CM	Davey et al. (1976)
	Green sunfish	LC50	2	50	1.8 G,5.7 CM	Davey et al. (1976)
	Green sunfish	LC50	3	40	1.8 G,5.7 CM	Davey et al. (1976)
	Gulf toadfish	LC50	4	520	JUVENILE, 99(73-116) MG	Hansen et al. (1986)
	Gulf toadfish	BCF	49	1.4	EMBRYO - LARVAE	Hansen et al. (1986)
	Gulf toadfish	BCF	49	3.7	EMBRYO - LARVAE	Hansen et al. (1986)
	Gulf toadfish	BCF	49	8.2	EMBRYO - LARVAE	Hansen et al. (1986)
	Gulf toadfish	BCF	49	9.7	EMBRYO - LARVAE	Hansen et al. (1986)
	Gulf toadfish	BCF	49	18	EMBRYO - LARVAE	Hansen et al. (1986)
	Gulf toadfish	BCF	49	21	EMBRYO - LARVAE	Hansen et al. (1986)
	Gulf toadfish	BCF	49	46.0	EMBRYO - LARVAE	Hansen et al. (1986)
	Gulf toadfish	BCF	49	46.0	EMBRYO - LARVAE	Hansen et al. (1986)
	Gulf toadfish	BCF	49	50.0	EMBRYO - LARVAE	Hansen et al. (1986)
	Gulf toadfish	BCF	49	93.0	EMBRYO - LARVAE	Hansen et al. (1986)
	Gulf toadfish	BCF	49	150	EMBRYO - LARVAE	Hansen et al. (1986)
	Gulf toadfish	GRO	49	1.4	EMBRYO - LARVAE	Hansen et al. (1986)
	Gulf toadfish	GRO	49	3.7	EMBRYO - LARVAE	Hansen et al. (1986)
	Gulf toadfish	GRO	49	18	EMBRYO - LARVAE	Hansen et al. (1986)
	Gulf toadfish	MOR	49	46.0	EMBRYO - LARVAE	Hansen et al. (1986)
	Gulf toadfish	MOR	49	93.0	EMBRYO - LARVAE	Hansen et al. (1986)
	Gulf toadfish	MOR	49	150	EMBRYO - LARVAE	Hansen et al. (1986)
	Inland silverside	LC50	4	4.2	72 D	Clark et al. (1985)
	Lake trout, siscowet	LC50	4	98	2.3 G	Johnson and Finley (1980)
	Largemouth bass	BCF	1	2.38	17.1 G ; 10.5 CM	Macek et al. (1972)
	Largemouth bass	BCF	1	0.995	17.1 G, 10.5 CM	Macek et al. (1972)
	Largemouth bass	BCF	3	1.73	17.1 G ; 10.5 CM	Macek et al. (1972)
	Largemouth bass	BCF	3	0.305	17.1 G ; 10.5 CM	Macek et al. (1972)
	Largemouth bass	BCF	7	0.20	17.1 G ; 10.5 CM	Macek et al. (1972)
	Largemouth bass	BCF	7	1.08	17.1 G, 10.5 CM	Macek et al. (1972)
	Largemouth bass	BCF	28	0.15	17.1 G ; 10.5 CM	Macek et al. (1972)
	Largemouth bass	BCF	28	0.165	17.1 G ; 10.5 CM	Macek et al. (1972)
	Largemouth bass	BCF	35	1.66	17.1 G ; 10.5 CM	Macek et al. (1972)
	Largemouth bass	BCF	35	0.595	17.1 G ; 10.5 CM	Macek et al. (1972)
	Largemouth bass	BCF	37	0.38	17.1 G ; 10.5 CM	Macek et al. (1972)
	Largemouth bass	BCF	37	1.02	17.1 G ; 10.5 CM	Macek et al. (1972)

Table 20. (continued) Toxicology of aquatic and terrestrial species. Chemical: Chlorpyriphos, CAS number: 2921882

Class	Species	Effect	Duration (Days)	Concentration (ug/l)	Life Stage	Reference
	Largemouth bass	BCF	49	0.04	17.1 G ; 10.5 CM	Macek et al. (1972)
	Largemouth bass	BCF	49	0.06	17.1 G ; 10.5 CM	Macek et al. (1972)
	Longnose killifish	LC50	4	4.1	NR	Schimmel et al. (1983)
	Medaka, high-eyes	LC50	1	310	NR	Shim and Self (1973)
	Milkfish, salmon-herring	LC50	3	0.15 mg/kg	FINGERLING	Tsai (1978)
	Milkfish, salmon-herring	LC50	3	0.010 mg/kg	FRY, 6.0-6.5 CM, 2.8-3.2 G	Tsai (1978)
	Mosquitofish (Gambusia affinis)	LC0	2	500	2.54 CM	Darwazeh and Mulla (1974)
	Mosquitofish (Gambusia affinis)	LC50	1	190	NR	Ahmed (1977)
	Mosquitofish (Gambusia affinis)	LC50	1	200	NR	Ahmed (1977)
	Mosquitofish (Gambusia affinis)	LC50	1	200	NR	Ahmed (1977)
	Mosquitofish (Gambusia affinis)	LC50	1	220	NR	Ahmed (1977)
	Mosquitofish (Gambusia affinis)	LC50	1	1400	MATURE GRAVID FEMALES,0.6G,3.2CM	Davey et al. (1976)
	Mosquitofish (Gambusia affinis)	LC50	1	4000	NR	Hansen et al. (1972)
	Mosquitofish (Gambusia affinis)	LC50	2	440	MATURE GRAVID FEMALES,0.6G,3.2CM	Davey et al. (1976)
	Mosquitofish (Gambusia affinis)	LC50	3	260	MATURE GRAVID FEMALES,0.6G,3.2CM	Davey et al. (1976)
	Mosquitofish (Gambusia affinis)	LC50	4	280	0.5 G	Carter and Graves (1972)
	Mosquitofish (Gambusia affinis)	LC50	4	570	NR	Scirocchi and Erme (1980)
	Mosquitofish (Gambusia affinis)	AVO	1 hr	100	20-45 MM	Hansen et al. (1972)
	Mosquitofish (Gambusia affinis)	BCF	1	<4	NR	Hurlbert et al. (1970)
	Mosquitofish (Gambusia affinis)	BCF	1	<4	NR	Hurlbert et al. (1970)
	Mosquitofish (Gambusia affinis)	BCF	2	<4	NR	Hurlbert et al. (1970)
	Mosquitofish (Gambusia affinis)	BCF	2	<4	NR	Hurlbert et al. (1970)
	Mosquitofish (Gambusia affinis)	BCF	4 hr	10	NR	Hurlbert et al. (1970)
	Mosquitofish (Gambusia affinis)	BCF	4 hr	10	NR	Hurlbert et al. (1970)
	Mosquitofish (Gambusia affinis)	BCF	4 hr	223	NR	Hurlbert et al. (1970)
	Mosquitofish (Gambusia affinis)	BCF	4 hr	223	NR	Hurlbert et al. (1970)
	Mosquitofish (Gambusia affinis)	LET	4 hr	<4-223	ADULT AND NYMPHS	Hurlbert et al. (1970)
	Mosquitofish (Gambusia affinis)	MOR	1	0.10	2.5 CM	Darwazeh and Mulla (1974)
	Mosquitofish (Gambusia affinis)	MOR	1	0.50	2.5 CM	Darwazeh and Mulla (1974)
	Mosquitofish (Gambusia affinis)	MOR	1	0.50	2.5 CM	Darwazeh and Mulla (1974)
	Mosquitofish (Gambusia affinis)	MOR	1	1000	2.54 CM	Darwazeh and Mulla (1974)
	Mosquitofish (Gambusia affinis)	MOR	2	<4-10	NR	Hurlbert et al. (1970)
	Mosquitofish (Gambusia affinis)	MOR	2	<4-223	NR	Hurlbert et al. (1970)
	Mosquitofish (Gambusia affinis)	MOR	5	0.05	2.5 CM	Darwazeh and Mulla (1974)
	Mosquitofish (Gambusia affinis)	MOR	15	0.011	NR	Hurlbert et al. (1970)
	Mosquitofish (Gambusia affinis)	TKL	1	1	NR	Johnson (1978a)
	Mosquitofish (Gambusia affinis)	TKL	1	25	18-53 MM	Johnson (1977)
	Mosquitofish (Gambusia affinis)	TKL	2	5	NR	Johnson (1978a)
	Motsugo, stone moroko	ENZ	0.20	0.000025 m	4-8 CM, 1-5 G	Kanazawa (1983)
	Mullet	ENZ	NR	3	NR	Fytizas and Vassiliou (1980)
	Mummichog	EC50EZ	0.50	1.44	NR	Thirugnanam and Forgash (1977)
	Mummichog	EC50EZ	0.50	25200	NR	Thirugnanam and Forgash (1977)
	Mummichog	LC50	4	4.65	1.67 G,5.54 CM	Thirugnanam and Forgash (1977)

	Mummichog	LT50	NR	5.6	1.67 G,5.54 CM	Thirugnanam and Forgash (1977)
	Mummichog	ENZ	1	1.0	1.67 G, 5.54 CM	Thirugnanam and Forgash (1977)
	Northern pike, pike	LC50	2	3.3	NR	Scirocchi and Erme (1980)
	Oikawa	LC50	1	1700	NR	Shim and Self (1973)
	Rainbow trout,donaldson trout	LC50	1	53	0.6-1.5 G	Macek et al. (1969)
	Rainbow trout,donaldson trout	LC50	1	110	0.6-1.5 G	Macek et al. (1969)

Table 20. (continued) Toxicology of aquatic and terrestrial species. Chemical: Chlorpyriphos, CAS number: 2921882

Class	Species	Effect	Duration (Days)	Concentration (μg/l)	Life Stage	Reference
	Rainbow trout,donaldson trout	LC50	1	550	0.6-1.5 G	Macek et al. (1969)
	Rainbow trout,donaldson trout	LC50	2	11.4	JUVENILE, 1.0 G	Holcombe et al. (1982)
	Rainbow trout,donaldson trout	LC50	2	240	NR	Scirocchi and Erme (1980)
	Rainbow trout,donaldson trout	LC50	3	8.0	JUVENILE, 1.0 G	Holcombe et al. (1982)
	Rainbow trout,donaldson trout	LC50	4	7.1	0.6-1.5 G	Macek et al. (1969)
	Rainbow trout,donaldson trout	LC50	4	7.1	1.4 G	Johnson and Finley (1980)
	Rainbow trout,donaldson trout	LC50	4	8.0	JUVENILE, 1.0 G	Holcombe et al. (1982)
	Rainbow trout,donaldson trout	LC50	4	9	3.0 G	Phipps and Holcombe (1985)
	Rainbow trout,donaldson trout	LC50	4	15	0.6-1.5 G	Macek et al. (1969)
	Rainbow trout,donaldson trout	LC50	4	51	0.6-1.5 G	Macek et al. (1969)
	Rainbow trout,donaldson trout	LC50	NR	7600	NR	Meyer (1981)
	Rainbow trout,donaldson trout	LC50	NR	8950	NR	Meyer (1981)
	Roach	LC50	4	120.	NR	Scirocchi and Erme (1980)
	Sheepshead minnow	LC50	4	136	NR	Schimmel et al. (1983)
	Sheepshead minnow	AVO	0.50	100	20-40 MM	Hansen (1969)
	Sheepshead minnow	AVO	NR	100	20-40 MM	Hansen (1970)
	Striped mullet	LC50	4	5.4	NR	Schimmel et al. (1983)
	Tench	LC50	3	45	NR	Scirocchi and Erme (1980)
	Tidewater silverside	LC50	4	1.3	60 D	Clark et al. (1985)
	Tilapia (Tilapia nilotica)	LC50	0.5	132	1.5 G, 41.5 MM	El-Refai et al. (1976)
	Tilapia (Tilapia nilotica)	LC50	0.5	140	5.36 G, 64 MM	El-Refai et al. (1976)
	Tilapia (Tilapia nilotica)	LC50	0.5	180	13.8 G, 89 MM	El-Refai et al. (1976)
	Tilapia (Tilapia nilotica)	LC50	0.5	200	5.36 G, 64 MM	El-Refai et al. (1976)
	Tilapia (Tilapia nilotica)	LC50	1	84	1.5 G, 41.5 MM	El-Refai et al. (1976)
	Tilapia (Tilapia nilotica)	LC50	1	90	5.36 G, 64 MM	El-Refai et al. (1976)
	Tilapia (Tilapia nilotica)	LC50	1	120	5.36 G, 64 MM	El-Refai et al. (1976)
	Tilapia (Tilapia nilotica)	LC50	1	139	13.8 G, 89 MM	El-Refai et al. (1976)
	Tilapia (Tilapia aurea)	LC50	1	418	1.14 G	Herzberg (1987)
	Tilapia (Tilapia nilotica)	LC50	2	62	1.5 G, 41.5 MM	El-Refai et al. (1976)
	Tilapia (Tilapia nilotica)	LC50	2	70	5.36 G, 64 MM	El-Refai et al. (1976)
	Tilapia (Tilapia nilotica)	LC50	2	100	5.36 G, 64 MM	El-Refai et al. (1976)
	Tilapia (Tilapia nilotica)	LC50	2	114	13.8 G, 89 MM	El-Refai et al. (1976)
	Tilapia (Tilapia nilotica)	LC50	3	151	19.3 G	Herzberg (1987)
	Tilapia (Tilapia aurea)	BCF	5	72-1060	1.14 G	Herzberg (1987)
	Tilapia (Tilapia aurea)	BCF	5	72-1060	1.14 G	Herzberg (1987)
	Tilapia (Tilapia aurea)	BCF	5	72-1060	1.14 G	Herzberg (1987)
	Tilapia (Tilapia aurea)	BCF	5	72-1060	1.14 G	Herzberg (1987)
	Tooth carp	LC50	2	0.215 μl/l	NR	Boumaiza et al. (1979)
	Tooth carp	LC50	2	0.2045 μl/l	NR	Boumaiza et al. (1979)
	Tooth carp	LC50	4	0.169 μl/l	NR	Boumaiza et al. (1979)
	Tooth carp	LC50	4	0.1634 μl/l	NR	Boumaiza et al. (1979)
	White sucker	BCF	1	6.4	JUVENILE	Siefert (1987)
	White sucker	BCF	3	4.5	JUVENILE	Siefert (1987)
	White sucker	BCF	5	2.4	JUVENILE	Siefert (1987)
	White sucker	BCF	7	1.76	JUVENILE	Siefert (1987)
	White sucker	BCF	14	0.77	JUVENILE	Siefert (1987)

	White sucker	BCF	21	0.39	JUVENILE	Siefert (1987)
	White sucker	STR	28	0.16-17.3	JUVENILE	Siefert (1987)
INSECT	Backswimmer (Neoplea striola)	LC50	2	2.42	NR	Siefert (1987)
	Backswimmer (Neoplea striola)	LC50	2	3.17	NR	Siefert (1987)
	Backswimmer (Neoplea striola)	LC50	3	1.59	NR	Siefert (1987)
	Backswimmer (Neoplea striola)	LC50	3	1.76	NR	Siefert (1987)
	Backswimmer (Neoplea striola)	LC50	4	1.22	NR	Siefert (1987)

Table 20. (continued) Toxicology of aquatic and terrestrial species. Chemical: Chlorpyriphos, CAS number: 2921882

Class	Species	Effect	Duration (Days)	Concentration (μg/l)	Life Stage	Reference
	Backswimmer (Neoplea striola)	LC50	4	1.56	NR	Siefert (1987)
	Backswimmer (Neoplea striola)	LC50	6	0.97	NR	Siefert (1987)
	Backswimmer (Neoplea striola)	STR	1.25	>6.1	NR	Siefert (1987)
	Backswimmer (Notonecta undulata)	LC50	1	35.2	ADULT	Roberts and Miller (1971)
	Backswimmer (Notonecta sp)	LET	6 hr	9-10	NR	Siefert (1987)
	Beetle (Berosus styliferus)	LC50	1	9	ADULT	Ahmed (1977)
	Beetle (Helophorus sp)	ABD	65	72	ADULT	Hurlbert et al. (1972)
	Beetle (Hydrophilus triangularis)	LC50	1	20	LARVA	Ahmed (1977)
	Beetle (Hydrophilus triangularis)	LC50	1	30	ADULT	Ahmed (1977)
	Beetle (Hygrotus sp)	LC50	1	40	ADULT	Ahmed (1977)
	Beetle (Laccophilus fasciatus)	LC50	1	2.1	ADULT	Roberts and Miller (1971)
	Beetle (Laccophilus decipiens)	LC50	1	4.6	ADULT	Ahmed (1977)
	Beetle (Laccophilus fasciatus)	ABD	14	<0.1-1.6	LARVAE	Roberts and Miller (1971)
	Beetle (Laccophilus sp)	ABD	65	7.2	LARVAE	Hurlbert et al. (1972)
	Beetle (Laccophilus sp)	ABD	65	7.2	ADULTS	Hurlbert et al. (1972)
	Beetle (Laccophilus sp)	ABD	65	72	LARVAE	Hurlbert et al. (1972)
	Beetle (Laccophilus sp)	ABD	65	72	ADULTS	Hurlbert et al. (1972)
	Beetle (Laccophilus fasciatus)	ABD	77	0.9-2.7	LARVAE	Roberts and Miller (1971)
	Beetle (Peltodytes sp)	LC50	3	0.9	ADULT,5 MG	Federle and Collins (1976)
	Beetle (Peltodytes sp)	LC50	4	0.8	ADULT,5 MG	Federle and Collins (1976)
	Beetle (Thermonectus basillaris)	LC50	1	6	ADULT	Ahmed (1977)
	Beetle (Tropisternus lateralis)	LC50	1	8	ADULT	Ahmed (1977)
	Beetle (Tropisternus lateralis)	LC50	1	52	LARVA	Ahmed (1977)
	Beetle (Tropisternus lateralis)	ABD	65	7.2	LARVAE	Hurlbert et al. (1972)
	Beetle (Tropisternus lateralis)	ABD	65	7.2	ADULT	Hurlbert et al. (1972)
	Beetle (Tropisternus lateralis)	ABD	65	72	LARVAE	Hurlbert et al. (1972)
	Beetle (Tropisternus lateralis)	ABD	65	72	ADULT	Hurlbert et al. (1972)
	Blackfly (Simulium ornatum)	HAT	1	1	EGG	Muirhead-Thomson and Merryweather (1969)
	Blackfly (Simulium ornatum)	HAT	1	1000	EGG	Muirhead-Thomson and Merryweather (1969)
	Blackfly (Simulium ornatum)	MOR	1	100	EGG	Muirhead-Thomson and Merryweather (1969)
	Blackfly family	ABD	0.25	100	LARVAE	Wallace et al. (1973)
	Blackfly family	ABD	0.25	100	LARVAE	Wallace et al. (1973)
	Blackfly family	ABD	0.25	100	LARVAE	Wallace et al. (1973)
	Blackfly family	ABD	0.25	100	LARVAE	Wallace et al. (1973)

	Blackfly family	ABD	0.25	100	LARVAE	Wallace et al. (1973)
	Blackfly family	ABD	0.25	100	LARVAE	Wallace et al. (1973)
	Blackfly family	ABD	0.25	100	LARVAE	Wallace et al. (1973)
	Blackfly family	ABD	0.25	100	LARVAE	Wallace et al. (1973)
	Blackfly family	ABD	0.25	100	LARVAE	Wallace et al. (1973)
	Blackfly family	ABD	0.25	100	LARVAE	Wallace et al. (1973)
	Blackfly family	ABD	0.25	100	LARVAE	Wallace et al. (1973)
	Blackfly family	ABD	0.25	100	LARVAE	Wallace et al. (1973)
	Blackfly family	ABD	0.25	100	LARVAE	Wallace et al. (1973)
	Blackfly family	ABD	0.25	100	LARVAE	Wallace et al. (1973)
	Blackfly family	ABD	0.25	100	LARVAE	Wallace et al. (1973)
	Blackfly family	ABD	0.25	100	LARVAE	Wallace et al. (1973)
	Blackfly family	ABD	0.25	100	LARVAE	Wallace et al. (1973)
	Blackfly family	ABD	0.25	100	LARVAE	Wallace et al. (1973)
	Blackfly family	DRF	0.08 hr	400	LARVAE, 3RD-6TH INSTAR	Jamnback and Frempong-Boadu (1966)

Table 20. (continued) Toxicology of aquatic and terrestrial species. Chemical: Chlorpyriphos, CAS number: 2921882

Class	Species	Effect	Duration (Days)	Concentration (µg/l)	Life Stage	Reference
	Blackfly family	DRF	0.08 hr	4000	LARVAE, 3RD-6TH INSTAR	Jamnback and Frempong-Boadu (1966)
	Blackfly family	DRF	0.25	100	LARVAE	Wallace et al. (1973)
	Blackfly family	DRF	0.25	100	LARVAE	Wallace et al. (1973)
	Blackfly family	DRF	0.25	100	LARVAE	Wallace et al. (1973)
	Blackfly family	DRF	0.25	100	LARVAE	Wallace et al. (1973)
	Blackfly family	DRF	0.25	100	LARVAE	Wallace et al. (1973)
	Blackfly family	DRF	0.25	100	LARVAE	Wallace et al. (1973)
	Caddisfly family	LC50	2	0.87	NR	Siefert (1987)
	Caddisfly family	LC50	4	0.77	NR	Siefert (1987)
	Caddisfly family	NOR	2	0.62	NR	Siefert (1987)
	Caddisfly order	ABD	0.25	100	LARVAE	Wallace et al. (1973)
	Caddisfly order	ABD	0.25	100	LARVAE	Wallace et al. (1973)
	Caddisfly order	ABD	0.25	100	LARVAE	Wallace et al. (1973)
	Caddisfly order	ABD	0.25	100	LARVAE	Wallace et al. (1973)
	Caddisfly order	ABD	0.25	100	LARVAE	Wallace et al. (1973)
	Caddisfly order	ABD	0.25	100	LARVAE	Wallace et al. (1973)
	Caddisfly order	DRF	0.25	100	LARVAE	Wallace et al. (1973)
	Caddisfly order	STR	5 hr	8.6-15.9	NR	Siefert (1987)
	Dragonfly and damselfly order	ABD	65	7.2	NAIADS	Hurlbert et al. (1972)
	Giant water bug	LC50	1	15	ADULT	Ahmed (1977)
	Insect class	ABD	65	7.2	LARVAE, NYMPHS, AND ADULTS	Hurlbert et al. (1972)
	Insect class	ABD	65	7.2	LARVAE, NYMPHS, AND ADULTS	Hurlbert et al. (1972)
	Insect class	ABD	65	72	LARVAE, NYMPHS, AND ADULTS	Hurlbert et al. (1972)
	Insect class	ABD	65	72	LARVAE, NYMPHS, AND ADULTS	Hurlbert et al. (1972)
	Mayfly (Ephemerella sp)	LC50	2	0.40	NR	Siefert (1987)
	Mayfly (Ephemerella sp)	LC50	3	0.33	NR	Siefert (1987)
	Mayfly family	ABD	65	7.2	NYMPH	Hurlbert et al. (1972)
	Mayfly family	ABD	65	72	NYMPH	Hurlbert et al. (1972)
	Mayfly order	ABD	0.25	100	NYMPH	Wallace et al. (1973)
	Mayfly order	ABD	0.25	100	NYMPH	Wallace et al. (1973)
	Mayfly order	ABD	0.25	100	NYMPH	Wallace et al. (1973)
	Mayfly order	ABD	0.25	100	NYMPH	Wallace et al. (1973)
	Mayfly order	ABD	0.25	100	NYMPH	Wallace et al. (1973)
	Mayfly order	ABD	0.25	100	NYMPH	Wallace et al. (1973)
	Mayfly order	DRF	0.25	100	NYMPH	Wallace et al. (1973)
	Midge (Chaoborus americanus)	LC50	0.75	2.36	NR	Siefert (1987)
	Midge (Chaoborus americanus)	LC50	1.75	1.29	NR	Siefert (1987)
	Midge (Chaoborus americanus)	LC50	4.75	0.85	NR	Siefert (1987)
	Midge (Chaoborus americanus)	STR	0.4167	9.5-15.9	NR	Siefert (1987)
	Midge (Chironomus sp)	EC50IM	1	0.42	LARVAE, 4TH INSTAR	Mulla and Khasawinah (1969)
	Midge (Chironomus tentans)	EC50IM	1	6.4	3RD-4TH INSTAR	Karnak and Collins (1974)
	Midge (Chironomus sp)	EC50IM	2	1.1	4TH INSTAR	Norland et al. (1974)
	Midge (Chironomus sp)	EC50IM	2	230	4TH INSTAR	Norland et al. (1974)
	Midge (Chironomus utahensis)	LC50	1	1.2	4TH INSTAR	Ali and Mulla (1978a)
	Midge (Chironomus utahensis)	LC50	1	1.2	4TH INSTAR	Ali and Mulla (1977)

	Midge (Chironomus utahensis)	LC50	1	5.4	4TH INSTAR	Ali and Mulla (1978a)
	Midge (Chironomus decorus)	LC50	1	7	4TH INSTAR	Ali and Mulla (1978a)
	Midge (Chironomus decorus)	LC50	1	46	4TH INSTAR	Ali and Mulla (1978a)
	Midge (Chironomus stigmaterus)	ABD	3	0.06	LARVAE	Mulla and Khasawinah (1969)
	Midge (Chironomus stigmaterus)	ABD	3	0.06	LARVAE	Mulla and Khasawinah (1969)
	Midge (Chironomus stigmaterus)	ABD	3	0.11	LARVAE	Mulla and Khasawinah (1969)

Table 20. (continued) Toxicology of aquatic and terrestrial species. Chemical: Chlorpyriphos, CAS number: 2921882

Class	Species	Effect	Duration (Days)	Concentration (µg/l)	Life Stage	Reference
	Midge (Chironomus utahensis)	ABD	42	0.22 kg/ha	LARVAE	Ali and Mulla (1977)
	Midge (Chironomus sp)	ABD	49	0.14 kg/ha	LARVAE	Ali and Mulla (1977)
	Midge (Cricotopus sp)	LC50	1	6.5	4TH INSTAR	Ali and Mulla (1977)
	Midge (Goeldichironomus holoprassinus)	EC50IM	1	0.97	LARVAE, 4TH INSTAR	Mulla and Khasawinah (1969)
	Midge (Goeldichironomus holoprassinus)	ABD	3	0.06	LARVAE	Mulla and Khasawinah (1969)
	Midge (Goeldichironomus holoprassinus)	ABD	3	0.06	LARVAE	Mulla and Khasawinah (1969)
	Midge (Goeldichironomus holoprassinus)	ABD	3	0.28	LARVAE	Mulla and Khasawinah (1969)
	Midge (Paratanytarsus sp)	LET	0.75	1.6	NR	Siefert (1987)
	Midge (Procladius sp)	LC50	1	0.5	4TH INSTAR	Ali and Mulla (1978a)
	Midge (Procladius sp)	LC50	1	0.5	4TH INSTAR	Ali and Mulla (1977)
	Midge (Procladius sp)	LC50	1	71	4TH INSTAR	Ali and Mulla (1978a)
	Midge (Procladius sp)	ABD	42	0.22 kg/ha	LARVAE	Ali and Mulla (1977)
	Midge (Procladius sp)	ABD	70	0.14 kg/ha	LARVAE	Ali and Mulla (1977)
	Midge (Tanypus grodhausi)	EC50IM	1	0.5	LARVAE, 4TH INSTAR	Mulla and Khasawinah (1969)
	Midge (Tanypus grodhausi)	EC50IM	1	5.7	LARVAE, 4TH INSTAR	Mulla and Khasawinah (1969)
	Midge (Tanypus grodhausi)	ABD	3	0.06	LARVAE	Mulla and Khasawinah (1969)
	Midge (Tanypus grodhausi)	ABD	3	0.06	LARVAE	Mulla and Khasawinah (1969)
	Midge (Tanypus grodhausi)	ABD	3	0.11	LARVAE	Mulla and Khasawinah (1969)
	Midge (Tanypus grodhausi)	ABD	3	0.28	LARVAE	Mulla and Khasawinah (1969)
	Midge family	ABD	0.25	100	LARVAE	Wallace et al. (1973)
	Midge family	ABD	0.25	100	LARVAE	Wallace et al. (1973)
	Midge family	ABD	0.25	100	LARVAE	Wallace et al. (1973)
	Midge family	ABD	0.25	100	LARVAE	Wallace et al. (1973)
	Midge family	ABD	0.25	100	LARVAE	Wallace et al. (1973)
	Midge family	ABD	0.25	100	LARVAE	Wallace et al. (1973)
	Midge family	ABD	28	<0.1-1.6	ADULT	Roberts and Miller (1971)
	Midge family	ABD	84	0.9-2.7	ADULT	Roberts and Miller (1971)
	Midge family	DRF	0.25	100	LARVAE	Wallace et al. (1973)

	Mosquito (Aedes cantans)	LC100	3	10	YOUNG 4TH INSTAR	Rettich (1979)
	Mosquito (Aedes vexans)	LC50	0.2917	1.70	NR	Siefert (1987)
	Mosquito (Aedes vexans)	LC50	0.2917	2.27	NR	Siefert (1987)
	Mosquito (Aedes triseriatus)	LC50	1	0.20	1ST INSTAR	Nelson and Evans (1973)
	Mosquito (Aedes aegypti)	LC50	1	0.30	1ST INSTAR	Nelson and Evans (1973)
	Mosquito (Aedes triseriatus)	LC50	1	0.36	2ND INSTAR	Nelson and Evans (1973)
	Mosquito (Aedes aegypti)	LC50	1	0.43	2ND INSTAR	Nelson and Evans (1973)
	Mosquito (Aedes vexans)	LC50	1	0.49	3RD INSTAR	Nelson and Evans (1973)
	Mosquito (Aedes sticticus)	LC50	1	0.5	LARVAE,4TH INSTAR	Rettich (1977)
	Mosquito (Aedes triseriatus)	LC50	1	0.77	3RD INSTAR	Nelson and Evans (1973)
	Mosquito	LC50	1	0.86	4TH INSTAR	Nelson and Evans (1973)
	Mosquito (Aedes vexans)	LC50	1	1.0	LARVAE,4TH INSTAR	Rettich (1977)
	Mosquito (Aedes cantans)	LC50	1	1.1	LARVAE,4TH INSTAR	Rettich (1977)
	Mosquito (Aedes communis)	LC50	1	1.2	LARVAE,4TH INSTAR	Rettich (1977)
	Mosquito (Aedes aegypti)	LC50	1	1.26	3RD INSTAR	Nelson and Evans (1973)
	Mosquito (Aedes triseriatus)	LC50	1	1.44	4TH INSTAR	Nelson and Evans (1973)
	Mosquito (Aedes aegypti)	LC50	1	2.31	4TH INSTAR	Nelson and Evans (1973)

Table 20. (continued) Toxicology of aquatic and terrestrial species. Chemical: Chlorpyriphos, CAS number: 2921882

Class	Species	Effect	Duration (Days)	Concentration (µg/l)	Life Stage	Reference
	Mosquito (Aedes punctor)	LC50	1	2.7	LARVAE,4TH INSTAR	Rettich (1977)
	Mosquito (Aedes excrucians)	LC50	1	3.3	LARVAE,4TH INSTAR	Rettich (1977)
	Mosquito (Aedes flavescens)	MOR	1	0.28	3RD AND 4TH INSTAR LARVAE	Dixon and Brust (1971)
	Mosquito (Aedes flavescens)	MOR	1	0.28	3RD AND 4TH INSTAR LARVAE	Dixon and Brust (1971)
	Mosquito (Aedes flavescens)	MOR	1	0.28	3RD AND 4TH INSTAR LARVAE	Dixon and Brust (1971)
	Mosquito (Anopheles freeborni)	LC50	1	3	LARVA	Ahmed (1977)
	Mosquito (Anopheles albimanus)	LC50	1	8	4TH INSTAR	Hemingway and Georghiou (1983)
	Mosquito (Culex pipiens molestus)	LC100	3	2	4TH INSTAR	Rettich (1979)
	Mosquito (Culex pipiens)	LC50	1	0.16	1ST INSTAR	Nelson and Evans (1973)
	Mosquito (Culex tritaeniorhynchus)	LC50	1	0.32	LARVAE	Shim and Self (1973)
	Mosquito (Culex pipiens)	LC50	1	0.34	2ND INSTAR	Nelson and Evans (1973)
	Mosquito (Culex pipiens molestus)	LC50	1	0.5	LARVAE	Rettich (1979)
	Mosquito (Culex pipiens)	LC50	1	0.5	LAB REARED LARVAE	Roberts and Miller (1971)
	Mosquito (Culex pipiens)	LC50	1	0.50	3RD INSTAR	Nelson and Evans (1973)
	Mosquito (Culex pipiens)	LC50	1	0.64	4TH INSTAR	Nelson and Evans (1973)
	Mosquito (Culex pipiens)	LC50	1	1.0	FIELD COLLECTED LARVAE	Roberts and Miller (1971)
	Mosquito (Culex pipiens molestus)	LC50	1	1.2	LARVAE	Rettich (1979)
	Mosquito (Culex pipiens molestus)	LC50	1	1.2	LARVAE,4TH INSTAR	Rettich (1977)
	Mosquito (Culex pipiens pipiens)	LC50	1	1.6	LARVAE,4TH INSTAR	Rettich (1977)
	Mosquito (Culex tarsalis)	LC50	1	2	LARVA	Ahmed (1977)
	Mosquito (Culex quinquefasciatus)	LC50	1	2.22	3RD INSTAR LARVA	Bolke et al. (1985)
	Mosquito (Culex quinquefasciatus)	LC50	1	2.34	3RD INSTAR LARVA	Bolke et al. (1985)
	Mosquito (Culex quinquefasciatus)	LC50	1	2.8	3RD OR 4TH INSTAR LARVAE	El-Khatib (1985)
	Mosquito (Culex quinquefasciatus)	LC50	1	3.75	3RD INSTAR LARVA	Bolke et al. (1985)
	Mosquito (Culex quinquefasciatus)	LC50	1	3.96	3RD INSTAR LARVA	Bolke et al. (1985)
	Mosquito (Culex quinquefasciatus)	LC50	1	4.1	LATE 3RD OR EARLY 4TH INSTAR LARVAE	El-Khatib (1985)
	Mosquito (Culex quinquefasciatus)	LC50	1	4.72	3RD INSTAR LARVA	Bolke et al. (1985)
	Mosquito (Culex quinquefasciatus)	LC50	1	4.90	3RD INSTAR LARVA	Bolke et al. (1985)
	Mosquito (Culex quinquefasciatus)	LC50	1	4.93	3RD INSTAR LARVA	Bolke et al. (1985)
	Mosquito (Culex quinquefasciatus)	LC50	1	6.21	3RD INSTAR LARVA	Bolke et al. (1985)
	Mosquito (Culex quinquefasciatus)	LC50	1	8.93	3RD INSTAR LARVA	Bolke et al. (1985)
	Mosquito (Culex pipiens molestus)	LC50	2	0.2	LARVAE	Rettich (1979)
	Mosquito (Culex pipiens molestus)	LC50	2	1.5	LARVAE	Rettich (1979)
	Mosquito (Culex pipiens)	LC50	NR	2.6	2ND INSTAR LARVAE	Saleh (1988)
	Mosquito (Culex pipiens quinquefasciata)	LET	1	0.7	3RD-4TH INSTAR LARVAE	Roberts and Miller (1970)
	Mosquito (Culex pipiens quinquefasciata)	LET	1	0.1 kg/ha	4TH INSTAR LARVAE	Mount et al. (1970)
	Mosquito (Culex pipiens quinquefasciata)	MOR	1	0.7	3RD-4TH INSTAR LARVAE	Roberts and Miller (1970)
	Mosquito (Culiseta melanura)	LC50	1	0.46	1ST INSTAR	Nelson and Evans (1973)
	Mosquito (Culiseta melanura)	LC50	1	0.58	2ND INSTAR	Nelson and Evans (1973)
	Mosquito (Culiseta melanura)	LC50	1	1.97	3RD INSTAR	Nelson and Evans (1973)
	Mosquito (Culiseta melanura)	LC50	1	2.20	4TH INSTAR	Nelson and Evans (1973)
	Mosquito (Culiseta annulata)	LC50	1	3.5	LARVAE,4TH INSTAR	Rettich (1977)
	Mosquito (Wyeomyia smithii)	DVP	7	1	2ND INSTAR LARVAE	Strickman (1985)
	Mosquito (Wyeomyia smithii)	MOR	7	1	2ND INSTAR LARVAE	Strickman (1985)
	Mosquito family	LET	1	0.018	LARVAE	Dixon and Brust (1971)
	Mosquito family	LET	1	0.028	LARVAE	Dixon and Brust (1971)

	Mosquito family	LET	1	0.028	LARVAE	Dixon and Brust (1971)
	Mosquito family	MOR	1	0.28	LARVAE	Dixon and Brust (1971)
	Mosquito family	MOR	1	0.28	LARVAE	Dixon and Brust (1971)
	Mosquito family	MOR	1	0.28	LARVAE	Dixon and Brust (1971)
	Phantom midge (Chaoborus punctipennis)	LC50	1	5.4	LARVAE	Roberts and Miller (1971)
	Phantom midge (Chaoborus punctipennis)	ABD	63	0.9-2.7	LARVAE	Roberts and Miller (1971)
	Phantom midge (Chaoborus punctipennis)	ABD	84	<0.1-1.6	LARVAE	Roberts and Miller (1971)
	Phantom midge (Chaoborus sp)	LET	1	100	LARVAE	Hughes (1977)

Table 20. (continued) Toxicology of aquatic and terrestrial species. Chemical: Chlorpyriphos, CAS number: 2921882

Class	Species	Effect	Duration (Days)	Concentration (µg/l)	Life Stage	Reference
	Phantom midge (Chaoborus sp)	MOR	2	1	LARVAE	Hughes (1977)
	Stonefly (Claassenia sabulosa)	LC50	1	8.2	20-25 MM	Sanders and Cope (1968)
	Stonefly (Claassenia sabulosa)	LC50	2	1.8	20-25 MM	Sanders and Cope (1968)
	Stonefly (Claassenia sabulosa)	LC50	4	0.57	2ND YR CLASS	Johnson and Finley (1980)
	Stonefly (Claassenia sabulosa)	LC50	4	0.57	20-25 MM	Sanders and Cope (1968)
	Stonefly (Plecoptera)	ABD	0.25	100	NYMPHS	Wallace et al. (1973)
	Stonefly (Plecoptera)	ABD	0.25	100	NYMPHS	Wallace et al. (1973)
	Stonefly (Plecoptera)	ABD	0.25	100	NYMPHS	Wallace et al. (1973)
	Stonefly (Plecoptera)	ABD	0.25	100	NYMPHS	Wallace et al. (1973)
	Stonefly (Plecoptera)	ABD	0.25	100	NYMPHS	Wallace et al. (1973)
	Stonefly (Plecoptera)	ABD	0.25	100	NYMPHS	Wallace et al. (1973)
	Stonefly (Plecoptera)	DRF	0.25	100	NYMPH	Wallace et al. (1973)
	Stonefly (Pteronarcella badia)	LC50	1	4.2	15-20 MM	Sanders and Cope (1968)
	Stonefly (Pteronarcys californica)	LC50	1	50	30-35 MM	Sanders and Cope (1968)
	Stonefly (Pteronarcella badia)	LC50	2	1.8	15-20 MM	Sanders and Cope (1968)
	Stonefly (Pteronarcys californica)	LC50	2	18	30-35 MM	Sanders and Cope (1968)
	Stonefly (Pteronarcella badia)	LC50	4	0.38	15-20 MM	Sanders and Cope (1968)
	Stonefly (Pteronarcys californica)	LC50	4	10	2ND YR CLASS	Johnson and Finley (1980)
	Stonefly (Pteronarcys californica)	LC50	4	10	30-35 MM	Sanders and Cope (1968)
	Water boatman (Corisella decolor)	ABD	1	<4-10	ADULT AND NYMPHS	Hurlbert et al. (1970)
	Water boatman (Corisella decolor)	ABD	1	<4-223	ADULT AND NYMPHS	Hurlbert et al. (1970)
	Water boatman (Corisella sp)	ABD	65	7.2	NYMPH	Hurlbert et al. (1972)
	Water boatman (Corisella sp)	ABD	65	7.2	ADULTS	Hurlbert et al. (1972)
	Water boatman (Corisella sp)	ABD	65	72	NYMPH	Hurlbert et al. (1972)
	Water boatman (Corisella sp)	ABD	65	72	ADULTS	Hurlbert et al. (1972)
	Water boatman (Corisella decolor)	ABD	70	0.011	ADULT AND NYMPHS	Hurlbert et al. (1970)
	Water strider	ABD	56	0.9-2.7	NYMPH AND ADULT	Roberts and Miller (1971)
	Water strider	ABD	56	<0.1-1.6	NYMPH AND ADULT	Roberts and Miller (1971)
	Waterbug order	ABD	65	7.2	NYMPH	Hurlbert et al. (1972)
	Waterbug order	ABD	65	7.2	ADULT	Hurlbert et al. (1972)
	Waterbug order	ABD	65	72	NYMPH	Hurlbert et al. (1972)
	Waterbug order	ABD	65	72	ADULT	Hurlbert et al. (1972)
	White dotted mosquito	LC50	1	0.32	3RD INSTAR	Nelson and Evans (1973)
MULLUSCA	Salt marsh snail	POP	90	28 g/ha	NR	Fitzpatrick and Sutherland (1978)
	Snail (Aplexa hypnorum)	LC50	4	>806	ADULT	Phipps and Holcombe (1985)
PLATYHELMI	Turbellarian, flatworm	MOR	1	4	1-1.5 CM	Levy and Miller (1978)
	Turbellarian, flatworm	MOR	1	4	1-1.5 CM	Levy and Miller (1978)
ROTIFERA	Rotifer (Asplanchna brightwelli)	ABD	28	<4-223	NR	Hurlbert et al. (1970)
	Rotifer (Asplanchna brightwelli)	ABD	74	7.2	NR	Hurlbert et al. (1972)
	Rotifer (Asplanchna brightwelli)	ABD	74	72	NR	Hurlbert et al. (1972)
	Rotifer (Brachionus sp)	ABD	74	7.2	NR	Hurlbert et al. (1972)
	Rotifer (Brachionus angularis)	ABD	74	7.2	NR	Hurlbert et al. (1972)
	Rotifer (Brachionus sp)	ABD	74	72	NR	Hurlbert et al. (1972)
	Rotifer (Brachionus quadridentata)	ABD	76	7.2	NR	Hurlbert et al. (1972)
	Rotifer (Brachionus budapestinensis)	ABD	76	7.2	NR	Hurlbert et al. (1972)
	Rotifer (Brachionus urceolaris)	ABD	76	7.2	NR	Hurlbert et al. (1972)
	Rotifer (Brachionus bidentata)	ABD	76	7.2	NR	Hurlbert et al. (1972)
	Rotifer (Brachionus plicatilis)	ABD	76	7.2	NR	Hurlbert et al. (1972)
	Rotifer (Brachionus calyciflorus)	ABD	76	7.2	NR	Hurlbert et al. (1972)
	Rotifer (Brachionus angularis)	ABD	76	72	NR	Hurlbert et al. (1972)

Table 20. (continued) Toxicology of aquatic and terrestrial species. Chemical: Chlorpyriphos, CAS number: 2921882

Class	Species	Effect	Duration (Days)	Concentration (ug/l)	Life Stage	Reference
	Rotifer (Brachionus quadridentata)	ABD	76	72	NR	Hurlbert et al. (1972)
	Rotifer (Brachionus budapestinensis)	ABD	76	72	NR	Hurlbert et al. (1972)
	Rotifer (Brachionus urceolaris)	ABD	76	72	NR	Hurlbert et al. (1972)
	Rotifer (Brachionus bidentata)	ABD	76	72	NR	Hurlbert et al. (1972)
	Rotifer (Brachionus plicatilis)	ABD	76	72	NR	Hurlbert et al. (1972)
	Rotifer (Brachionus calyciflorus)	ABD	76	72	NR	Hurlbert et al. (1972)
	Rotifer (Epiphanes brachionus)	ABD	76	7.2	NR	Hurlbert et al. (1972)
	Rotifer (Epiphanes brachionus)	ABD	76	72	NR	Hurlbert et al. (1972)
	Rotifer (Filinia terminalis)	ABD	76	7.2	NR	Hurlbert et al. (1972)
	Rotifer (Filinia terminalis)	ABD	76	72	NR	Hurlbert et al. (1972)
	Rotifer (Hexarthra intermedia)	ABD	76	7.2	NR	Hurlbert et al. (1972)
	Rotifer (Hexarthra intermedia)	ABD	76	72	NR	Hurlbert et al. (1972)
	Rotifer (Keratella sp)	ABD	76	7.2	NR	Hurlbert et al. (1972)
	Rotifer (Keratella sp)	ABD	76	72	NR	Hurlbert et al. (1972)
	Rotifer (Lecane sp)	ABD	76	7.2	NR	Hurlbert et al. (1972)
	Rotifer (Lecane sp)	ABD	76	72	NR	Hurlbert et al. (1972)
	Rotifer (Lepadella sp)	ABD	76	7.2	NR	Hurlbert et al. (1972)
	Rotifer (Lepadella sp)	ABD	76	72	NR	Hurlbert et al. (1972)
	Rotifer (Monostyla sp)	ABD	76	7.2	NR	Hurlbert et al. (1972)
	Rotifer (Monostyla quadridentata)	ABD	76	7.2	NR	Hurlbert et al. (1972)
	Rotifer (Monostyla sp)	ABD	76	72	NR	Hurlbert et al. (1972)
	Rotifer (Monostyla quadridentata)	ABD	76	72	NR	Hurlbert et al. (1972)
	Rotifer (Platyias quadricornis)	ABD	76	7.2	NR	Hurlbert et al. (1972)
	Rotifer (Platyias quadricornis)	ABD	76	72	NR	Hurlbert et al. (1972)
	Rotifer (Polyarthra trigla)	ABD	76	7.2	NR	Hurlbert et al. (1972)
	Rotifer (Polyarthra trigla)	ABD	76	72	NR	Hurlbert et al. (1972)
	Rotifer (Testudinella patina)	ABD	76	7.2	NR	Hurlbert et al. (1972)
	Rotifer (Testudinella patina)	ABD	76	72	NR	Hurlbert et al. (1972)
	Rotifer phylum	ABD	76	7.2	NR	Hurlbert et al. (1972)
	Rotifer phylum	ABD	76	72	NR	Hurlbert et al. (1972)

Table 21. Toxicology of aquatic and terrestrial species. Chemical: DCPA, CAS number: 1861321

Class	Species	Effect	Duration (Days)	Concentration (ug/l)	Life Stage	Reference
ALGAE	Algae,phytoplankton,algal mat	PGR	4 hr	1000	NR	Butler (1964)
	Green algae (Chlamydomonas eugametos)	PGR	2	3300	INIT CONC 100000 CELLS/ML	Hess (1980)
	Green algae (Chlamydomonas eugametos)	PGR	2	33000	INIT CONC 100000 CELLS/ML	Hess (1980)
	Green algae (Chlamydomonas eugametos)	PGR	4	200000	2ND D OF LOG PHASE	Vance and Smith (1969)
	Green algae (Chlorella pyrenoidosa)	PGR	4	200000	2ND D OF LOG PHASE	Vance and Smith (1969)
	Green algae (Scenedesmus quadricauda)	PGR	4	200000	2ND D OF LOG PHASE	Vance and Smith (1969)
ANNELIDA	Tubificid worm (Tubifex tubifex)	LC50	2	286000	NR	Voronkin and Loshakov (1973)
CRUSTACEA	Brown shrimp	NOR	2	1000	NR	Butler (1964)
	Water flea (Daphnia pulex)	LC50	3 hr	>40000	NR	Nishiuchi and Hashimoto (1975)
	Water flea (Moina macrocopa)	LC50	3 hr	>40000	NR	Nishiuchi and Hashimoto (1975)

Table 21. (continued) Toxicology of aquatic and terrestrial species. Chemical: DCPA, CAS number: 1861321

Class	Species	Effect	Duration (Days)	Concentration (µg/l)	Life Stage	Reference
FISH	Bluegill	LC50	1	1000000	NR	Hughes and Davis (1964)
	Bluegill	LC50	2	700000	NR	Hughes and Davis (1964)
	Common, mirror, colored, carp	LC50	2	>10000	NR	Nishiuchi and Hashimoto (1975)
	Goldfish	LC50	2	>10000	NR	Nishiuchi and Hashimoto (1975)
	Medaka, high-eyes	LC50	2	>10000	NR	Nishiuchi and Hashimoto (1975)
	Sheepshead minnow	NOR	2	1000	JUVENILE	Butler (1964)
MOLLUSCA	American or virginia oyster	EC50GR	4	250	JUVENILE	Butler (1964)
TRACHEOPHYT	Duckweed (Lemna perpusilla)	NOR	7	300000	NR	Nishiuchi (1974)
MAMMAL	Rat	LC50	4 hr	>5.7 MG/L		Farm Chemicals Handbook (1990)
	Rat	LD50		>10000 MG/KG		Farm Chemicals Handbook (1990)

Table 23. Toxicology of aquatic and terrestrial species. Chemical: Dicamba, CAS number: 1918009

Class	Species	Effect	Duration (Days)	Concentration (µg/l)	Life Stage	Reference
AMPHIBIA	Brown frog	LC50	1	205000	TADPOLE,1-2 WK	Johnson (1976)
	Brown frog	LC50	2	166000	TADPOLE,1-2 WK	Johnson (1976)
	Brown frog	LC50	4	106000	1-2 WK	Johnson (1976)
	Tusked frog	LC50	1	220000	TADPOLE,1-2 WK	Johnson (1976)
	Tusked frog	LC50	2	202000	TADPOLE,1-2 WK	Johnson (1976)
	Tusked frog	LC50	4	185000	TADPOLE,1-2 WK	Johnson (1976)
CRUSTACEA	Aquatic sowbug (Asellus brevicaudus)	LC50	2	>100000	EARLY INSTAR	Sanders (1970a)
	Aquatic sowbug (Asellus brevicaudus)	LC50	4	>100000	MATURE	Johnson and Finley (1980)
	Crayfish (Orconectes nais)	LC50	2	>100000	EARLY INSTAR	Sanders (1970a)
	Grass shrimp (Palaemonetes kadiakensis)	LC50	2	>100000	EARLY INSTAR	Sanders (1970a)
	Grass shrimp (Palaemonetes kadiakensis)	LC50	4	>56000	MATURE	Johnson and Finley (1980)
	Ostracod (Cypridopsis vidua)	EC50IM	2	>100000	EARLY INSTAR	Sanders (1970a)
	Scud (Gammarus lacustris)	LC50	1	10000	2 MO	Sanders (1969)
	Scud (Gammarus lacustris)	LC50	2	5800	2 MO	Sanders (1969)
	Scud (Gammarus fasciatus)	LC50	2	>100000	EARLY INSTAR	Sanders (1970a)
	Scud (Gammarus lacustris)	LC50	4	3900	2 MO	Sanders (1969)
	Scud (Gammarus fasciatus)	LC50	4	>100000	MATURE	Johnson and Finley (1980)
	Water flea (Daphnia magna)	EC50IM	2	>100000	EARLY INSTAR	Sanders (1970a)
	Water flea (Daphnia magna)	EC50IM	2	>100000	1ST INSTAR	Johnson and Finley (1980)

Table 23. (continued) Toxicology of aquatic and terrestrial species. Chemical: Dicamba, CAS number: 1918009

Class	Species	Effect	Duration (Days)	Concentration (µg/l)	Life Stage	Reference
	Water flea (Daphnia pulex)	LC50	3 hr	>40000	NR	Nishiuchi and Hashimoto (1975)
	Water flea (Moina macrocopa)	LC50	3 hr	>40000	NR	Nishiuchi and Hashimoto (1975)
FISH	Bluegill	LC50	4	>50000	0.9 G	Johnson and Finley (1980)
	Coho salmon,silver salmon	MOR	6	109900	YEARLING	Lorz et al. (1979)
	Common, mirror, colored, carp	LC50	2	>40000	NR	Nishiuchi and Hashimoto (1975)
	Cutthroat trout	LC50	4	>50000	FINGERLING, 0.4-0.8 G	Woodward (1982)
	Goldfish	LC50	2	>40000	NR	Nishiuchi and Hashimoto (1975)
	Medaka, high-eyes	LC50	2	>40000	NR	Nishiuchi and Hashimoto (1975)
	Mosquitofish (Gambusia affinis)	LC50	1	516000	NR	Johnson (1978a)
	Mosquitofish (Gambusia affinis)	LC50	2	510000	NR	Johnson (1978a)
	Mosquitofish (Gambusia affinis)	LC50	4	465000	NR	Johnson (1978a)
	Rainbow trout,donaldson trout	LC50	4	28000	0.8 G	Johnson and Finley (1980)
BIRD	Bobwhite quail	LC50	NR	>4640		EPA (1983)
	Bobwhite quail	LC50	NR	>5620		EPA (1983)
	Bobwhite quail	LC50	NR	>5620		EPA (1983)
	Bobwhite quail	LC50	NR	>10000		EPA (1983)
	Mallard duck	LC50	NR	>4640		EPA (1983)
	Mallard duck	LC50	NR	>5620		EPA (1983)
	Mallard duck	LC50	NR	>5620		EPA (1983)
	Mallard duck	LC50	NR	>10000		EPA (1983)
	Mallard duck	LD50	NR	>2510		EPA (1983)
	Mallard duck	LD50	NR	>2510		EPA (1983)
	Mallard duck	LD50	NR	>2510		EPA (1983)
MAMMAL	Rat	LD50	NR	757		USDA Forest Service (1989)

Table 24. Toxicology of aquatic and terrestrial species. Chemical: Dicamba, Sodium salt, CAS number: 62610393

Class	Species	Effect	Duration (Days)	Concentration (µg/l)	Life Stage	Reference
CRUSTACEA	Water flea (Daphnia magna)	ABN	75	11500-45000	GENERATION 3 & 4	Trofimova (1979)
	Water flea (Daphnia magna)	DVP	75	23000-45000	4 GENERATIONS	Trofimova (1979)
	Water flea (Daphnia magna)	MOR	75	67000	4 GENERATIONS	Trofimova (1979)
FISH	Bluegill	LC50	1	20000	NR	Hughes and Davis (1962)
	Bluegill	LC50	1	67500	NR	Hughes and Davis (1962)

	Bluegill	LC50	1	600000	NR	Hughes and Davis (1962)
	Bluegill	LC50	2	20000	NR	Hughes and Davis (1962)
	Bluegill	LC50	2	67500	NR	Hughes and Davis (1962)
	Bluegill	LC50	2	410000	NR	Hughes and Davis (1962)

Table 53. Toxicology of aquatic and terrestrial species. Chemical: Trichlorfon, CAS number: 52686

Class	Species	Effect	Duration (Days)	Concentration (µg/l)	Life Stage	Reference
INVERTEBRATE	Honey bee	LO MOR	NR	2.00 KG/HA	ADULT	Korpela and Tulisalo (1974)
MAMMAL	Mouse (Mus sp.)	LD0.1	7	362.18 MG/KG	ADULT	Haley et al. (1975)
	Mouse (Mus sp.)	LD1	7	430.23 MG/KG	ADULT	Haley et al. (1975)
	Mouse (Mus sp.)	LD1	7	458.28	ADULT	Haley et al. (1975)
	Mouse (Mus sp.)	LD16	7	580.97 MG/KG	ADULT	Haley et al. (1975)
	Mouse (Mus sp.)	LD16	7	659.87	ADULT	Haley et al. (1975)
	Mouse (Mus sp.)	LD50	7	726.97 MG/KG	ADULT	Haley et al. (1975)
	Mouse (Mus sp.)	LD50	7	866.23	ADULT	Haley et al. (1975)
	Mouse (Mus sp.)	LO PHY	7	450.00 MG/KG	ADULT	Haley et al. (1975)
	Mouse (Mus sp.)	LO PHY	7	450.00 MG/KG	ADULT	Haley et al. (1975)
	Mouse (Mus sp.)	LO SIGNS	7	450.00 MG/KG	ADULT	Haley et al. (1975)
	Mouse (Mus sp.)	LO SIGNS	7	450.00 MG/KG	ADULT	Haley et al. (1975)
	Rat	LO PATH	30	50.00 MG/KG	120-150 D	Finkiewicz-Murawiejs 1978
	Rat	LO PHY	16	50.00 MG/KG	ADULT	Staples et al. (1976)
	Rat	LO PHY	16	76.00 MG/KG	ADULT	Staples et al. (1976)
	Rat	LO REP	16	75.00 MG/KG	ADULT	Staples et al. (1976)
	Rat	LO REP	16	432.00 MG/KG	ADULT	Staples et al. (1976)
	Rat	LO SIGNS	16	150.00 MG/KG	ADULT	Staples et al. (1976)
	Rat	NO REP	16	50.00 MG/KG	ADULT	Staples et al. (1976)
	Rat	NO REP	16	375.00 MG/KG	ADULT	Staples et al. (1976)
	Rat	NO SIGNS	16	75.00 MG/KG	ADULT	Staples et al. (1976)

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APPENDIX A

FIGURE A-3 GUIDE TO TURFGRASS PEST CONTROL
UNIVERISTY OF CALIFORNIA COOPERATIVE EXTENSION

CAUTION

PLANT
PESTICIDE USE WARNING — READ THE LABEL

CAUTION

Pesticides are poisonous and must be used with caution. READ the label CAREFULLY BEFORE opening a container. Precautions and directions MUST be followed exactly. Special protective equipment as indicated must be used.

STORAGE: Keep all pesticides in original containers only. Store separately in a locked shed or area. Keep all pesticides out of the reach of children, unauthorized personnel, pets and livestock. DO NOT STORE with foods, feeds or fertilizers. Post warning signs on pesticide storage areas.

USE: The suggestions given in this publication are based upon best current information. Follow directions: measure accurately to avoid residues exceeding tolerances, use exact amounts as indicated on the label or lesser amounts given in this publication. Use a pesticide only on crops, plants or animals shown on the label.

CONTAINER DISPOSAL: Consult your County Agricultural Commissioner for correct procedures for rinsing and disposing of empty containers. Do not transport pesticides in vehicles with foods, feeds, clothing, or other materials, and never in a closed cab with the vehicle driver.

RESPONSIBILITY: The grower is legally responsible for proper use of pesticides including drift to other crops or properties, and for excessive residues. Pesticides should not be applied over streams, rivers, ponds, lakes, run-off irrigation or other aquatic areas except where specific use for that purpose is intended.

BENEFICIAL INSECTS: Many pesticides are highly toxic to honey bees and other beneficial insects. The farmer, the beekeeper and the pest control industry should cooperate closely to keep losses of beneficial species to a minimum.

PROCESSED CROPS: Some processors will not accept a crop treated with certain chemicals. If your crop is going to a processor, be sure to check with the processor before making a pesticide application.

POSTING TREATED FIELDS: When worker safety reentry intervals are established be sure to keep workers out and post the treated areas with signs when required indicating the safe reentry date.

PERMIT REQUIREMENTS: Many pesticides require a permit from the County Agricultural Commissioner before possession or use. When such compounds are recommended in this publication, they are marked with an asterisk (*).

PLANT INJURY: Certain chemicals may cause injury or give less than optimum pest control if used at the wrong stage of plant development; in certain soil types; when temperatures are too high or too low; the wrong formulation is used; and excessive rates or incompatible materials are used.

PERSONAL SAFETY: Follow label directions exactly. Avoid splashing, spilling, leaks, spray drift or clothing contamination. Do NOT eat, smoke, drink, or chew while using pesticides. Provide for emergency medical care in advance.

To simplify information, trade names of products have been used. No endorsement of named products is intended, nor is criticism implied of similar products which are not mentioned.

GUIDE TO TURFGRASS PEST CONTROL

(to be used with *Turfgrass Pests,* Publication 4053)

JUNE 1988

Cooperative Extension University of California
Division of Agriculture and Natural Resources

LEAFLET 2209

For information about ordering this publication
or about ordering Publication 4053,
Turfgrass Pests, write to:

Publications
Division of Agriculture and Natural Resources
University of California
6701 San Pablo Avenue
Oakland, California 94608-1239

or telephone (415) 642-2431

Leaflet 2209

Printed in the United States of America.

This leaflet supplies information concerning chemicals that can be recommended for use in controlling pests of turfgrass. It cannot be used properly without *Turfgrass Pests*, Publication 4053, also published by the University of California, Division of Agriculture and Natural Resources. To obtain that publication, see the ordering instructions above.

Because of frequent changes in regulations, as well as new discoveries, information regarding chemicals is often short-lived. What can be recommended today may be declared illegal next week—or a new and better chemical may be discovered the week after. This leaflet, therefore, will be revised and reissued as often as necessary to keep it current. So—BEFORE APPLYING ANY CHEMICAL LISTED HERE—note the date on the cover of this leaflet. If it is not current, please check with your local University of California county farm advisor, or write to Publications at the address above. **MOST IMPORTANT**, check the pesticide label for the specific use before application.

GUIDE TO TURFGRASS PEST CONTROL

(to be used with *Turfgrass Pests*, Publication 4053)

THE AUTHORS

Information and tables herein were prepared on—

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- **disease control** by Arthur H. McCain, Extension Plant Pathologist, Berkeley; and Robert M. Endo, Professor of Plant Pathology, and Howard D. Ohr, Extension Plant Pathologist, Riverside
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- **rodent control** by Terrell P. Salmon, Extension Wildlife Specialist, Davis

HOW TO USE THIS LEAFLET

The companion publication *Turfgrass Pests* will help you identify your pest, whether it be an insect, disease, weed, or rodent. In most cases, we will suggest cultural practices or other nonchemical means to avoid or control problems. More often than not, cultural practices are safer and cheaper than pesticide applications. This is true not only from a curative approach but—more importantly—from a preventive one as well. Proper turf variety selection, irrigation, fertilization, mowing height, and thatch removal will result in healthy, vigorous turf. The increased vigor allows the turf to withstand insect, disease, and nematode damage better and to recover more quickly. Healthy turf also can out-compete weeds and reduce the chances of their becoming established. The net result will be less pesticide use and less hazard of human exposure.

If chemical control is still called for, this leaflet lists one or more materials that can be recommended. In all cases:

1. Observe safety precautions. *Safe* handling and application are as important as *effective* application.
2. Follow manufacturer's recommendations as to dosage. Applying more can be dangerous, injurious to turf, and costly; applying less can result in poor control—or no control at all.
3. Keep in mind that you, the applicator, are responsible for any damage done to neighboring turf or to other plants as a result of your material's drift.
4. Find out if you need a use permit from the County Agricultural Commissioner. Certain pesticides or groups of pesticides are designated as restricted materials. Their possession and use are subject to special restrictions under regulations of the California Department of Food and Agriculture. These pesticides include insecticides, herbicides, fungicides, fumigants, rodenticides, and avicides. Materials that require a use permit are designated in this publication with a footnote.
5. Observe all posting or re-entry requirements for all pesticides.

Also, be warned—

Remember that certain pesticides are toxic to plants if used at the wrong stage of plant development or when temperatures are too high. Injury may also result from an excessive application or the wrong formulation, or from mixing incompatible materials. Inert ingredients, such as wetters, spreaders, emulsifiers, diluents, and solvents can cause plant injury. Formulations are often changed by manufacturers, so plant injury may occur even though no injury was noted in previous seasons.

WEED CONTROL

To use the tables in this section with the companion publication *Turfgrass Pests* (Publication 4053),

1. Identify the weed or weeds you want to control by looking at the color photographs of Common Turfgrass Weeds in *Turfgrass Pests.*
2. Determine the best time of year for control measures by consulting the Characteristics of Turfgrass Weeds chart in *Turfgrass Pests.*
3. Use the table in this leaflet to determine the best chemical to apply.
4. Consult the Herbicide Formulation table in *Turfgrass Pests* for suggestions on how to apply the chemical.
5. For information regarding measurements, see the Measurements, Calculations, and Preparing the Sprayer section in *Turfgrass Pests.*
6. IN ALL CASES, follow the suggestions in the Safe and Effective Use of Pesticide Chemicals section in *Turfgrass Pests.*

HERBICIDE SELECTION GUIDE

Weed	Nonselective spot treatment in established turf	Bentgrass (*Agrostis* sp.)	Bermudagrass (*Cynodon dactylon*)	Kentucky bluegrass or perennial ryegrass (*Poa pratensis* or *Lolium perenne*)	Fescue (*Festuca arundinacea*)	Zoysia	Dichondra (*Dichondra micrantha*)
		Treatment material. For specific rates, timing, etc., see *HERBICIDE SPECIFICATIONS*					
		Selective in: (type of turf)		Selective in: (type of turf)			
Broadleaf annual							
Black medic *Medicago lupulina*	dicamba*	dicamba*† 2,4-D +mecoprop +dicamba*§	dicamba*† 2,4-D+mecoprop +dicamba*	dicamba*† 2,4-D+mecoprop +dicamba* triclopyr	dicamba*† 2,4-D+mecoprop +dicamba* triclopyr	—‡	—‡
Chickweed *Stellaria media*	dicamba*	dicamba*†	dicamba*† 2,4-D+mecoprop +dicamba* benefin benefin +oryzalin¶ pendimethalin¶ benefin +trifluralin¶	dicamba*† 2,4-D+mecoprop +dicamba* triclopyr benefin¶ benefin +trifluralin¶ pendimethalin¶	dicamba*† 2,4-D+mecoprop +dicamba* triclopyr benefin¶ benefin +trifluralin¶	—‡	diphenamid¶ napropamide¶ benefin +oryzalin¶ benefin +trifluralin¶
Clover, California bur *Medicago polymorpha* var. *vulgaris*	dicamba* mecoprop	dicamba*† mecoprop† 2,4-D +mecoprop +dicamba*§	dicamba*† mecoprop† 2,4-D +mecoprop +dicamba*§	dicamba*† mecoprop† 2,4-D +mecoprop +dicamba*§	dicamba*† mecoprop† 2,4-D +mecoprop +dicamba*§	—‡	diphenamid¶ napropamide¶
Geranium, cutleaf *Geranium dissectum*	2,4-D amine*†	2,4-D amine*†#	2,4-D amine*† 2,4-D +mecoprop +dicamba*	2,4-D amine*† 2,4-D +mecoprop +dicamba*	2,4-D amine*† 2,4-D +mecoprop +dicamba*	—‡	—‡

Continued on next page

* Restricted herbicide: permit required from County Agricultural Commissioner.
† When a single product is mentioned, you can assume that combinations containing that product will also give control.
‡ Either the weed is not a problem or no chemical is available for the weed in this situation.
§ Use bentgrass formulation only.
¶ Must be applied before weed emergence.
# 2,4-D can injure bentgrass. Use low rates or special formulations.
** Seedling applications only.

HERBICIDE SELECTION GUIDE—*Continued*

Treatment material. For specific rates, timing, etc., see *HERBICIDE SPECIFICATIONS*

Weed	Nonselective spot treatment in established turf	Selective in: (type of turf) Bentgrass (*Agrostis* sp.)	Bermudagrass (*Cynodon dactylon*)	Kentucky bluegrass or perennial ryegrass (*Poa pratensis* or *Lolium perenne*)	Fescue (*Festuca arundinacea*)	Zoysia	Dichondra (*Dichondra micrantha*)
Broadleaf annual—Continued							
Knotweed, prostrate *Polygonum aviculare*	dicamba*	dicamba* mecoprop 2,4-D amine*#	dicamba* mecoprop 2,4-D ester* 2,4-D+mecoprop +dicamba* benefin +oryzalin¶ pendimethalin¶ benefin¶ benefin +oxadiazon¶ benefin +trifluralin¶	dicamba* mecoprop 2,4-D ester* 2,4-D+mecoprop +dicamba* pendimethalin¶ benefin¶ benefin +trifluralin¶ benefin +oxadiazon (bluegrass only)¶	dicamba* mecoprop 2,4-D ester* 2,4-D+mecoprop +dicamba* pendimethalin¶ benefin¶ benefin +trifluralin¶	benefin +oryzalin¶ pendimethalin¶ benefin +trifluralin¶	napropamide¶
Lettuce, prickly *Lactuca scariola*	2,4-D amine*	2,4-D amine*#	2,4-D amine* benefin +oxadiazon¶	2,4-D amine* benefin +oxadiazon (bluegrass only)¶	2,4-D amine*	—‡	—‡
Mallow, little (cheeseweed) *Malva parviflora* (biennial)	2,4-D ester*	2,4-D amine*#	2,4-D ester* 2,4-D+mecoprop +dicamba* benefin +oxadiazon¶	2,4-D ester* 2,4-D+mecoprop +dicamba* benefin +oxadiazon (bluegrass only)¶	2,4-D ester* 2,4-D+mecoprop +dicamba*	—‡	—‡
Oxtongue, bristly *Picris echioides* (biennial)	2,4-D amine*	2,4-D amine*#	2,4-D amine* 2,4-D+mecoprop +dicamba*	2,4-D amine* 2,4-D+mecoprop +dicamba*	2,4-D amine* 2,4-D+mecoprop +dicamba*	—‡	—‡
Pearlwort, birdseye *Sagina procumbens*	mecoprop	dicamba*† mecoprop†	dicamba*† mecoprop† pendimethalin¶ benefin +oryzalin¶	dicamba*† mecoprop† pendimethalin¶ benefin +trifluralin¶	dicamba*† mecoprop† pendimethalin¶ benefin +trifluralin¶	benefin +oryzalin¶ benefin +trifluralin¶	napropamide¶

* Restricted herbicide: permit required from County Agricultural Commissioner.
† When a single product is mentioned, you can assume that combinations containing that product will also give control.
‡ Either the weed is not a problem or no chemical is available for the weed in this situation.
§ Use bentgrass formulation only.
¶ Must be applied before weed emergence.
# 2,4-D can injure bentgrass. Use low rates or special formulations.
**Seedling applications only.

Continued on next page

HERBICIDE SELECTION GUIDE—*Continued*

Weed	Nonselective spot treatment in established turf	Treatment material. For specific rates, timing, etc., see *HERBICIDE SPECIFICATIONS* — Selective in: (type of turf): Bentgrass (*Agrostis* sp.)	Bermudagrass (*Cynodon dactylon*)	Kentucky bluegrass or perennial ryegrass (*Poa pratensis* or *Lolium perenne*)	Fescue (*Festuca arundinacea*)	Zoysia	Dichondra (*Dichondra micrantha*)
Broadleaf annual—Continued							
Pigweed, redroot *Amaranthus retroflexus*	2,4-D amine*	2,4-D amine*†# dicamba*†	2,4-D amine*† dicamba*† pendimethalin¶ benefin¶ benefin +oxadiazon¶ benefin +oryzalin¶	2,4-D amine*† dicamba*† pendimethalin¶ benefin¶ benefin +oxadiazon (bluegrass only)¶ benefin +trifluralin¶	2,4-D amine*† dicamba*† pendimethalin¶ benefin +trifluralin¶	benefin +oryzalin¶ benefin +trifluralin¶	napropamide¶
Pimpernel, scarlet *Anagallis arvensis*	2,4-D amine*	2,4-D amine*#	2,4-D amine*† pendimethalin¶ benefin +oryzalin¶ benefin +oxadiazon¶	2,4-D amine*† pendimethalin¶ benefin +trifluralin¶ benefin +oxadiazon (bluegrass only)¶	2,4-D amine*† pendimethalin¶ benefin +trifluralin¶	benefin +oryzalin¶	napropamide¶
Purslane, common *Portulaca oleracea*	2,4-D amine*	2,4-D amine*#	DCPA¶ 2,4-D amine*† pendimethalin¶ benefin¶ benefin +oryzalin¶ benefin +trifluralin¶ benefin +oxadiazon¶	DCPA¶ 2,4-D amine*† pendimethalin¶ benefin¶ benefin +trifluralin¶ benefin +oxadiazon (bluegrass only)¶	DCPA¶ 2,4-D amine*† pendimethalin¶ benefin¶ benefin +trifluralin¶	benefin +oryzalin¶ benefin¶	napropamide¶
Soliva (spurweed) *Soliva sessilis*	2,4-D ester*#	2,4-D amine*#	2,4-D amine* bromoxynil	2,4-D ester* bromoxynil	2,4-D ester* bromoxynil	bromoxynil +MSMA	—‡
Speedwell, birdseye *Veronica persica*	—‡	—‡	benefin¶ 2,4-D+mecoprop +dicamba*	benefin¶ 2,4-D+mecoprop +dicamba*	—‡	—‡	—‡

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§ Use bentgrass formulation only.

¶ Must be applied before weed emergence.

\# 2,4-D can injure bentgrass. Use low rates or special formulations.

**Seedling applications only.

HERBICIDE SELECTION GUIDE—*Continued*

Weed	Nonselective spot treatment in established turf	Treatment material. For specific rates, timing, etc., see *HERBICIDE SPECIFICATIONS* Selective in: (type of turf) Bentgrass (*Agrostis* sp.)	Bermudagrass (*Cynodon dactylon*)	Kentucky bluegrass or perennial ryegrass (*Poa pratensis* or *Lolium perenne*)	Fescue (*Festuca arundinacea*)	Zoysia	Dichondra (*Dichondra micrantha*)
Broadleaf annual—Continued							
Spurge, spotted *Euphorbia maculata*	glyphosate	—‡	bromoxynil DCPA¶ pendimethalin¶ benefin +oryzalin¶	bromoxynil DCPA¶ pendimethalin¶ benefin +trifluralin¶	DCPA¶ pendimethalin¶ benefin +trifluralin¶	benefin +oryzalin¶ pendimethalin¶	—‡
Broadleaf perennial							
Bindweed, field *Convolvulus arvensis*	2,4-D amine*	2,4-D amine*#	2,4-D+mecoprop +dicamba* benefin +oryzalin¶ pendimethalin¶**	2,4-D+mecoprop +dicamba* pendimethalin¶** benefin +trifluralin¶**	2,4-D+mecoprop +dicamba* pendimethalin¶** benefin +trifluralin¶**	pendimethalin¶** benefin+oryzalin¶**	—‡
Catsear, spotted *Hypochoeris radicata*	2,4-D amine*	2,4-D amine*# 2,4-D+mecoprop +dicamba*§	2,4-D amine* 2,4-D+mecoprop +dicamba*	2,4-D amine* 3,4-D+mecoprop +dicamba*	2,4-D amine* 2,4-D+mecoprop +dicamba*	—‡	—‡
Chickweed, mouseear *Cerastium vulgatum*	mecoprop	dicamba* mecoprop 2,4-D +mecoprop +dicamba*	dicamba* mecoprop 2,4-D+mecoprop +dicamba*	dicamba* mecoprop 2,4-D+mecoprop +dicamba*	dicamba* mecoprop 2,4-D+mecoprop +dicamba*	—‡	—‡
Clover, white *Trifolium repens*	mecoprop dicamba*	dicamba* mecoprop 2,4-D +mecoprop +dicamba*	dicamba* mecoprop 2,4-D+mecoprop +dicamba*	dicamba* mecoprop 2,4-D+mecoprop +dicamba* triclopyr	dicamba* mecoprop 2,4-D+mecoprop +dicamba* triclopyr	—‡	monuron neburon
Daisy, English *Bellis perennis*	dicamba*	dicamba* 2,4-D +mecoprop +dicamba*§	dicamba* dicamba+2,4-D* 2,4-D +mecoprop +dicamba*	dicamba* dicamba+2,4-D* 2,4-D +mecoprop +dicamba*	dicamba* dicamba+2,4-D* 2,4-D +mecoprop +dicamba*	—‡	—‡

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§ Use bentgrass formulation only.
¶ Must be applied before weed emergence.
# 2,4-D can injure bentgrass. Use low rates or special formulations.
**Seedling applications only.

Weed	Treatment material. For specific rates, timing, etc., see *HERBICIDE SPECIFICATIONS* Nonselective spot treatment in established turf	Selective in: (type of turf) Bentgrass (*Agrostis* sp.)	Bermudagrass (*Cynodon dactylon*)	Kentucky bluegrass or perennial ryegrass (*Poa pratensis* or *Lolium perenne*)	Fescue (*Festuca arundinacea*)	Zoysia	Dichondra (*Dichondra micrantha*)
Broadleaf perennials—Continued							
Dandelion *Taraxacum officinale*	2,4-D amine*	2,4-D amine*# 2,4-D +mecoprop +dicamba*§	2,4-D amine* 2,4-D+mecoprop +dicamba*	2,4-D amine* 2,4-D+mecoprop +dicamba*	2,4-D amine* 2,4-D+mecoprop +dicamba*	—‡	—‡
Dichondra *Dichondra micrantha*	—‡	2,4-D amine*#	2,4-D ester*	2,4-D ester*	2,4-D ester*	—‡	—‡
Dock, curly *Rumex crispus*	dicamba* 2,4-D amine* triclopyr	dicamba* 2,4-D amine*# 2,4-D +mecoprop +dicamba*§	dicamba* 2,4-D amine* 2,4-D+mecoprop* +dicamba*	dicamba* 2,4-D amine* 2,4-D+mecoprop +dicamba* triclopyr	dicamba* 2,4-D amine* 2,4-D+mecoprop +dicamba* triclopyr	—‡	—‡
Healall (selfheal) *Prunella vulgaris*	—‡	dicamba+2,4-D* 2,4-D +mecoprop +dicamba*§	dicamba+2,4-D* 2,4-D +mecoprop +dicamba*§	dicamba+2,4-D* 2,4-D+mecoprop +dicamba*	dicamba+2,4-D*	—‡	—‡
Plantain, broadleaf *Plantago major*	2,4-D amine*	2,4-D amine*# 2,4-D +mecoprop +dicamba*§	2,4-D amine* 2,4-D+mecoprop +dicamba*	2,4-D amine* 2,4-D+mecoprop +dicamba*	2,4-D amine* 2,4-D+mecoprop +dicamba*	—‡	—‡
Plantain, buckhorn *Plantago lanceolata*	2,4-D amine*	2,4-D amine*# 2,4-D +mecoprop +dicamba*§	2,4-D amine* 1,4-DD+mecoprop +dicamba*	2,4-D amine* 2,4-D+mecoprop +dicamba*	2,4-D amine* 2,4-D+mecoprop +dicamba*	—‡	—‡
Sorrel, red *Rumex acetosella*	dicamba*	dicamba*	dicamba* 2,4-D+mecoprop +dicamba*	dicamba* 2,4-D+mecoprop +dicamba*	dicamba* 2,4-D+mecoprop +dicamba*	—‡	—‡
Woodsorrel, creeping *Oxalis corniculata*	triclopyr	—‡	2,4-D+mecoprop +dicamba +MSMA* pendimethalin¶** benefin +oryzalin¶**	triclopyr pendimethalin¶** benefin +trifluralin¶**	triclopyr pendimethalin¶** benefin +trifluralin¶**	pendimethalin¶** benefin +oryzalin¶**	—‡

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\# 2,4-D can injure bentgrass. Use low rates or special formulations.

**Seedling applications only.

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HERBICIDE SELECTION GUIDE—*Continued*

Weed	Nonselective spot treatment in established turf	Treatment material. For specific rates, timing, etc., see *HERBICIDE SPECIFICATIONS* — Selective in: (type of turf) Bentgrass (*Agrostis* sp.)	Bermudagrass (*Cynodon dactylon*)	Kentucky bluegrass or perennial ryegrass (*Poa pratensis* or *Lolium perenne*)	Fescue (*Festuca arundinacea*)	Zoysia	Dichondra (*Dichondra micrantha*)
Broadleaf perennial—Continued							
Yarrow, common *Achillea millefolium*	2,4-D ester*	—‡	2,4-D ester* dicamba* 2,4-D+mecoprop +dicamba*	2,4-D ester* dicamba* 2,4-D+mecoprop +dicamba*	2,4-D ester* dicamba* 2,4-D+mecoprop +dicamba*	—‡	—‡
Narrowleaf annual							
Barnyardgrass *Echinochloa crusgalli*	glyphosate	bensulide¶	bensulide¶ DCPA¶ benefin¶ benefin +oryzalin¶ pendimethalin¶ benefin +oxadiazon¶	bensulide DCPA¶ benefin¶ pendimethalin¶ benefin +oxadiazon (bluegrass only)¶ benefin +trifluralin¶	bensulide¶ DCPA¶ benefin¶ pendimethalin¶ benefin +trifluralin¶	bensulide¶ benefin +oryzalin¶ pendimethalin¶	napropamide¶ bensulide¶ diphenamid¶ fluazifop
Bluegrass, annual *Poa annua*	glyphosate	bensulide¶	bensulide¶ benefin¶ oxadiazon¶ pronemide¶ pendimethalin¶ benefin +trifluralin¶ benefin +oxadiazon¶	bensulide¶ benefin¶ oxadiazon¶ pendimethalin¶ benefin¶ +trifluralin¶ benefin +oxadiazon (bluegrass only)¶	bensulide¶ benefin¶ pendimethalin¶ benefin +trifluralin¶	bensulide¶ pendimethalin¶ benefin +oryzalin¶	bensulide¶ diphenamid¶ napropamide¶
Foxtail, yellow *Setaria glauca*	glyphosate	—‡	bensulide¶ DCPA¶ benefin¶ pronamide¶ benefin +oryzalin¶ benefin +trifluralin¶	bensulide¶ DCPA¶ benefin¶ pendimethalin¶ benefin +trifluralin¶	bensulide¶ DCPA¶ benefin¶ pendimethalin¶ benefin +trifluralin¶	bensulide¶ benefin +oryzalin¶ pendimethalin¶	napropamide¶

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**Seedling applications only.

HERBICIDE SELECTION GUIDE—*Continued*

Weed	Nonselective spot treatment in established turf	Treatment material. For specific rates, timing, etc., see *HERBICIDE SPECIFICATIONS* — Selective in: (type of turf) Bentgrass (*Agrostis* sp.)	Bermudagrass (*Cynodon dactylon*)	Kentucky bluegrass or perennial ryegrass (*Poa pratensis* or *Lolium perenne*)	Fescue (*Festuca arundinacea*)	Zoysia	Dichondra (*Dichondra micrantha*)
Narrowleaf annual—Continued							
Crabgrass, large *Digitaria sanguinalis*	glyphosate[¶]	bensulide[¶] DSMA[¶]	benefin[¶] bensulide[¶] DCPA[¶] DSMA MSMA CMA benefin +oxadiazon[¶] benefin +oryzalin[¶] pendimethalin[¶] benefin +trifluralin[¶]	benefin[¶] bensulide[¶] DCPA[¶] DSMA MSMA CMA benefin +trifluralin[¶] benefin +oxadiazon (bluegrass only)[¶] pendimethalin[¶]	benefin[¶] bensulide[¶] DCPA[¶] DSMA MSMA CMA benefin +trifluralin[¶] pendimethalin[¶]	pendimethalin[¶] MSMA[¶] benefin +oryzalin[¶]	bensulide[¶] diphenamid[¶] napropamide[¶] fluazifop[¶]
Crabgrass, smooth *Digitaria ischaemun*	glyphosate	bensulide[¶] DSMA	benefin[¶] bensulide[¶] DCPA[¶] DSMA CMA MSMA benefin +oxadiazon[¶] benefin +oryzalin[¶] pendimethalin[¶] benefin +trifluralin[¶]	benefin[¶] bensulide[¶] DCPA[¶] DSMA CMA MSMA benefin +trifluralin[¶] benefin +oxadiazon[¶] pendimethalin[¶]	benefin[¶] bensulide[¶] DCPA[¶] DSMA CMA MSMA benefin +trifluralin[¶] pendimethalin (bluegrass only)[¶]	MSMA pendimethalin[¶] benefin +oryzalin[¶]	bensulide[¶] diphenamid[¶] napropamide[¶] fluazifop
Goosegrass *Eleusine indica*	glyphosate	bensulide[¶]	bensulide[¶] pendimethalin[¶] benefin +oxadiazon[¶] benefin +oryzalin[¶] benefin +trifluralin[¶]	bensulide[¶] pendimethalin[¶] benefin +oxadiazon (bluegrass only)[¶] benefin +trifluralin[¶]	bensulide pendimethalin[¶] benefin +trifluralin[¶]	pendimethalin[¶] benefin +oryzalin[¶]	bensulide[¶] napropamide[¶] fluazifop

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[‡] Either the weed is not a problem or no chemical is available for the weed in this situation.

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[§] Use bentgrass formulation only.
[¶] Must be applied before weed emergence.
[#] 2,4-D can injure bentgrass. Use low rates or special formulations.
[**] Seedling applications only.

HERBICIDE SELECTION GUIDE—*Continued*

Weed	Treatment material. For specific rates, timing, etc., see *HERBICIDE SPECIFICATIONS*						
	Nonselective spot treatment in established turf	Selective in: (type of turf)					
		Bentgrass (*Agrostis* sp.)	Bermudagrass (*Cynodon dactylon*)	Kentucky bluegrass or perennial ryegrass (*Poa pratensis* or *Lolium perenne*)	Fescue (*Festuca arundinacea*)	Zoysia	Dichondra (*Dichondra micrantha*)
Narrowleaf annual—Continued							
Ryegrass, Italian *Lolium multiflorum*	glyphosate	—‡	pronamide¶ pendimethalin¶ benefin +oryzalin¶ benefin +oxadiazon¶ benefin +trifluralin¶	pendimethalin¶ benefin +oxadiazon (bluegrass only)¶ benefin +trifluralin¶	pendimethalin¶ benefin +trifluralin¶	benefin +oryzalin¶	fluazifop napropamide¶
Narrowleaf perennial							
Bentgrass *Agrostis* sp.	dazomet metham glyphosate	—‡	2,4-D ester*	—‡	—‡	—‡	fluazifop
Bermudagrass *Cynodon dactylon*	dazomet metham glyphosate	—‡	—‡	siduron	siduron	—‡	fluazifop
Bluegrass, Kentucky *Poa pratensis*	dazomet metham glyphosate	—‡	—‡	—‡	—‡	—‡	diphenamid¶
Dallisgrass *Paspalum dilatatum*	dazomet metham glyphosate	DSMA	DSMA MSMA pendimethalin¶** benefin +oryzalin¶**	DSMA MSMA pendimethalin¶** benefin +trifluralin¶**	DSMA MSMA pendimethalin¶** benefin +trifluralin¶**	benefin +oryzalin¶** pendimethalin¶**	fluazifop napropamide¶
Fescue, tall *Festuca arundinacea*	dazomet metham glyphosate	—‡	—‡	—‡	—‡	—‡	fluazifop
Kikuyugrass *Pennisetum clandestinum*	dazomet metham glyphosate	—‡	—‡	siduron	siduron	—‡	fluazifop

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§ Use bentgrass formulation only.

¶ Must be applied before weed emergence.

\# 2,4-D can injure bentgrass. Use low rates or special formulations.

**Seedling applications only.

HERBICIDE SELECTION GUIDE—*Continued*

		Treatment material. For specific rates, timing, etc., see *HERBICIDE SPECIFICATIONS*					
		Selective in: (type of turf)					
Weed	Nonselective spot treatment in established turf	Bentgrass (*Agrostis* sp.)	Bermudagrass (*Cynodon dactylon*)	Kentucky bluegrass or perennial ryegrass (*Poa pratensis* or *Lolium perenne*)	Fescue (*Festuca arundinacea*)	Zoysia	Dichondra (*Dichondra micrantha*)
Narrowleaf perennial—Continued							
Nutsedge, yellow *Cyperus esculentus*	glyphosate bentazon	DSMA	DSMA MSMA bentazon	DSMA MSMA bentazon	DSMA MSMA bentazon	DSMA MSMA	—‡
St. Augustinegrass *Stenotaphrum secundatum*	dalapon dazomet metham glyphosate	2,4-D amine*#	2,4-D ester*	2,4-D ester*	2,4-D ester*	—‡	—‡
Velvetgrass, German *Holcus mollis*	metham glyphosate dazomet	—‡	—‡	—‡	—‡	—‡	fluazifop

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**Seedling applications only.

HERBICIDE SPECIFICATIONS

Trade names given here in parentheses next to the chemical names do not constitute an endorsement by the University of California, nor do they indicate criticism of any similar products not included in the listing.

Where a single herbicide is listed for a weed species, it is the active compound for control. The same herbicide may be found in combination or may be combined by the applicator with other products, unless the label specifically prohibits mixing the two products. Combinations generally broaden the range of weed species controlled.

Read and follow the label instructions as to the herbicide application rate and the safe handling and application of the herbicide.

NOTE: ai/A = active ingredient per acre; ae = acid equivalent

benefin (Balan)

Formulation: Granules or with fertilizer.
Use: Selective, soil-applied, preemergent.
Rate: 3 lb ai/A.
Remarks:
a) For crabgrass: Apply 2 to 3 weeks before initial germination (January for Los Angeles, Basin, early to mid-February for Central Valley and central coast, mid-February to March 1 for northern California and north coastal areas). Sprinkle-irrigate after application to wash herbicide off leaves and into the soil.
b) For annual bluegrass: Apply 2 to 3 weeks before initial germination (August-September). Sprinkle-irrigate after application to wash herbicide off leaves and into the soil.
c) For speedwell: Apply preemergence in January.
d) Often combined with other preemergence herbicides for longer residual.
NOTE: Do not apply to bentgrass greens.

benefin plus oryzalin (XL)

Formulation: Granules or with fertilizer.
Use: Selective, soil-applied, preemergent.
Rate: 2 to 3 lb ai/A.
Remarks: For use on warm season grasses only. Apply on established turf prior to germination of annual weeds. Do not aerate or verticut after application. Do not overseed with grasses for 12 to 16 weeks after application. Do not use on bluegrass, ryegrass, or fescue turf.

benefin plus trifluralin (Team)

Formulation: Granules or with fertilizer.
Use: Selective, soil-applied, preemergent.
Rate: *For cool season species:* 1.5 to 2 lb ai/A. *For warm season species:* 2 to 3 lb ai/A.
Remarks: Apply on established turf in the spring 1 to 2 weeks before expected germination of summer annuals (crabgrass, goosegrass, foxtail, or barnyardgrass). For annual bluegrass control: apply in the late summer or early fall before germination. A second application can be applied 10 to 12 weeks after the first in the southern part of the state to control late-germinating weeds. Do not overseed grasses for 12 to 16 weeks after application.

bensulide (Betasan, Scotts Halts, Scotts Super Halts Plus, Super Pax Crabgrass Control with Betasan, Presan)

Formulation: Emulsifiable liquid, granular, with fertilizer.
Use: Selective, soil-applied, preemergent.
Rate: 7.5 to 10 lb ai/A.
Remarks: Safest preemergence control material in bentgrass. For crabgrass: Apply 2 to 3 weeks before initial germination (January for Los Angeles Basin and south coast area, early to mid-February for Central Valley and central coast, mid-February to March 1 for northern California and north coastal areas).
NOTE: Crabgrass may germinate and become established in turf in late summer if lower rates are used. Good management will allow use of lower rates.
Rate: 7.5 lb ai/A in fall and 7.5 lb ai/A in midwinter (Jan.-Feb.).
Remarks: For annual bluegrass: Apply in early fall before annual bluegrass germinates. Normally mid-August to mid-September.
NOTE: Exclude children and pets during application and until treated area has been thoroughly sprinkler-irrigated.

bentazon (Basagran)

Formulation: 4 lb ai/gal emulsifiable concentrate.
Use: Selective, postemergent.
Rate: 1 to 2 lb ai/A in 40 gal water/A.
Remarks: For yellow nutsedge in grass turf. The nutsedge should be growing vigorously with good soil moisture. If control is not as desired, apply a second treatment after 10 to 14 days. Do not apply more than 3 lb per season. For optimum control, do not mow 3 to 5 days before or after application. Basagran can be mixed with 2,4-D (Basagran 1 lb + 2,4-D 1 lb) for nutsedge and other broadleaf control. Do not use on newly seeded or sprigged turf.

bromoxynil (Buctril, Buctril 4EC, ME4 Brominal)

Formulation: 2 lb/gal emulsifiable concentrate; 4 lb/gal emulsifiable concentrate (Buctril 4EC, ME4 Brominal).
Use: Selective, foliage-applied, contact.
Rate: 0.375 to 0.5 lb ai/A at 3- to 4-leaf stage or up to 6-inch weed height, or on rosette plants before they exceed 1½ inches in diameter; 1 lb ai/A for seedling spurweed, spiny fruited crowfoot, black medic, and hop clover; 2 lb ai/A for seedling prostrate spurge.
Remarks: Particularly beneficial at 0.375 to 0.5 lb ai/A on seedling grasses aged 3 weeks or older to control broadleaf weeds. Use lower rates on small weeds and higher rates on large weeds. Apply in at least 20 gallons of water per acre. May be tank-mixed with other broadleaf materials such as 2,4-D and 2,4DP, MCPP, dicamba, MSMA, or DSMA, or combinations of these materials, depending upon the weed species present.

cacodylic acid (Scotts Spot Grass & Weed Control, Liquid Edger, Best Lawn Edger & Trimmer, Germain's Fresh Start Grass & Weed Killer, Acme Weed-N-Grass Killer, Rad-E-Cate 25)

Formulation: Soluble liquid and soluble powder.
Use: Nonselective, foliage-applied, postemergent, contact.
Rate: 6 to 8 lb ai+1 qt surfactant/A.
Remarks: Apply principally for the control of annual weeds before cultivating and planting turf.

CAMA (Super Dal-E-Rad Calar, Ortho Crabgrass Killer, Formula II)

Formulation: Soluble liquid or soluble powder.
Use: Selective, foliage-applied, translocated.
Rate: 2.0 to 2.5 lb ai/A.
Remarks: Temperature and turf type determine degree of selectivity. Use low rate for young crabgrass in fine-leaved fescue turf—or when daily high temperature exceeds 85°F.
Use high rate for mature crabgrass in Kentucky bluegrass or bermudagrass turf or when temperature is 85°F or less.
NOTE: Apply uniformly over area regardless of distribution of crabgrass. Hesitating over more weedy spots may cause excessive rate and injure or kill turf. Repeat at 5- to 7-day intervals for total of 2 to 3 treatments for crabgrass. May temporarily discolor turf. May injure St. Augustine, fine fescue, and some bentgrass species.

dazomet (Basamid)

Formulation: 99% granular.
Use: Nonselective, soil-applied, fumigant, preplant.
Rate: 275 lb ai/A or 10 oz/100 sq ft.
Remarks: Apply in water; mix into soil 6 inches deep with a power tiller. Seed in 3 weeks if temperature is over 60°F and soil is moist but not wet. Wash into soil with sprinkler irrigation when spot treating. Effective principally on annual weeds.

DCPA (Acme Garden Weed Preventer Granules, Acme Garden Weed Preventer Spray, Best DCPA 5 Granules, Dacthal W-75 for Turf, Pax Crabgrass & Spurge Preventer Plus Fertilizer, Dacthal G-5)

Formulation: Wettable powder, granular, formulated with fertilizer.
Use: Selective, soil-applied, preemergent.
Rate: 10 lb ai/A.
Remarks: Apply 2 to 3 weeks before initial crabgrass germination (January for Los Angeles Basin and south coast area, early to mid-February for Central Valley and central coast area, mid-February to March 1 for northern California and north coast area).
NOTE: Do not use on bentgrass and dichondra. Exclude children and pets during application and until treated area has been thoroughly sprinkler-irrigated. Young crabgrass plants may become established in turf in late summer if lower rates are used.
NOTE: Will not control crabgrass after germination. Apply for annual bluegrass control at end of August or beginning of September.

dicamba (Banvel 4-S)

Formulation: Soluble liquid.
Use: Selective, foliage-applied, translocated.
Rate: 1/4 lb/A in 40 gal water.
Remarks: Apply for chickweeds, clovers, English daisy, prostrate knotweed, pearlwort, red sorrel, curly dock. Do not apply more than two times per year. Also for spot spraying (applies to 4 lb ae/gal formulation).
NOTE: Do not exceed 1/2 lb ae/A per season. Active through the soil; do not use where roots of ornamental plants may extend into treated area. Spray on calm days to avoid spray drift onto susceptible crops or ornamentals. Often used at low rates in combination with 2,4-D and mecoprop. Nonselective on dichondra.

dicamba+2,4-D* (Super D Weedone, Scotts Lawn Weed Control, Scotts Spot Dandelion Control, Super Pax Weed'N Feed, Provel Lawn and Turf Herbicide)

Formulation: Soluble liquid, granular formulated with fertilizer.
Use: Selective, foliage-applied, translocated.
Rate: Varies with specific product.
Remarks: For English daisy or other difficult to control broadleaf weeds where there is dandelion or plantain present.
NOTE: Do not exceed 1/4 lb ae/A of dicamba on bentgrass turf. Active through the soil; do not use where roots of ornamentals may extend into treated area. Spray on calm days to avoid spray drift onto susceptible crops or ornamentals. Nonselective on dichondra.

dicamba+2,4-D+mecoprop* (Lilly/Miller Feed & Weed, Lilly/Miller Spot Weeder, Miller's Lawn & Turf Weed Bomb, Best Lawn Weed Killer, Acme Super Weed-No-More, Acme Super Chickweed Killer, Acme Southern Weed-No-More, Acme Weed-No-More Spot Weeder, Miller's Lawn & Turf Weedkiller)

Formulation: Emulsifiable concentrate.
Use: Selective, foliage-applied, translocated.
Low Rate: 0.075 to 0.11 lb dicamba/A+0.18 to 1.1 lb 2,4-D/A+0.55 to 0.75 lb mecoprop/A.
High rate: 0.08 to 0.12 lb dicamba/A+0.64 to 0.96 lb 2,4-D/A+0.32 to 0.48 lb mecoprop/A.
Remarks: For broad-spectrum control of broadleaf weeds. Use lower rates for bentgrass, hybrid bermudagrass and other sensitive turfgrasses. Nonselective on dichondra. Avoid applying to drought- and heat-stressed turf. Do not irrigate within 24 hours of application. Newly seeded turf should not be treated until after the second or third mowing. Bentgrass most sensitive turfgrass. Read label for further application directions.

diphenamid (Enide)

Formulation: Wettable powder or granular formulated with fertilizer.
Use: Selective, soil-applied, preemergent.
Rate: 10 lb ai/A.
Remarks:
a) For dichondra turf only: Effective preemergence and early postemergence mainly for grass control.
b) For annual bluegrass: Apply in early fall and spring.
c) For crabgrass: January for Los Angeles Basin; February for Central Valley and central coast; March for northern California and north coast area.

*Restricted herbicide: permit required from County Agricultural Commissioner.

d) For bermudagrass: Apply to suppress growth, does not eradicate established plants.
NOTE: Will seriously injure or kill turfgrasses. Exclude children and pets during application and until treated area has been thoroughly sprinkler-irrigated.

DSMA (Chacon Crabgrass Control, Weedone Crabgrass Killer, Scotts Summer Crabgrass Control, DSMA Liquid)

Formulation: Soluble liquid or soluble powder.
Use: Selective, foliage-applied, translocated.
Low Rate: 3 lb ai/A in 175 to 200 gal water. Use lower rate on bentgrasses and fine-leaved fescues. Sufficient rate for young crabgrass, and with repeated monthly sprays for established dallisgrass and nutsedge. Use if daily temperatures exceed 80°F.
High Rate: 4 lb ai/A in 175 to 200 gal water. Use higher rate for mature crabgrass. Requires 2 to 3 resprays at 5- to 7-day intervals. Satisfactory rate for use in bermudagrass, and if temperatures are 80°F or lower in Kentucky bluegrass as well. Will yellow zoysia turf.
Remarks: Effective in controlling crabgrass, dallisgrass, and nutsedge. Temperature, soil moisture, and turf type determine degree of turf-selectivity. Avoid spraying under hot, droughty conditions. Bents, fine-leaved fescues, and dichondra are most sensitive; bermudagrass is most tolerant. Do not use on St. Augustine turf.

fluazifop (Ortho Grass-B-Gon)

Formulation: 0.5% liquid.
Use: Selective, postemergent.
Rate: Spray directly from bottle according to label instructions.
Remarks: For selective grass control in dichondra only. Will not control annual bluegrass. Apply when the grass is young and vigorous and has good soil moisture. Retreatments may be required for hard-to-kill weeds such as bermudagrass, dallisgrass, and kikuyugrass. Will not control nutsedge.

glyphosate (Roundup, Ortho Kleenup Systemic Grass and Weed Killer, Lilly/Miller Knock-Out Weed & Grass Killer)

Formulation: Soluble liquid.
Use: Nonselective, foliage-applied, translocated.
Rate: 1 to 5 lb ai/A in 20 to 40 gal water or 2 to 3 oz/gal/1,000 sq ft.
Remarks: Apply to rapidly growing weeds. *Annual weeds:* If shorter than 6 inches, apply 1 lb ai/A; if 6 inches or taller, apply 1.5 lb ai/A. Allow minimum of 3 days between application and renovation

or cultivation. *Perennial weeds:* Apply to vigorous but nearly mature weeds (bermudagrass: summer to fall; field bindweed, at full bloom). Apply 4 to 5 lb ai/A.
In a mowed turf grass area, ***omit at least one mowing*** before application. Delay verticutting, removing sod or tillage for at least 7 days after treatment. To maximize control allow the soil surface and root area to dry after verticutting or sod removal before replanting. When turf or ornamentals are to be planted, a followup preemergence program is required to control the seed of perennials.

mecoprop (Chipco Turf Herbicide MCPP)

Formulation: Soluble liquid.
Use: Selective, foliage-applied, translocated.
Rate: 1.5 lb ae/A+1 qt surfactant per 100 gal spray. *For spot spraying:* Use same concentration per 100 gal or 3 to 4 tsp+2 tsp surfactant/gal water.
Remarks: Clover, prostrate knotweed, pearlwort.
NOTE: Spray on calm days to avoid spray drift onto susceptible crops or ornamentals. Prostrate knotweed should be treated when young (2 to 4 inches in diameter). Nonselective on dichondra. (Rate for spot spraying applies only to formulations containing 2 or 2.5 lb ae/gal.)

metham (Vapam)

Formulation: Soluble liquid.
Use: Preplant or nonselective soil-applied fumigant.
Rate: 430 lb ai/A or 10 lb ai/1,000 sq ft.
Remarks: Apply in water on calm day; follow immediately with sprinkler irrigation to seal the soil surface or, preferably, cover with vaporproof covering. Seed in 2 weeks on light sandy soils, in 3 to 4 weeks on heavier clay or mulch (organic) soils. Extend waiting period if temperature is below 60°F. Two applications usually required to eradicate bermudagrass or kikuyugrass. Roto-tilling before treatment will enhance control.

MSMA (Acme Crabgrass & Nutgrass Killer, Germain's Improved Crabgrass Killer, Bueno 6)

Formulation: Soluble liquid.
Use: Selective, foliage-applied, translocated.
Rate: 3 to 4 lb ai/A.

Remarks: Temperature and turf type determine degree of selectivity. Use lower rate for nutsedge control, on bentgrass, and on other turf types when daily temperature exceeds 85°F. Apply at monthly intervals for control of dallisgrass and nutsedge.
NOTE: Apply uniformly over area regardless of distribution of the weed. Hesitating with sprayer over weedier spots may cause excessive rate and injure or kill the turf. Repeated applications of high rates reduces kikuyugrass. Turf may be temporarily discolored. Injurious to St. Augustine grass, red fescue, dichondra, and zoysia.

napropamide (Devrinol)

Formulation: 50% wettable powder, 5% granular.
Use: Selective, preemergent.
Rate: 2 to 3 lb ai/A.
Remarks: Apply at seeding or on established dichondra. Principally for grass control, but will control some broadleaf weeds. Follow treatment with a minimum of 1 inch of water to wash material from the leaves and into the soil.

oxadiazon (Ronstar)

Formulation: 50% wettable powder, 2% granular.
Use: Selective, soil-applied, preemergent.
Rate: 2 to 4 lb ai/A.
Remarks: Wettable powder to be used only on dormant established bermudagrass, St. Augustine, or zoysiagrass turf. The granule formulation can be used safely on most other grass species except bentgrass. Do not use on dichondra. Some foliar injury can be observed if the granules are applied to wet foliage or the herbicide is not washed from the leaves after application. Has not been effective for control of prostrate spurge or creeping woodsorrel (Oxalis) in California. Do not use on newly seeded turf. Apply the wettable powder formulation at least 2 weeks before turf greens in the spring.

oxadiazon plus benefin (Regalstar)

Formulation: 1% oxadiazon and 0.5% benefin on a ureaformaldehyde fertilizer.
Use: Selective, soil-applied, preemergent.
Rate: 2 lb ai/A oxadiazon and 1 lb/A benefin.
Remarks: Use only on bermudagrass and bluegrass for the control of summer annual weeds (crabgrass and goosegrass). May be used on

newly sprigged bermudagrass after stolons have rooted and filled in the bare spaces. Apply in early spring before crabgrass germination. Apply to newly seeded bermudagrass and bluegrass after grass has been mowed at least twice. For commercial use only; not for use on home lawns.

pronamide (Kerb)

Formulation: 50% wettable powder.
Use: Selective, preemergent, postemergent.
Rate: 0.5 to 1.5 lb ai/A.
Remarks: Apply rates necessary to control the stage of growth of the annual bluegrass. Apply 0.5 to 1.0 lb preemergence or early postemergence; 0.75 to 1.0 lb postemergence, early tillering to heading; 1.0 to 2.0 lb seed-forming stage. Apply the low rate to light sandy soils and the high rate to loamy and clayey soils. Control is slow to be observed (4 to 6 weeks). Do not apply to areas to be overseeded within 90 days of treatment. Use only on bermudagrass. Irrigate (1/2 inch) within 2 days to get pronamide into the root zone.

siduron (Tupersan)

Formulation: 50% wettable powder.
Use: Selective, soil-applied, preemergent.
Rate: 2 to 6 lb ai/A—new spring plantings (when no more than 3 lb are used at planting, a second application of 2 to 3 lb should be made 4 weeks later); 8 to 12 lb ai/A—fall plantings or established turf. Apply the low rates on sandy soils and higher rates on loamy and clayey soils.
Remarks: Used for the selective control of seedlings of summer grasses (including crabgrass, bermudagrass, and dallisgrass). Since seeds of these grasses occur for more than 1 year, a preemergence program must be followed for 2 years following renovation of warm season turf. Do not allow contact with the sprayed area until material has dried. At least 1/2 inch of water is required to wash the material off of the turf and into the soil.

triclopyr (Turflon)

Formulation: 4 lb/gal emulsifiable concentrate.
Use: Selective, postemergent.
Rate: 0.25 to 0.5 lb ai/A in 50 to 100 gal of water. Use on cool season turf species only.

Remarks: Especially useful for creeping woodsorrel *(Oxalis)* control. Apply on vigorously growing broadleaf weeds, preferably in the spring or fall. May be retreated 4 weeks following the first application for hard-to-kill weeds. To broaden weed spectrum and control dandelion, use a tank mix of amine or low volatile ester of 2,4-D with triclopyr. Do not apply around trees or shrubs, since injury may result. Do not follow application with an irrigation within 4 hours.

2,4-D* low-volatile esters (Chacon, Broad-Leaf Weed Killer, Esteron 99 Concentrate, Weedone LV-4 [others])

Formulation: Emulsifiable.
Use: Selective, foliage-applied, translocated.
Rate: 2 lb ae in 100 gal water/A or 4 tsp formulation per 1 gal water for spot treatment.
Remarks: To control common yarrow, speedwells, mallows, mature knotweed.

2,4-D* oil-soluble amines (Dacamine, Emulsamine E-3)

Formulation: Emulsifiable.
Use: Selective, foliage-applied, translocated.
Rate: 1 lb ae in 100 gal water/A or 2 tsp of 2 lb/gal formulation/gal water for spot treatment.
Remarks: To control dandelion, plantain, young knotweed (2- to 4-leaf stage).
Do not exceed 1 lb ae/A on bentgrass. Some injury may result. Apply only on established turfgrass. Use in dichondra turf only as a nonselective spot treatment. Apply only on calm days to avoid drift.

2,4-D* water-soluble amines (Formula 40, Weedar 64, 2,4-D Amine No. 4, others)

Use: Selective, foliage-applied, translocated.
Rate: 1 lb ae+1 qt surfactant in 100 gal water/A or 2 tsp formulation+2 tsp surfactant to 1 gal water for spot treatment.
Remarks: To control dandelion, plantain, young pigweed.
NOTE: On bentgrasses use water-soluble amine only and do not exceed 3/4 lb ae/A.
Rate: 2 lb ae+1 qt surfactant in 100 gal water/A or 4 tsp formulation+2 tsp. surfactant to 1 gal water for spot treatment.
Remarks: To control young knotweed (2- to 4-leaf stage), field bindweed, wild lettuce, filaree.

*Restricted herbicide; permit required from County Agricultural Commissioner.

DISEASES

RECOMMENDED FUNGICIDES

Disease	Fungicidal control (Use rates and frequencies recommended by the manufacturer)	Disease	Fungicidal control (Use rates and frequencies recommended by the manufacturer)
Anthracnose	chlorothalonil mancozeb triadimefon thiophanate-methyl	Fusarium patch	benomyl fenarimol iprodione mancozeb thiophanate-methyl triadimefon vinclozolin
Dollar spot	anilazine benomyl chlorothalonil fenarimol iprodione mancozeb thiophanate thiophanate-methyl thiram triadimefon vinclozolin	Helminthosporium leaf spot	anilazine captan chlorothalonil
		Leaf blotch	iprodione mancozeb
		Melting out	maneb thiram
Fairy ring	Complete soil sterilization. Methyl bromide* Soil-wetting agents may be helpful.	Powdery mildew	triadimefon fenarimol†
		Pythium blight or grease spot	chloroneb etridiazole mancozeb metalaxyl propamocarb
Fusarium blight complex	Complete control with fungicides has not been attained in California. benomyl fenarimol iprodione mancozeb thiophanate thiophanate-methyl triadimefon Water fungicides in after application.	Red thread	chlorothalonil iprodione mancozeb triadimefon fenarimol vinclozolin

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RECOMMENDED FUNGICIDES—*Continued*

Disease	Fungicidal control (Use rates and frequencies recommended by the manufacturer)	Disease	Fungicidal control (Use rates and frequencies recommended by the manufacturer)
Rhizoctonia blight (brown patch)	anilazine benomyl captan chlorothalonil fenarimol iprodione mancozeb PCNB thiophanate thiophanate-methyl thiram triadimefon	Smut, loose	Treat seed with captan or thiram. Fungicides used for stripe smut might be effective.
		Smut, stripe	benomyl fenarimol thiophanate thiophanate-methyl triadimefon Treat seed with thiram or captan.
Rust	Triadimefon is most effective. oxycarboxin Also helpful: anilazine chlorothalonil mancozeb	Southern blight	PCNB (Water into the turf.) triadimefon
		Spring dead spot	fenarimol‡ Benomyl applied experimentally in the fall provides some control.
Seed rot and damping off	Treat seed with thiram or captan. Fumigate soil before planting with dazomet, metham sodium or methyl bromide*	Take-all patch	fenarimol§ triadimefon§

*Permit for possession or use required from County Agricultural Commissioner.
†Powdery mildew is not listed on product label, but there are reports of effectiveness.
‡Registration on spring dead spot is pending in California.
§Take-all patch is not listed on this label, but there are reports of effectiveness.

COMMON, CHEMICAL, AND TRADE NAMES OF TURF FUNGICIDES

The following is a list of turf fungicides and the trade names under which they may be purchased at nurseries or supply houses. The chemical names are given in lowercase letters; the trade names, many of which are copyrighted, have their initial letters capitalized. Mercury and cadmium compounds are not included.

Some products not mentioned are known to give excellent results in University tests, but are not yet registered for commercial use, and therefore cannot be recommended.

anilazine = 4,6-dichloro-*N*-(2-chlorophenyl)-1,3,5-triazin-2-amine: Best Turf Fungicide, Dyrene.

benomyl = methyl 1-(butylcarbamoyl)-2-benzimidazolecarbamate: Tersan 1991, Scotts DSB Fungicide.

captan = *N*-trichloromethylthio-4-cyclohexene-1,2-dicarboximide: Orthocide, Captan.

chloroneb = 1,4-dichloro-2,5-dimethyoxybenzene: Terraneb, Scotts Fungicide II.

chlorothalonil = tetrachloroisophthalonitrile: Daconil 2787, Best Turf Disease Control, Turf Care, Scotts 101BS Fungicide, Ortho Liquid Lawn Disease Control.

dicloran = 2,6-dichloro-4-nitroanaline: Botran.

etridiazole = 5-ethoxy-3-trichloromethyl-1,2,4-thiadiazole: Koban, Terrazole.

fenarimol = -(2-chlorophenyl)- -(4-chlorophenyl)-5-pyrimidinemethanol: Rubigan.

folpet = *N*-(trichloromethylthio)phthalimide: Folpan, Folpet, Phaltan.

iprodione = 3-(3,5-dichlorophenyl)-*N*-(1-methylethyl)-2,4-dioxo-1-imidazolidenecarboximide: Chipco 26019, Scotts Fungicide VI.

mancozeb = coordination product of zinc ion and manganous ethylenebisdithiocarbamate: Fore, Best Multipurpose Disease Control.

maneb = manganese ethylenebisdithiocarbamate: Tersan LSR, Manzate 200.

metalaxyl = *N*-(2,6-dimethylphenyl)-*N*-(methoxyacetyl) alanine methyl ester: Subdue.

oxycarboxin = 2,3-dihydro-5-carboxanilido-6-methyl-1,4-oxathiin-4,4-dioxide: Plantvax.

PCNB = pentachloronitrobenzene: Fungiclor, Terraclor, Scotts FF II, Turfcide.

propamocarb = propyl [3-(dimethylamino) propyl] carbamate monohydrochloride: Banol.

thiophanate = diethyl,4,4-*o*-phenylenebis(3-thioallophanate): Cleary's-3336, Proturf Systemic Fungicide.

thiophanate-methyl = dimethyl [(1,2-phenylene) bis (iminocarbonothioyl)] bis (carbamate): Fungo 50, Ropsin M, Scotts Systemic Fungicide, Scotts DSB Fungicide.

thiram = tetramethylthiuram disulfide: D&P, Spotrete, Turf-Tox, Thiuran 75.

triadimefon = 1-(4-chlorophenoxy)-3,3-dimethyl-1-(1*H*-1,2,4-triazol-1-yl)-2-butanone: Bayleton, Scotts Fungicide 7.

vinclozolin = 3-(3,5-dichlorophenyl)-5-ethenyl-5-methyl-2,4-oxazolidinedione: Vorlan.

Combinations

dazomet = 3,5-dimethyl tetrahydro-1,3,5-2 thiadiazine-2-thione: Basamid.

methyl bromide* = methyl bromide: Bed Fume, Bromex, Brom-O-Gas, MBC Fumigant, Pestmaster Soil Fumigant, Tribrome, Weedfume.

MIT = methyl isothiocyanate: Vorlex (Vorlex is 20% MIT and 80% chlorinated hydrocarbon).

SMDC = sodium methyldithiocarbamate: Vapam, Soil-Prep.

*Permit required from County Agricultural Commissioner for possession or use.

INSECTS, MITES, AND MOLLUSCS

Insect and related pest damage to lawns often resembles the symptoms of diseases, nematodes, poor soil conditions, or other factors. Therefore, before you apply insecticides, it is usually best to make sure that insects are causing the damage.

HOW TO LOOK FOR INSECTS

Use the pyrethrum test. Mix 1 tablespoon of a commercial pyrethrum preparation (containing 1% to 2% pyrethrins) in 1 gallon of water and apply to 1 square yard of lawn. This brings vegetable weevil larvae, lawn moth larvae (sod webworms), cutworms, and other caterpillars to the surface within 10 minutes. It also brings up earwigs, but does not indicate whether white grubs or billbugs are present. Finding a few caterpillars is normal. Usually, no insecticide is needed unless there are more than 5 cutworms or 15 lawn moth larvae per square yard.

Select an area containing some living grass, and examine the soil around the roots for the white, legless larvae (grubs) of billbugs or the C-shaped, legged larvae of June beetles (white grubs). When abundant, these insects can eat away the roots of the grass so the turf can be rolled back like a carpet. If you find more than one billbug grub or one white grub per square foot, apply an insecticide.

For spider mites, leafhoppers, and flea beetles, examine the leaves, stems, and crowns of the plants. For snails and slugs, look for the dry mucous trails left by these pests.

CONTROL MEASURES FOR LAWN INSECTS, MITES, AND MOLLUSCS

Pest	Pesticide	Remarks
Lawn moths (sod webworms) (grasses)	Dursban spray or granules Sprays with *Bacillus thuringiensis* Orthene Soluble Powder Proxol/Dylox spray carbaryl (Sevin)*	Mow lawn and water well before treatment. Apply when plants are dry. With sprays, do not water again until necessary.
Cutworms and armyworms (grasses and dichondra)	Dursban spray or granules Orthene Soluble Powder Proxol/Dylox spray carbaryl (Sevin)*	Mow lawn and water well before treatment. Apply when plants are dry. Follow sprays with an equal amount of water to carry insecticide into plant crowns.
Vegetable weevil, leafhoppers (grasses) flea beetle (a pest of dichondra during warmer months)	malathion spray Dursban spray (vegetable weevil and flea beetle only)	Mow lawn and water well before treatment. Apply when plants are dry. Do not water again until necessary.
Fungus gnats, march flies	Orthene Soluble Powder (leafhoppers only)	Repeat applications may be necessary for flea beetles.
White grubs	Dursban spray or granules Mocap* granules Proxol/Dylox, Turcam	Water heavily after application to wash insecticide into plant root zone. Do not wash insecticide away by flooding. Repeat applications may be necessary.

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*Permit from County Agricultural Commissioner required for possession or use.

CONTROL MEASURES FOR LAWN INSECTS, MITES, AND MOLLUSCS—*Continued*

Pest	Pesticide	Remarks
Chinch bug	Mocap* granules	Water heavily after application to wash insecticide into plant crown. Do not wash insecticide away by flooding. Repeat applications may be necessary.
Snails and slugs	bait or granules containing metaldehyde or metaldehyde plus Sevin* or Mesurol	Apply in late evening. Control with baits is improved by sprinkling area lightly with water before treatment to activate snails and slugs.

*Permit from County Agricultural Commissioner required for possession or use.

COMMON, TRADE, AND CHEMICAL NAMES OF TURF INSECTICIDES

acephate=*O,S*-dimethyl acetylphosphoramidothioate: Orthene.

***Bacillus thuringiensis* var. *kurstaki*:** several.

bendiocarb=2,2-dimethyl-1,3-benzodioxol-4-yl methylcarbamate: Turcam.

carbaryl=1-napthyl *N*-methylcarbamate: Sevin.*

chlorpyrifos=*O,O*-diethyl *O*-(3,5,6-trichloro-2-pyridyl) phosphorothioate: Dursban.

ethoprop=*O*-ethyl *S,S*-dipropyl phosphorodithioate: Mocap.

malathion=diethyl mercaptosuccinate, *S*-ester with *O,O*-dimethyl phosphorodithioate: Malathion, Cythion.

methiocarb metmercapturon=3,5-dimethyl-4-(methylthio)phenyl methylcarbamate: Mesurol.

metaldehyde=metacetaldehyde: Metaldehyde.

trichlorfon=dimethyl (2,2,2-trichloro-1-hydroxyethyl)phosphonate: Dylox, Proxol.

NEMATODES

Make sure to investigate local restrictions on the handling and application of nematode-control chemicals. Read container labels and follow instructions carefully. Some of the materials listed may not be used without a permit from the County Agricultural Commissioner. Some are not available to the home-owner and must be applied by a licensed Pest Control Operator.

REGISTERED PREPLANT AND POSTPLANT CHEMICALS FOR NEMATODE CONTROL ON TURF

Chemical	Pests controlled*	Tarping required?	Application method
Preplant materials			
Methyl bromide†	1, 2, 3, 4	yes	inject from 1- to 1½-lb compressed gas canisters every 100 sq ft under polyethylene tarps
Chloropicrin†	1, 2, 3, 4	no	inject; preferably, cover with polyethylene tarps
SMDC†	1, 2, 3, 4	no	sprinkle on and water in, or apply through sprinklers
Dichloropropene	1	no	inject
Postplant materials‡			
Fensulfothion†	1	no	granules
Phenamiphos (fenamiphos)†	1	no	granules
Ethoprop†	1	no	granules

*1 = nematodes, 2 = fungi, 3 = insects, 4 = weeds.

†Restricted material; permit required from County Agricultural Commissioner.

‡None of the materials listed for postplant application is labeled for use on golf greens at this time.

COMMON, CHEMICAL, AND TRADE NAMES OF TURF NEMATICIDES

chloropicrin = trichloronitromethane.

SMDC = sodium *N*-methyldithiocarbamate: Vapam.

1,3-D = 1,3-dichloropropene: Telone.

methyl bromide = bromomethane.

phenamiphos (fenamiphos) = ethyl 3-methyl-4-(methylthio) phenyl (1-methylethyl) phosphoramidate: Nemacur.

ethoprop = *O*-ethyl *S,S*-dipropyl phosphorodithioate: Mocap.

RODENTS AND RELATED VERTEBRATE PESTS

Rodents and related vertebrate pests of turfgrass can cause severe damage and management problems. Early detection of these pests is important, since their presence often leads to damage. If uncontrolled, their populations will likely increase to intolerable levels.

Before control measures are taken, the animal believed to be the cause of the problem must be correctly identified. The resolution of the problem will depend on this. Use *Turfgrass Pests* (Publication 4053) to identify the pest, its sign (indicators of activity), and the type of damage done. Nonlethal and non-chemical control methods are effective in many instances. Long-term management of the turf and surrounding areas is often the best approach for prevention of rodent and related vertebrate pest damage.

WARNING

The descriptions of toxicants and poison baits given here are intended as brief guides to their properties and uses. ALL ARE HAZARDOUS to some degree and should be handled carefully and kept in locked storage when not in use. In all cases, follow label instructions carefully. Some toxicants discussed are restricted-use materials. Permits from the County Agricultural Commissioner's Office are required for purchase or use of such materials. In some cases, when limited quantities are used, no permit is required. Check with the Agricultural Commissioner's Office to be sure.

GENERAL INFORMATION ON TOXIC BAITS

Many toxicants for turfgrass rodents and similar pests are formulated as baits on whole grains or pelleted cereals. To provide adequate control, a bait must be consumed in sufficient quantities. Care should be taken to use good-quality, fresh bait appropriate to the target pest. When using poison baits, take care to insure the safety of children, pets, and nontarget animals. Follow product label instructions carefully.

Multiple-feeding baits. Anticoagulant baits are both cumulative and slow-acting and thus must be consumed over a period of 5 or more days in order to be effective. They are probably the safest rodent baits for use around homes and other inhabited areas, although they must still be used with care. Many types and brands are available. Whole-grain baits are commonly used, but pelleted baits can also work well. Moisture-resistant paraffin block baits are useful along drainage ditches and in areas where moisture may cause other baits to spoil.

Because the pest must feed on most anticoagulant baits for 5 or more days, the bait must remain available until the population is controlled. As with trapping, bait placement is very important—the animal has to find and eat the bait. If you broadcast the bait, you will probably have to apply it every other day for three or four treatments.

Single-feeding baits. Strychnine and zinc phosphide are toxicants that kill after only one feeding. No retreatment with these materials is recommended (except strychnine for pocket gophers), since the animal often becomes bait shy after consuming a sublethal dose. All rodenticides (i.e., poison baits) should be considered hazardous to children, pets, and nontarget animals, and this is especially true of strychnine and zinc phosphide. Follow product label instructions carefully to avoid potential hazards.

FUMIGANTS

Chemicals in the fumigant group are used to control burrowing rodents (primarily ground squirrels). Effectiveness depends on the production and retention of a toxic gas concentration within the burrow system. These factors are affected by soil density, moisture, temperature, soil cracks through which gases escape, and burrow capacity. Application time, labor, and equipment usually limit the fumigation method to smaller infestations, or to follow-up for other methods. Some fumigants present the possibility of accidental fires, so caution is needed. Because all fumigants are toxic to people and animals, never use them beneath buildings.

CONTROL MEASURES FOR RODENTS AND RELATED PESTS

Pest	Rodenticide	Remarks
Ground squirrel (*Spermophilus beecheyii*)	anticoagulant (bait)	Most effective in early summer or fall, but can be used whenever squirrels eat the bait. Use in bait boxes or stations to prevent access to bait by children, pets, and nontarget wildlife, or broadcast by hand or by mechanical means according to label instructions. Squirrels may first enter bait stations as many as 4 to 10 days after application. Uninterrupted access to bait for 5 to 10 days is required for good control. When broadcasting bait, repeat applications as specified on the label. Population reduction may not occur for 2 to 4 weeks.

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CONTROL MEASURES FOR RODENTS AND RELATED PESTS—*Continued*

Pest	Rodenticide	Remarks
	strychnine (bait)	Restricted-Use Material. Most effective on squirrels north of Sacramento and San Francisco in early summer and fall, and in other areas during the fall when the squirrels pouch grain or seeds. Scatter bait near burrow openings according to label directions. Use only once per season.
	zinc phosphide (bait)	Restricted-Use Material. Most effective in early summer and fall when squirrels are active and taking grain baits. Scatter near burrow openings according to label directions. Use only once per season.
	aluminum phosphide (fumigant)	Restricted-Use Material. Use when squirrels are active aboveground. Most effective when soil is moist—during the spring or after irrigation. Place tablets in burrow opening, stuff with crumpled newspaper, and cover with soil. Treat all burrow openings. Retreat any newly opened burrows in 3 to 4 days.
	gas cartridge (fumigant)	Use when squirrels are active aboveground. Most effective when soil is moist, such as during the spring or after irrigation. Place cartridge in active burrow, ignite, push it as deep as possible with a stick, and cover the opening. Treat all burrows. Retreat newly opened burrows in 3 to 4 days.
Jackrabbit (*Lepus californicas*)	anticoagulant (bait)	Place bait in a bait station in an area frequented by rabbits (near trails or resting and feeding areas). Bait must be fed on for 5 days or more to be effective. Population reduction may not occur for 2 to 4 weeks.
	strychnine (bait)	Restricted-Use Material. Establish baiting sites about 100 yards from the turf area being damaged. Place prebait (unpoisoned bait) at 10- to 15-yard intervals, preferably along the rabbit trail. Prebait for 3 to 5 days to condition rabbits to feed at the baiting site. Once adequate feeding occurs, remove prebait and place bait at the same site. After 1 to 2 days of bait exposure, remove all uneaten bait. Do not treat more than once per season.
Meadow vole (*Microtus spp.*)	anticoagulant (bait)	Place in vole holes or runways or broadcast by hand or by mechanical means according to label. Repeat treatment every other day for 3 to 4 applications or as specified on label.

Continued on next page

CONTROL MEASURES FOR RODENTS AND RELATED PESTS—*Continued*

Pest	Rodenticide	Remarks
	zinc phosphide (bait)	Restricted-Use Material. Place in vole holes or runways or broadcast by hand or by mechanical means according to label. To avoid bait shyness, apply only once in a 4- to 6-month period.
	aluminum phosphide* (fumigant)	Restricted-Use Material. Use when soil moisture is high. Place tablets in all burrow openings and cover. Treat all active holes. To find active burrows, cover all openings with soil 7 to 10 days before treatment. Retreat newly open burrows in 3 to 4 days. Repeat applications may be necessary. Generally not used unless other materials have been ineffective.
Mole *(Scapanus spp.)*	strychnine* (bait)	Restricted-Use Material. Baiting for moles is considered relatively ineffective. Place bait underground into deep mole tunnels. Check for activity 3 to 5 days after treatment by knocking down mounds. Repeated treatments are often necessary.
	gas cartridge* (fumigant)	Place in the deeper underground burrow system, ignite, and plug entry hole. Check for new activity the following day by knocking down mounds and subsurface tunnels. Treat again if necessary.
	aluminum phosphide* (fumigant)	Restricted-Use Material. Place tablets in deep underground tunnels and plug the opening. Several placements per burrow system are necessary. Check for activity in 2 to 3 days by knocking down mounds and subsurface tunnels. Treat again if necessary.
Pocket gopher *(Thomomys spp.)*	strychnine (bait)	Restricted-Use Material. Place bait underground in gopher burrow using probe or mechanical bait applicator. After 3 to 5 days, knock down all mounds and recheck for new activity. Treat again as necessary.
	anticoagulant (bait)	Place bait underground in burrow system as above. Follow label recommendations on baiting quantity, placement, and number of repeat applications. Gopher activity will likely continue for 1 to 3 weeks after baiting because of the slow action of these materials.
	zinc phosphide* (bait)	Restricted-Use Material. Place bait underground in burrow system as above. After 3 to 5 days, knock down mounds to check for new activity.

Continued on next page

Little or no information has been published on this material's effectiveness in California against this pest.

CONTROL MEASURES FOR RODENTS AND RELATED PESTS—*Continued*

Pest	Rodenticide	Remarks
	aluminum phosphide* (fumigant)	Restricted-Use Material. Use when soil moisture is high. Place tablets in gopher tunnel and seal opening. Several placements may be necessary for each burrow system. Check for activity by knocking down mounds 2 to 4 days after treatment. Repeat application may be necessary.
Skunk *(Spilogale putorius, Mephitis mephitis)* and raccoon *(Procyon lotor)*		No chemicals are registered as repellents or toxicants. Sometimes controlling turf grubs reduces the damage from skunks and raccoons since it reduces their food supply, causing them to move on. Fences can be effective.
Other: Chemicals registered but not recommended for use in turf		
	compound 1080	Highly restricted material for use by or under the direct supervision of government employees. Not generally applied in turf areas.
	methyl bromide	Restricted-Use Material. Place gas using special applicator in underground burrow. THIS MATERIAL IS PHYTOTOXIC, AND IS NOT RECOMMENDED FOR USE IN TURF. EXTENSIVE DAMAGE TO PLANTS MAY OCCUR.

Issued in furtherance of Cooperative Extension work, Acts of May 8 and June 30, 1914, in cooperation with the U.S. Department of Agriculture. Kenneth R. Farrell, Director of Cooperative Extension, University of California.

7.5M-rev-8/88-JC/FB/ALS

APPENDIX B

Draft Version -- Simulated Pesticide Movement Summary Tables

Bendiocarb

Simulation Completed
Summary Statistics Completed
Tables Completed
Graphs Completed
Discussion in Progress

Table 3.7-17. Mean Annual Flux of Bendiocarb from a 30 Year Simulation of an Established USGA Green on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	0.00	0.00	0.000
Maximum	200682.97	1003:70	0.008
Mean	7252.71	39.96	2.683E-04
SD	36553.74	182.60	0.001
Median	1.72	0.02	2.405E-09

Table 3.7-18. Mean Annual Flux of Bendiocarb from a 30 Year Simulation of an Established Wahiawa Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	4.69E-08	1.23E-07	7.64E-09
Maximum	89020.60	2766.20	1.135
Mean	3629.60	129.67	0.042
SD	16182.05	503.48	0.207
Median	52.86	4.66	2.40E-05

Table 3.7-19. Mean Annual Flux of Bendiocarb from a 30 Year Simulation of an Established Kolekole Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	5.00E-08	1.31E-08	2.14E-09
Maximum	94280.70	2929.60	2.95
Mean	3848.15	137.57	0.11
SD	17138.17	533.25	0.54
Median	56.36	4.97	6.84E-05

Table 3.7-20. Monthly Concentration of Bendiocarb (ng L^{-1})[1] Beneath the Root Zone from a 30 Year Simulation of an Established USGA Green on the Proposed Galbraith Trust.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	2.90E-10	8.44E-11	3.36E-12	5.03E-05
Mean	3.90E-12	1.78E-12	7.86E-14	4.31E-08
SD	2.25E-11	7.36E-12	2.92E-13	3.91E-07
Median	0.00	0.00	0.00	0.00
	May	**June**	**July**	**August**
Minimum	0.00	0.00	0.00	0.00
Maximum	1.45E-06	3.45E-08	8.37E-10	3.60E-11
Mean	1.32E-08	3.21E-10	8.35E-12	3.05E-13
SD	1.01E-07	2.43E-09	5.93E-11	2.50E-12
Median	1.22E-18	0.00	0.00	0.00
	September	**October**	**November**	**December**
Minimum	0.00	0.00	0.00	0.00
Maximum	7.71E-13	4.04E-08	1.40E-07	9.27E-09
Mean	7.53E-15	3.23E-10	1.51E-09	8.67E-11
SD	5.44E-14	2.78E-09	1.06E-08	6.44E-10
Median	0.00	0.00	0.00	0.00

[1]Detection limit for most pesticides under optimum research conditions is in the range of 1 ng L^{-1}.

Table 3.7-21. Monthly Concentration of Bendiocarb (ng L^{-1}) Beneath the Root Zone from a 30 Year Simulation of an Established Wahiawa Fairway Soil on the Proposed Galbraith Trust Estate.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	9.64E-09	8.81E-09	3.11E-10	9.49E-05
Mean	2.91E-10	1.27E-10	5.60E-12	8.89E-07
SD	1.13E-09	6.59E-10	2.31E-11	7.86E-06
Median	7.66E-17	6.90E-18	1.46E-18	7.08E-15
	May	**June**	**July**	**August**
Minimum	0.00	0.00	0.00	0.00
Maximum	3.11E-05	8.32E-07	2.14E-08	1.40E-09
Mean	3.04E-07	9.10E-09	2.78E-10	1.91E-11
SD	2.17E-06	5.90E-08	1.58E-09	1.00E-10
Median	6.50E-13	1.55E-13	2.85E-14	2.04E-14
	September	**October**	**November**	**December**
Minimum	0.00	0.00	0.00	0.00
Maximum	3.70E-09	6.07E-06	3.50E-06	2.50E-07
Mean	2.64E-11	5.17E-08	4.68E-08	3.10E-09
SD	2.51E-10	4.18E-07	2.72E-07	1.76E-08
Median	1.78E-15	1.13E-15	4.23E-15	6.51E-15

Table 3.7-22. Monthly Concentration of Bendiocarb (ng L^{-1}) Beneath the Root Zone from a 30 Year Simulation of an Established Kolekole Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	2.86E-08	2.60E-08	9.19E-10	2.88E-04
Mean	8.86E-10	3.77E-10	1.66E-11	2.70E-06
SD	3.42E-09	1.95E-09	6.83E-11	2.38E-05
Median	2.30E-16	2.00E-17	4.45E-18	2.29E-14
	May	**June**	**July**	**August**
Minimum	0.00	0.00	0.00	0.00
Maximum	9.44E-05	2.53E-06	6.51E-08	4.27E-09
Mean	9.24E-07	2.79E-08	8.53E-10	5.93E-11
SD	6.59E-06	1.79E-07	4.79E-09	3.07E-10
Median	2.26E-12	5.38E-13	9.82E-14	6.78E-14
	September	**October**	**November**	**December**
Minimum	0.00	0.00	0.00	0.00
Maximum	1.25E-08	1.88E-05	1.07E-05	7.60E-07
Mean	8.92E-11	1.61E-07	1.43E-07	9.50E-09
SD	8.48E-10	1.29E-06	8.27E-07	5.33E-08
Median	5.92E-15	3.75E-15	1.37E-14	1.91E-14

Table 3.7-23. Risk Level of Annual Bendiocarb Transport from an Established USGA Green at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Bendiocarb Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff (g ha^{-1} yr^{-1})	1.15	2.46
Sediment (g ha^{-1} yr^{-1})	0.02	0.02
Leachate (ug ha^{-1} yr^{-1})	6.96E-8	1.81E-5

Table 3.24. Risk Level of Annual Bendiocarb Transport from an Established Wahiawa Fairway Soil at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Bendiocarb Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff (g ha^{-1} yr^{-1})	1.32	2.63
Sediment (g ha^{-1} yr^{-1})	0.05	0.16
Leachate (ug ha^{-1} yr^{-1})	0.002	0.008

Table 3.7-25. Risk Level of Annual Bendiocarb Transport from an Established Kolekole Fairway Soil at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Bendiocarb Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff (g ha^{-1} yr^{-1})	1.40	2.80
Sediment (g ha^{-1} yr^{-1})	0.06	0.17
Leachate (ug ha^{-1} yr^{-1})	0.006	0.023

Figure 3.7-##a, b - Figure 3.7-24.

Chlorpyrifos

Simulation Completed
Summary Statistics Completed
Tables Completed
Graphs Completed
Discussion in Progress

Table 3.7-26. Mean Annual Flux of Chlorpyrifos from a 30 Year Simulation of an Established USGA Green on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	0.00	0.00	0.00
Maximum	6030.40	722.17	0.00
Mean	242.12	32.59	0.00
SD	1095.48	130.99	0.00
Median	18.99	4.06	0.00

Table 3.7-27. Mean Annual Flux of Chlorpyrifos from a 30 Year Simulation of an Established Wahiawa Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	0.02	0.06	0.00
Maximum	2103.77	1578.29	5.78E-12
Mean	99.51	87.66	3.67E-13
SD	381.20	286.83	1.06E-12
Median	12.34	13.36	6.68E-14

Table 3.7-28. Mean Annual Flux of Chlorpyrifos from a 30 Year Simulation of an Established Kolekole Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	0.02	0.06	0.00
Maximum	2245.52	1684.63	1.76E-11
Mean	106.23	93.57	1.12E-12
SD	406.89	306.15	3.22E-12
Median	13.17	14.26	2.06E-13

Table 3.7-20. Monthly Concentration of Chlorpyrifos (ng L^{-1})[1] Beneath the Root Zone from a 30 Year Simulation of an Established USGA Green on the Proposed Galbraith Trust.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	0.00	0.00
Mean	0.00	0.00	0.00	0.00
SD	0.00	0.00	0.00	0.00
Median	0.00	0.00	0.00	0.00
	May	**June**	**July**	**August**
Minimum	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	0.00	0.00
Mean	0.00	0.00	0.00	0.00
SD	0.00	0.00	0.00	0.00
Median	0.00	0.00	0.00	0.00
	September	**October**	**November**	**December**
Minimum	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	0.00	0.00
Mean	0.00	0.00	0.00	0.00
SD	0.00	0.00	0.00	0.00
Median	0.00	0.00	0.00	0.00

[1]Detection limit for most pesticides under optimum research conditions is in the range of 1 ng L^{-1}.

Table 3.7-21. Monthly Concentration of Chlorpyrifos (ng L^{-1}) Beneath the Root Zone from a 30 Year Simulation of an Established Wahiawa Fairway Soil on the Proposed Galbraith Trust Estate.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	9.41E-18	1.27E-17	7.70E-18	1.53E-17
Mean	6.54E-20	3.57E-19	2.55E-19	3.38E-19
SD	6.43E-19	1.78E-18	1.17E-18	1.58E-18
Median	0.00	0.00	0.00	0.00
	May	**June**	**July**	**August**
Minimum	0.00	0.00	0.00	0.00
Maximum	1.34E-17	7.06E-18	5.13E-18	2.54E-18
Mean	3.38E-19	2.02E-19	1.24E-19	6.13E-20
SD	1.80E-18	1.09E-18	6.83E-19	3.37E-19
Median	0.00	0.00	0.00	0.00
	September	**October**	**November**	**December**
Minimum	0.00	0.00	0.00	0.00
Maximum	1.25E-18	0.00	0.00	0.00
Mean	1.26E-20	0.00	0.00	0.00
SD	1.19E-19	0.00	0.00	0.00
Median	0.00	0.00	0.00	0.00

Table 3.7-22. Monthly Concentration of Chlorpyrifos (ng L^{-1}) Beneath the Root Zone from a 30 Year Simulation of an Established Kolekole Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	3.43E-17	4.61E-17	2.81E-17	5.57E-17
Mean	3.76E-19	1.67E-18	1.45E-18	1.68E-18
SD	2.42E-18	6.51E-18	4.47E-18	5.86E-18
Median	0.00	0.00	0.00	0.00
	May	**June**	**July**	**August**
Minimum	0.00	0.00	0.00	0.00
Maximum	4.86E-17	2.57E-17	1.87E-17	9.22E-18
Mean	1.74E-18	1.03E-18	5.65E-19	2.24E-19
SD	6.55E-18	3.99E-18	2.49E-18	1.23E-18
Median	0.00	0.00	0.00	0.00
	September	**October**	**November**	**December**
Minimum	0.00	0.00	0.00	0.00
Maximum	4.55E-18	2.30E-18	2.28E-18	5.11E-18
Mean	1.11E-19	8.59E-20	7.17E-20	1.19E-19
SD	6.11E-19	3.83E-19	3.32E-19	6.71E-19
Median	0.00	0.00	0.00	0.00

Table 3.7-23. Risk Level of Annual Chlorpyrifos Transport from an Established USGA Green at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Chlorpyrifos Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff (g ha^{-1} yr^{-1})	0.08	0.15
Sediment (g ha^{-1} yr^{-1})	0.02	0.03
Leachate (ug ha^{-1} yr^{-1})	0.00	0.00

Table 3.7-33. Risk Level of Annual Chlorpyrifos Transport from an Established Wahiawa Fairway Soil at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Chlorpyrifos Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff (g ha^{-1} yr^{-1})	0.06	0.13
Sediment (g ha^{-1} yr^{-1})	0.07	0.13
Leachate (ug ha^{-1} yr^{-1})	3.00E-13	8.48E-13

Table 3.7-34. Risk Level of Annual Chlorpyrifos Transport from an Established Kolekole Fairway Soil at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Chlorpyrifos Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff (g ha^{-1} yr^{-1})	0.07	0.14
Sediment (g ha^{-1} yr^{-1})	0.08	0.14
Leachate (ug ha^{-1} yr^{-1})	9.14E-13	2.58E-12

Figure 3.7-##a, b - Figure 3.7-##.

Fenamiphos

Simulation Completed
Summary Statistics Completed
Tables Completed
Graphs Completed
Discussion in Progress

Table 3.7-35

Table 3.7-35. Mean Annual Flux of Fenamiphos from a 30 Year Simulation of an Established USGA Green on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss ($mg\ ha^{-1}\ yr^{-1}$)	Pesticide Sediment Loss ($mg\ ha^{-1}\ yr^{-1}$)	Net Pesticide Loss Past the Maximum Root Zone ($ug\ ha^{-1}\ yr^{-1}$)
Minimum	0.00	0.00	1.40E-06
Maximum	203268.56	217.60	310036.33
Mean	7727.78	9.81	10923.13
SD	37049.04	40.03	56523.59
Median	0.28	5.04E-04	0.88

Table 3.7-36. Mean Annual Flux of Fenamiphos from a 30 Year Simulation of an Established Wahiawa Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss ($mg\ ha^{-1}\ yr^{-1}$)	Pesticide Sediment Loss ($mg\ ha^{-1}\ yr^{-1}$)	Net Pesticide Loss Past the Maximum Root Zone ($ug\ ha^{-1}\ yr^{-1}$)
Minimum	7.85E-08	3.72E-09	2.43E-04
Maximum	156662.62	1024.17	67194.75
Mean	6723.38	52.24	2577.47
SD	28610.71	189.78	12228.74
Median	51.49	1.02	3.16

Table 3.7-37. Mean Annual Flux of Fenamiphos from a 30 Year Simulation of an Established Kolekole Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss ($mg\ ha^{-1}\ yr^{-1}$)	Pesticide Sediment Loss ($mg\ ha^{-1}\ yr^{-1}$)	Net Pesticide Loss Past the Maximum Root Zone ($ug\ ha^{-1}\ yr^{-1}$)
Minimum	8.11E-08	3.84E-09	5.20E-04
Maximum	162353.88	1061.29	124108.45
Mean	6999.20	54.52	4828.66
SD	29657.10	196.86	22583.54
Median	54.50	1.08	7.01

Table 3.7-38. Monthly Concentration of Fenamiphos ($ng\ L^{-1}$)[1] Beneath the Root Zone from a 30 Year Simulation of an Established USGA Green on the Proposed Galbraith Trust.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	7.89E-03	1.47E-03	6.72E-05	199.20
Mean	2.21E-04	4.70E-05	3.09E-06	1.84
SD	8.19E-04	1.40E-04	8.10E-06	16.25
Median	1.30E-10	1.02E-11	1.29E-12	1.57E-09
	May	**June**	**July**	**August**
Minimum	1.12E-18	0.00	0.00	0.00
Maximum	66.49	2.22	0.07	4.92E-03
Mean	0.68	0.02	9.15E-04	6.03E-05
SD	4.81	0.16	5.57E-03	3.57E-04
Median	2.06E-08	1.18E-09	2.47E-10	6.15E-09
	September	**October**	**November**	**December**
Minimum	0.00	0.00	0.00	0.00
Maximum	6.91E-04	7.46	2.11	0.18
Mean	6.99E-06	0.07	0.04	3.22E-03
SD	4.93E-05	0.53	0.19	0.01
Median	1.45E-09	3.49E-10	5.70E-10	2.02E-09

[1]Detection limit for most pesticides under optimum research conditions is in the range of 1 $ng\ L^{-1}$.

Table 3.7-39. Monthly Concentration of Fenamiphos ($ng\ L^{-1}$) Beneath the Root Zone from a 30 Year Simulation of an Established Wahiawa Fairway Soil on the Proposed Galbraith Trust Estate.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	1.62E-03	6.15E-04	2.79E-05	18.31
Mean	4.71E-05	1.16E-05	6.71E-07	0.19
SD	1.57E-04	4.80E-05	2.22E-06	1.53
Median	2.63E-11	1.61E-12	6.84E-13	9.95E-09
	May	**June**	**July**	**August**
Minimum	1.08E-18	0.00	0.00	0.00
Maximum	6.60	0.25	8.91E-03	8.27E-04
Mean	0.08	3.38E-03	1.46E-04	1.19E-05
SD	0.48	0.02	7.06E-04	6.09E-05
Median	2.27E-06	7.55E-07	1.52E-07	6.50E-08
	September	**October**	**November**	**December**
Minimum	0.00	0.00	0.00	0.00
Maximum	5.02E-03	0.96	0.19	0.02
Mean	3.76E-05	8.84E-03	4.31E-03	4.53E-04
SD	3.51E-04	0.07	0.02	1.58E-03
Median	6.04E-09	2.18E-09	6.52E-09	2.47E-09

Table 3.7-40. Monthly Concentration of Fenamiphos (ng L^{-1}) Beneath the Root Zone from a 30 Year Simulation of an Established Kolekole Fairway Soil on the Proposed Galbraith Trust Estate, Wahlawa, Hawaii.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	3.27E-03	1.03E-03	4.63E-05	37.40
Mean	9.39E-05	2.07E-05	1.19E-06	0.39
SD	3.07E-04	8.08E-05	3.75E-06	3.12
Median	5.50E-11	3.04E-12	1.06E-12	2.00E-08
	May	**June**	**July**	**August**
Minimum	2.26E-18	0.00	0.00	0.00
Maximum	13.49	0.51	0.02	1.69E-03
Mean	0.16	7.18E-03	3.09E-04	2.51E-05
SD	0.98	0.04	1.46E-03	1.25E-04
Median	6.64E-06	2.16E-06	4.19E-07	1.71E-07
	September	**October**	**November**	**December**
Minimum	0.00	0.00	0.00	0.00
Maximum	0.01	2.01	0.37	0.03
Mean	9.99E-05	0.02	8.89E-03	9.48E-04
SD	9.30E-04	0.14	0.04	3.25E-03
Median	1.56E-08	2.23E-09	1.49E-08	4.93E-09

Table 3.7-41. Risk Level of Annual Fenamiphos Transport from an Established USGA Green at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Fenamiphos Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahlawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff (g ha^{-1} yr^{-1})	0.63	2.13
Sediment (g ha^{-1} yr^{-1})	0.001	0.006
Leachate (ug ha^{-1} yr^{-1})	231.19	1624.88

Table 3.7-42. Risk Level of Annual Fenamiphos Transport from an Established Wahlawa Fairway Soil at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Fenamiphos Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahlawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff (g ha^{-1} yr^{-1})	1.06	4.73
Sediment (g ha^{-1} yr^{-1})	0.02	0.06
Leachate (ug ha^{-1} yr^{-1})	545.93	1919.01

Table 3.7-43. Risk Level of Annual Fenamiphos Transport from an Established Kolekole Fairway Soil at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Fenamiphos Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahlawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff (g ha^{-1} yr^{-1})	1.12	5.00
Sediment (g ha^{-1} yr^{-1})	0.02	0.06
Leachate (ug ha^{-1} yr^{-1})	1179.72	4092.58

Figure 3.7-##a, b - Figure 3.7-##.

Trichclorfon

Simulation Completed
Summary Statistics Completed
Table Completed Table 3.7-44
Graphs Completed
Discussion in Progress

Table 3.7-44. Mean Annual Flux of Trichlorfon from a 30 Year Simulation of an Established USGA Green on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	0.00	0.00	0.90
Maximum	516249.92	27.18	1.86E+09
Mean	28852.28	2.45	2.29E+08
SD	100096.38	6.96	4.75E+08
Median	1.63E-04	1.60E-08	1.91E+07

Table 3.7-45. Mean Annual Flux of Trichlorfon from a 30 Year Simulation of an Established Wahiawa Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	5.78E-09	1.32E-11	3.46
Maximum	951863.24	308.37	8.41E+08
Mean	71001.76	34.07	9.64E+07
SD	202391.76	84.89	2.12E+08
Median	586.35	0.48	9.14E+06

Table 3.7-46. Mean Annual Flux of Trichlorfon from a 30 Year Simulation of an Established Kolekole Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	4.66E-09	9.86E-12	3.42
Maximum	933930.36	302.49	8.89E+08
Mean	70916.08	34.18	1.06E+08
SD	200621.63	84.98	2.29E+08
Median	562.47	0.47	1.04E+07

Table 3.7-47. Monthly Concentration of Trichlorfon (ng L^{-1})[1] Beneath the Root Zone from a 30 Year Simulation of an Established USGA Green on the Proposed Galbraith Trust.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	1.27	0.03	5.13E-04	1.79E+06
Mean	0.04	5.17E-04	5.92E-06	5.89E+04
SD	0.13	2.68E-03	3.68E-05	1.99E+05
Median	3.8E-09	4.38E-11	8.65E-14	9.16E-14
	May	**June**	**July**	**August**
Minimum	0.00	0.00	0.00	0.00
Maximum	3.43E+05	7634.00	208.80	5.05
Mean	2.21E+04	616.86	17.16	0.39
SD	4.54E+04	1100.45	29.68	0.69
Median	3.12E+03	152.30	3.78	0.10
	September	**October**	**November**	**December**
Minimum	0.00	0.00	0.00	0.00
Maximum	2.94E+05	8.91E+04	2.53E+03	69.14
Mean	2.89E+03	2.99E+03	164.41	3.62
SD	2.22E+04	9.37E+03	374.05	8.90
Median	2.83E-03	1.93E-04	1.71E-05	3.50E-04

[1]Detection limit for most pesticides under optimum research conditions is in the range of 1 ng L^{-1}.

Table 3.7-48. Monthly Concentration of Trichlorfon (ng L^{-1}) Beneath the Root Zone from a 30 Year Simulation of an Established Wahiawa Fairway Soil on the Proposed Galbraith Trust Estate.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	1.94	0.03	9.85E-04	5.85E+05
Mean	0.10	1.41E-03	2.48E-05	1.95E+04
SD	0.23	3.65E-03	8.24E-05	7.13E+04
Median	4.15E-05	3.04E-10	1.45E-09	2.55E-08
	May	**June**	**July**	**August**
Minimum	0.00	0.00	0.00	0.00
Maximum	1.53E+05	5.36E+03	156.40	4.09
Mean	7.46E+03	241.62	8.09	0.23
SD	1.75E+04	554.07	16.38	0.41
Median	500.05	39.92	1.93	0.08
	September	**October**	**November**	**December**
Minimum	0.00	0.00	1.80E-18	0.00
Maximum	4.74E+04	2.47E+04	2.53E+03	71.28
Mean	453.08	813.66	102.71	5.53
SD	3.50E+03	2.39E+03	267.18	10.48
Median	2.99E-03	2.38E-04	2.28E-05	0.10

Table 3.7-49. Monthly Concentration of Trichlorfon (ng L^{-1}) Beneath the Root Zone from a 30 Year Simulation of an Established Kolekole Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	1.95	0.03	1.01E-03	6.54E+05
Mean	0.10	1.35E-03	2.28E-05	2.18E+04
SD	0.23	3.64E-03	8.09E-05	7.87E+04
Median	2.88E-05	2.69E-10	8.55E-10	1.72E-08
	May	**June**	**July**	**August**
Minimum	0.00	0.00	0.00	0.00
Maximum	1.61E+05	5.68E+03	164.90	4.27
Mean	8.35E+03	267.45	8.90	0.25
SD	1.93E+04	592.71	17.42	0.43
Median	644.85	49.11	2.21	0.09
	September	**October**	**November**	**December**
Minimum	0.00	0.00	1.58E-18	0.00
Maximum	5.65E+04	2.83E+04	2.70E+03	75.85
Mean	547.44	932.80	111.49	5.76
SD	4.20E+03	2.71E+03	282.98	11.00
Median	3.26E-03	2.55E-04	2.40E-05	0.14

Table 3.7-50. Risk Level of Annual Trichlorfon Transport from an Established USGA Green at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Trichlorfon Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff (g ha^{-1} yr^{-1})	1.24	30.13
Sediment (g ha^{-1} yr^{-1})	0.0002	0.004
Leachate (g ha^{-1} yr^{-1})	147.68	794.81

Table 3.7-51. Risk Level of Annual Trichlorfon Transport from an Established Wahiawa Fairway Soil at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Trichlorfon Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff (g ha^{-1} yr^{-1})	15.02	95.20
Sediment (g ha^{-1} yr^{-1})	0.01	0.07
Leachate (g ha^{-1} yr^{-1})	60.18	282.87

Table 3.7-52. Risk Level of Annual Trichlorfon Transport from an Established Kolekole Fairway Soil at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Trichlorfon Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff (g ha^{-1} yr^{-1})	14.88	95.48
Sediment (g ha^{-1} yr^{-1})	0.01	0.07
Leachate (ug ha^{-1} yr^{-1})	64.97	317.16

Benomyl

Simulation Completed
Summary Statistics Completed
Tables Completed Table 3.7-53
Graphs Completed
Discussion in Progress

Table 3.7-53. Mean Annual Flux of Benomyl from a 30 Year Simulation of an Established USGA Green on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	0.00	0.00	10182.54
Maximum	667566.70	952.96	1.02E+08
Mean	34826.34	62.66	2.26E+07
SD	121108.74	173.23	2.37E+07
Median	5966.12	16.91	1.41E+07

Table 3.7-54. Mean Annual Flux of Benomyl from a 30 Year Simulation of an Established Wahiawa Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	254.86	8.22	3300.79
Maximum	479050.29	4339.30	4.16E+07
Mean	43454.47	512.90	1.07E+07
SD	86450.07	792.66	1.06E+07
Median	25481.35	328.57	6859672.14

Table 3.7-55. Mean Annual Flux of Benomyl from a 30 Year Simulation of an Established Kolekole Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	228.07	7.36	65763.64
Maximum	472375.77	4272.85	5.08E+07
Mean	40031.85	470.17	1.35E+07
SD	84952.70	776.33	1.33E+07
Median	21408.82	282.46	8414949.36

Table 3.7-56. Monthly Concentration of Benomyl (ng L^{-1}) Beneath the Root Zone from a 30 Year Simulation of an Established USGA Green on the Proposed Galbraith Trust Estate.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	10110.00	10290.00	16300.00	15640.00
Mean	2268.22	2985.57	3545.70	4190.36
SD	2147.96	2591.04	3131.72	3700.46
Median	1525.00	2441.00	3489.50	3650.00
	May	**June**	**July**	**August**
Minimum	6.65E-7	5.56E-7	4.62E-7	4.25E-7
Maximum	14970.00	13570.00	11390.00	10020.00
Mean	4281.14	3724.37	3224.73	2878.75
SD	4035.33	3627.47	3129.95	2686.26
Median	3259.00	2718.00	2333.50	1942.50
	September	**October**	**November**	**December**
Minimum	0.01	0.01	0.00	0.05
Maximum	8330.00	8114.00	9401.00	10930.00
Mean	2477.73	2226.07	2232.31	2373.25
SD	2295.27	2161.27	2271.98	2296.17
Median	1619.00	1364.50	1230.00	1477.00

Table 3.7-57. Monthly Concentration of Benomyl (ng L^{-1}) Beneath the Root Zone from a 30 Year Simulation of an Established Wahiawa Fairway Soil on the Proposed Galbraith Trust Estate.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	3478.00	3641.00	3618.00	5670.00
Mean	744.55	959.96	1069.85	1189.50
SD	680.44	860.74	868.75	942.38
Median	628.25	752.90	1009.50	1149.50
	May	**June**	**July**	**August**
Minimum	0.00	9.06E-4	7.53E-4	6.92E-4
Maximum	5470.00	4891.00	4498.00	3737.00
Mean	1192.13	1039.31	914.91	820.53
SD	1037.93	940.99	838.37	717.40
Median	1006.50	841.10	702.05	633.05
	September	**October**	**November**	**December**
Minimum	0.08	0.06	0.06	0.71
Maximum	3104.00	2594.00	3200.00	3762.00
Mean	708.35	652.84	686.04	753.44
SD	611.24	590.28	658.24	718.52
Median	530.45	455.05	452.75	487.55

Table 3.7-58. Monthly Concentration of Benomyl (ng L^{-1}) Beneath the Root Zone from a 30 Year Simulation of an Established Kolekole Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	4585.00	5365.00	5219.00	7659.00
Mean	972.13	1282.91	1437.90	1611.89
SD	843.01	1150.34	1172.05	1309.91
Median	922.10	1049.00	1299.50	1564.00
	May	**June**	**July**	**August**
Minimum	0.003	0.003	0.002	0.002
Maximum	7389.00	6448.00	5930.00	4926.00
Mean	1605.39	1396.20	1226.07	1097.07
SD	1418.40	1275.47	1125.00	957.30
Median	1413.00	1192.00	1014.50	893.75
	September	**October**	**November**	**December**
Minimum	0.20	0.16	0.15	1.77
Maximum	4093.00	3437.00	3860.00	4398.00
Mean	946.09	865.49	895.01	975.50
SD	815.53	784.31	842.29	882.68
Median	752.35	646.15	589.20	691.20

Table 3.7-59. Risk Level of Annual Benomyl Transport from an Established USGA Green at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Benomyl Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff ($g\ ha^{-1}\ yr^{-1}$)	23.42	35.05
Sediment ($g\ ha^{-1}\ yr^{-1}$)	0.06	0.12
Leachate ($g\ ha^{-1}\ yr^{-1}$)	38.77	48.55

Table 3.7-60. Risk Level of Annual Benomyl Transport from an Established Wahiawa Fairway Soil at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Benomyl Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff ($g\ ha^{-1}\ yr^{-1}$)	47.45	64.53
Sediment ($g\ ha^{-1}\ yr^{-1}$)	0.63	0.97
Leachate ($g\ ha^{-1}\ yr^{-1}$)	17.59	21.98

Table 3.7-61. Risk Level of Annual Benomyl Transport from an Established Kolekole Fairway Soil at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Benomyl Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff ($g\ ha^{-1}\ yr^{-1}$)	42.88	60.03
Sediment ($g\ ha^{-1}\ yr^{-1}$)	0.64	0.83
Leachate ($g\ ha^{-1}\ yr^{-1}$)	21.65	28.79

Chlorothalinol

Simulation Completed
Summary Statistics Completed
Tables Completed — Table 3.7-62
Graphs Completed
Discussion in Progress

Table 3.7-62. Mean Annual Flux of Chlorothalinol from a 30 Year Simulation of an Established USGA Green on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	0.00	0.00	0.00
Maximum	246357.44	7776.65	0.00
Mean	10429.19	374.88	0.00
SD	44800.42	1413.03	0.00
Median	744.02	35.97	0.00

Table 3.7-63. Mean Annual Flux of Chlorothalinol from a 30 Year Simulation of an Established Wahiawa Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	0.41	0.33	6.20E-11
Maximum	89283.50	17644.88	1.62E-05
Mean	4516.17	1060.66	1.02E-06
SD	16190.09	3202.64	2.96E-06
Median	426.44	144.97	1.12E-07

Table 3.7-64. Mean Annual Flux of Chlorothalinol from a 30 Year Simulation of an Established Kolekole Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	0.43	0.35	1.87E-10
Maximum	95188.99	18811.80	4.79E-05
Mean	4815.85	1131.17	3.02E-06
SD	17260.98	3414.49	8.76E-06
Median	454.62	154.60	3.32E-07

Table 3.7-65. Monthly Concentration of Chlorothalinol (ng L^{-1})[1] Beneath the Root Zone from a 30 Year Simulation of an Established USGA Green on the Proposed Galbraith Trust.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	0.00	0.00
Mean	0.00	0.00	0.00	0.00
SD	0.00	0.00	0.00	0.00
Median	0.00	0.00	0.00	0.00
	May	June	July	August
Minimum	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	0.00	0.00
Mean	0.00	0.00	0.00	0.00
SD	0.00	0.00	0.00	0.00
Median	0.00	0.00	0.00	0.00
	September	October	November	December
Minimum	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	0.00	0.00
Mean	0.00	0.00	0.00	0.00
SD	0.00	0.00	0.00	0.00
Median	0.00	0.00	0.00	0.00

[1] Detection limit for most pesticides under optimum research conditions is in the range of 1 ng L^{-1}.

Table 3.7-66. Monthly Concentration of Chlorothalinol (ng L^{-1}) Beneath the Root Zone from a 30 Year Simulation of an Established Wahiawa Fairway Soil on the Proposed Galbraith Trust Estate.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	1.27E-10	1.66E-10	8.58E-11	1.20E-10
Mean	1.66E-12	5.81E-12	4.38E-12	4.62E-12
SD	9.03E-12	2.20E-11	1.26E-11	1.32E-11
Median	3.87E-14	4.97E-14	1.10E-13	1.38E-13
	May	June	July	August
Minimum	8.48E-18	3.60E-18	1.48E-18	0.00
Maximum	1.01E-10	4.45E-11	2.70E-11	1.11E-11
Mean	4.07E-12	2.06E-12	1.05E-12	4.94E-13
SD	1.28E-11	6.43E-12	3.40E-12	1.42E-12
Median	1.35E-13	5.67E-14	3.64E-14	4.45E-14
	September	October	November	December
Minimum	9.04E-18	7.76E-18	3.59E-18	2.03E-18
Maximum	4.58E-12	6.49E-12	1.19E-11	1.12E-11
Mean	2.16E-13	1.99E-13	5.61E-13	6.58E-13
SD	5.93E-13	7.20E-13	1.85E-12	1.83E-12
Median	2.31E-14	1.20E-14	7.05E-13	3.31E-14

Table 3.7-67. Monthly Concentration of Chlorothalinol (ng L^{-1}) Beneath the Root Zone from a 30 Year Simulation of an Established Kolekole Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	4.49E-10	5.88E-10	3.03E-10	4.21E-10
Mean	5.86E-12	2.05E-11	1.55E-11	1.63E-11
SD	3.20E-11	7.78E-11	4.47E-11	4.65E-11
Median	1.37E-13	1.76E-13	3.87E-13	4.87E-13
	May	June	July	August
Minimum	3.09E-17	1.31E-17	5.40E-18	3.62E-18
Maximum	3.55E-10	1.56E-10	9.46E-11	3.90E-11
Mean	1.43E-11	7.26E-12	3.70E-12	1.74E-12
SD	4.49E-11	2.26E-11	1.19E-11	5.00E-12
Median	4.80E-13	2.01E-13	1.29E-13	1.57E-13
	September	October	November	December
Minimum	3.25E-17	2.80E-17	1.30E-17	7.31E-18
Maximum	1.61E-11	2.30E-11	4.22E-11	3.94E-11
Mean	7.62E-13	7.02E-13	1.99E-12	2.33E-12
SD	2.08E-12	2.55E-12	6.55E-12	6.45E-12
Median	8.10E-14	4.28E-14	2.50E-14	1.18E-13

Table 3.7-68. Risk Level of Annual Chlorothalinol Transport from an Established USGA Green at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Chlorothalinol Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff (g ha^{-1} yr^{-1})	2.49	5.99
Sediment (g ha^{-1} yr^{-1})	0.20	0.45
Leachate (ug ha^{-1} yr^{-1})	0.00	0.00

Table 3.7-69. Risk Level of Annual Chlorothalinol Transport from an Established Wahiawa Fairway Soil at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Chlorothalinol Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff ($g\ ha^{-1}\ yr^{-1}$)	3.02	5.46
Sediment ($g\ ha^{-1}\ yr^{-1}$)	0.96	1.88
Leachate ($ug\ ha^{-1}\ yr^{-1}$)	1.04E-06	1.86E-06

Table 3.7-70. Risk Level of Annual Chlorothalinol Transport from an Established Kolekole Fairway Soil at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Chlorothalinol Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff ($g\ ha^{-1}\ yr^{-1}$)	3.22	5.83
Sediment ($g\ ha^{-1}\ yr^{-1}$)	1.02	2.00
Leachate ($ug\ ha^{-1}\ yr^{-1}$)	3.10E-06	5.51E-06

Figure 3.7-##a, b - Figure 3.7-##.

Metalaxyl

Simulation Completed
Summary Statistics Completed
Tables Completed — Table 3.7-71
Graphs Completed
Discussion in Progress

Table 3.7-71. Mean Annual Flux of Metalaxyl from a 30 Year Simulation of an Established USGA Green on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	0.00	0.00	6.71E-02
Maximum	310279.32	430.22	106368.61
Mean	12415.94	20.23	8336.35
SD	56406.42	78.19	22964.38
Median	94.11	0.40	419.39

Table 3.7-72. Mean Annual Flux of Metalaxyl from a 30 Year Simulation of an Established Wahiawa Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	0.01	6.60E-04	0.44
Maximum	212107.41	1833.43	31125.03
Mean	9989.58	103.71	3142.98
SD	38479.39	333.50	6774.33
Median	465.56	8.19	405.38

Table 3.7-73. Mean Annual Flux of Metalaxyl from a 30 Year Simulation of an Established Kolekole Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	0.02	6.87E-04	1.01
Maximum	220886.25	1909.16	60987.30
Mean	10437.20	108.56	6096.85
SD	40072.26	347.36	13130.40
Median	489.34	8.70	834.59

Table 3.7-74. Monthly Concentration of Metala[illegible])[1] Beneath the Root Zone from a 30 Year Simulation of an Established USGA Green on the Proposed Galbraith Trust.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	5.42	6.21	1.61	70.51
Mean	0.22	0.32	0.14	0.85
SD	0.78	0.85	0.29	6.81
Median	2.64E-04	2.50E-04	3.42E-04	2.31E-04
	May	**June**	**July**	**August**
Minimum	7.02E-09	2.28E-09	4.75E-10	9.88E-11
Maximum	45.02	10.50	2.30	1.04
Mean	0.85	0.20	0.06	0.02
SD	4.69	1.08	0.29	0.11
Median	8.28E-04	1.81E-04	1.02E-04	1.38E-04
	September	**October**	**November**	**December**
Minimum	3.59E-11	1.26E-10	8.42E-11	8.01E-11
Maximum	0.22	19.02	38.22	14.49
Mean	5.44E-03	0.24	0.88	0.37
SD	0.02	1.76	4.33	1.51
Median	4.92E-05	2.09E-05	1.89E-05	2.12E-04

[1]Detection limit for most pesticides under optimum research conditions is in the range of 1 ng L^{-1}.

Table 3.7-75. Monthly Concentration of Metalaxyl (ng L^{-1}) Beneath the Root Zone from a 30 Year Simulation of an Established Wahiawa Fairway Soil on the Proposed Galbraith Trust Estate.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	2.22	2.40	0.64	7.85
Mean	0.06	0.08	0.03	0.10
SD	0.21	0.26	0.07	0.72
Median	1.38E-04	1.33E-04	1.18E-04	1.10E-04
	May	**June**	**July**	**August**
Minimum	5.55E-08	2.00E-08	5.64E-09	2.82E-09
Maximum	4.98	1.31	0.41	0.20
Mean	0.12	0.03	0.01	6.25E-03
SD	0.53	0.14	0.05	0.02
Median	9.66E-04	2.50E-04	1.61E-04	1.01E-04
	September	**October**	**November**	**December**
Minimum	6.17E-10	4.45E-09	1.36E-09	4.94E-10
Maximum	0.04	3.05	3.71	1.50
Mean	1.60E-03	0.04	0.10	0.06
SD	5.28E-03	0.28	0.44	0.18
Median	3.83E-05	2.75E-05	7.80E-05	3.31E-04

Table 3.7-76. Monthly Concentration of Metalaxyl (ng L^{-1}) Beneath the Root Zone from a 30 Year Simulation of an Established Kolekole Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	4.21	4.48	1.18	17.17
Mean	0.12	0.15	0.06	0.22
SD	0.41	0.49	0.14	1.58
Median	3.16E-04	2.68E-04	2.56E-04	2.55E-04
	May	**June**	**July**	**August**
Minimum	0.00	4.56E-08	1.28E-08	5.90E-09
Maximum	10.88	2.87	0.89	0.44
Mean	0.26	0.07	0.03	0.01
SD	1.17	0.31	0.10	0.05
Median	2.33E-03	5.87E-04	3.78E-04	2.29E-04
	September	**October**	**November**	**December**
Minimum	1.29E-09	0.00	3.47E-08	1.26E-09
Maximum	0.09	6.86	8.00	3.23
Mean	3.69E-03	0.09	0.23	0.13
SD	0.01	0.64	0.96	0.39
Median	9.17E-05	7.18E-05	1.90E-04	7.96E-04

Table 3.7-77. Risk Level of Annual Metalaxyl Transport from an Established USGA Green at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Metalaxyl Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff (g ha^{-1} yr^{-1})	3.49	11.50
Sediment (g ha^{-1} yr^{-1})	0.01	0.02
Leachate (ug ha^{-1} yr^{-1})	4015.07	12620.02

Table 3.7-78. Risk Level of Annual Metalaxyl Transport from an Established Wahiawa Fairway Soil at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Metalaxyl Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff ($g\ ha^{-1}\ yr^{-1}$)	4.59	13.41
Sediment ($g\ ha^{-1}\ yr^{-1}$)	0.07	0.16
Leachate ($ug\ ha^{-1}\ yr^{-1}$)	3265.30	11971.53

Table 3.7-79. Risk Level of Annual Metalaxyl Transport from an Established Kolekole Fairway Soil at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Metalaxyl Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff ($g\ ha^{-1}\ yr^{-1}$)	4.88	14.22
Sediment ($g\ ha^{-1}\ yr^{-1}$)	0.08	0.17
Leachate ($ug\ ha^{-1}\ yr^{-1}$)	5962.34	23692.15

Figure 3.7-##a, b - Figure 3.7-##.

General Discussion on Fungicides

Pesticide Fate and Transport: Herbicides

Bensulide

Simulation Completed
Summary Statistics Completed
Tables Completed Table 3.7-80
Graphs Completed
Discussion in Progress

Table 3.7-80. Mean Annual Flux of Bensulide from a 30 Year Simulation of an Established USGA Green on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	0.00	0.00	2.17E-08
Maximum	1086510.55	7092.40	6.03
Mean	48604.59	371.77	0.67
SD	196911.61	1283.32	1.39
Median	5941.86	89.20	0.07

Table 3.7-81. Mean Annual Flux of Bensulide from a 30 Year Simulation of an Established Wahiawa Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	31.93	4.85	0.06
Maximum	478705.13	19649.99	535.50
Mean	27050.13	1348.11	60.21
SD	86319.55	3553.01	106.03
Median	7984.25	520.37	24.57

Table 3.7-82. Mean Annual Flux of Bensulide from a 30 Year Simulation of an Established Kolekole Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	33.82	5.14	0.17
Maximum	507332.59	20822.58	1354.36
Mean	28661.58	1428.80	150.03
SD	91486.05	3765.54	266.73
Median	8421.00	546.17	59.94

Table 3.7-83. Monthly Concentration of Bensulide (ng L^{-1})[1] Beneath the Root Zone from a 30 Year Simulation of an Established USGA Green on the Proposed Galbraith Trust.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	1.69E-03	1.80E-03	1.49E-03	1.02E-03
Mean	6.72E-05	1.19E-04	1.39E-04	1.10E-04
SD	1.95E-04	3.27E-04	3.12E-04	2.21E-04
Median	3.50E-06	6.50E-06	6.24E-06	9.99E-06
	May	**June**	**July**	**August**
Minimum	0.00	0.00	0.00	0.00
Maximum	8.30E-04	5.47E-04	4.35E-04	4.17E-04
Mean	8.77E-05	6.03E-05	4.53E-05	4.00E-05
SD	1.66E-04	1.13E-04	8.80E-05	7.95E-05
Median	7.24E-06	4.92E-06	3.44E-06	2.85E-06
	September	**October**	**November**	**December**
Minimum	1.66E-16	1.08E-16	8.52E-17	6.87E-16
Maximum	3.32E-04	2.19E-04	6.89E-04	7.27E-04
Mean	2.97E-05	2.40E-05	4.10E-05	5.82E-05
SD	6.07E-05	4.52E-05	1.12E-04	1.35E-04
Median	1.86E-06	1.76E-06	4.28E-06	4.36E-06

[1]Detection limit for most pesticides under optimum research conditions is in the range of 1 ng L^{-1}.

Table 3.7-84. Monthly Concentration of Bensulide (ng L^{-1}) Beneath the Root Zone from a 30 Year Simulation of an Established Wahiawa Fairway Soil on the Proposed Galbraith Trust Estate.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	0.01	0.01	0.01	0.03
Mean	7.35E-04	1.39E-03	1.56E-03	1.80E-03
SD	1.61E-03	2.63E-03	2.43E-03	3.14E-03
Median	2.17E-04	3.76E-04	5.76E-04	9.76E-04
	May	**June**	**July**	**August**
Minimum	6.29E-10	4.15E-10	2.70E-10	2.22E-10
Maximum	0.03	0.02	0.02	0.01
Mean	1.88E-03	1.41E-03	1.05E-03	7.69E-04
SD	3.89E-03	3.07E-03	2.39E-03	1.57E-03
Median	7.64E-04	5.12E-04	3.72E-04	3.21E-04
	September	**October**	**November**	**December**
Minimum	2.96E-08	1.93E-08	1.52E-08	1.92E-06
Maximum	6.77E-03	4.46E-03	7.38E-03	0.01
Mean	5.35E-04	4.61E-04	5.75E-04	7.30E-04
SD	1.03E-03	8.44E-04	1.15E-03	1.69E-03
Median	2.20E-04	1.51E-04	1.13E-04	1.31E-04

Table 3.7-85. Monthly Concentration of Bensulide (ng L^{-1}) Beneath the Root Zone from a 30 Year Simulation of an Established Kolekole Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	0.03	0.04	0.03	0.08
Mean	2.09E-03	4.03E-03	4.51E-03	5.24E-03
SD	4.55E-03	7.70E-03	7.08E-03	9.24E-03
Median	6.49E-04	1.09E-03	1.68E-03	2.80E-03
	May	**June**	**July**	**August**
Minimum	2.19E-09	1.45E-09	9.40E-10	7.73E-10
Maximum	0.08	0.06	0.05	0.03
Mean	5.47E-03	4.09E-03	3.06E-03	2.23E-03
SD	0.01	8.98E-03	6.96E-03	4.56E-03
Median	2.19E-03	1.48E-03	1.08E-03	9.08E-04
	September	**October**	**November**	**December**
Minimum	1.01E-07	6.54E-08	5.16E-08	6.52E-07
Maximum	0.02	0.01	0.02	0.03
Mean	1.55E-03	1.33E-03	1.64E-03	2.06E-03
SD	3.00E-03	2.45E-03	3.25E-03	4.70E-03
Median	6.32E-04	4.33E-04	3.27E-04	3.82E-04

Table 3.7-86. Risk Level of Annual Bensulide Transport from an Established USGA Green at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Bensulide Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff (g ha^{-1} yr^{-1})	20.63	43.27
Sediment (g ha^{-1} yr^{-1})	0.28	0.42
Leachate (ug ha^{-1} yr^{-1})	0.87	1.50

Table 3.7-87. Risk Level of Annual Bensulide Transport from an Established Wahiawa Fairway Soil at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Bensulide Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff (g ha^{-1} yr^{-1})	23.13	31.22
Sediment (g ha^{-1} yr^{-1})	1.56	2.20
Leachate (ug ha^{-1} yr^{-1})	86.51	127.76

Table 3.7-88. Risk Level of Annual Bensulide Transport from an Established Kolekole Fairway Soil at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Bensulide Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff (g ha^{-1} yr^{-1})	24.58	33.12
Sediment (g ha^{-1} yr^{-1})	1.66	2.35
Leachate (ug ha^{-1} yr^{-1})	221.00	307.74

Figure 3.7-##a, b - Figure 3.7-##.

2,4-D

Simulation Completed
Summary Statistics In Progress
Tables Completed
Graphs Completed
Discussion in Progress

Table 3.7-89

Table 3.7-89. Mean Annual Flux of 2,4-D from a 30 Year Simulation of an Established USGA Green on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	0.00	0.00	283.96
Maximum	210509.14	36.94	1.12E+08
Mean	9253.10	2.19	12277128.37
SD	38371.98	6.94	24233816.19
Median	5.67	1.74E-03	796333.53

Table 3.7-90. Mean Annual Flux of 2,4-D from a 30 Year Simulation of an Established Wahiawa Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	2.84E-04	1.98E-07	171.86
Maximum	303141.59	329.22	49102579.04
Mean	16550.57	23.95	4383121.32
SD	55501.28	62.51	9635038.86
Median	952.52	2.88	375904.02

Table 3.7-91. Mean Annual Flux of 2,4-D from a 30 Year Simulation of an Established Kolekole Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	2.72E-05	1.89E-07	208.99
Maximum	302822.07	328.80	58990792.08
Mean	16718.06	24.31	5528242.71
SD	55498.78	62.68	11731484.62
Median	987.78	2.97	571681.70

Table 3.7-92. Monthly Concentration of 2,4-D (ng L^{-1})[1] Beneath the Root Zone from a 30 Year Simulation of an Established USGA Green on the Proposed Galbraith Trust.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	25.86	1.79	0.13	70560.00
Mean	2.42	0.12	6.47E-03	2412.41
SD	4.30	0.26	0.02	9164.51
Median	9.63E-06	6.50E-07	9.10E-07	3.09E-05
	May	**June**	**July**	**August**
Minimum	2.65E-16	1.85E-17	2.19E-18	2.69E-16
Maximum	33060.00	4975.00	347.50	24.03
Mean	1985.21	190.04	17.47	1.72
SD	4633.22	510.20	38.68	3.13
Median	11.28	6.36	1.34	0.52
	September	**October**	**November**	**December**
Minimum	1.87E-17	3.51E-13	2.94E-12	4.97E-13
Maximum	4116.00	11790.00	3154.00	240.40
Mean	36.72	450.12	175.61	30.53
SD	312.76	1491.97	443.74	47.20
Median	0.06	9.96E-03	1.99E-03	1.13E-03

[1]Detection limit for most pesticides under optimum research conditions is in the range of 1 ng L^{-1}.

Table 3.7-93. Monthly Concentration of 2,4-D (ng L^{-1}) Beneath the Root Zone from a 30 Year Simulation of an Established Wahiawa Fairway Soil on the Proposed Galbraith Trust Estate.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	18.66	1.19	0.10	26850.00
Mean	1.56	0.13	0.01	567.02
SD	2.72	0.21	0.02	2581.39
Median	4.03E-05	1.21E-06	2.74E-06	6.13E-04
	May	**June**	**July**	**August**
Minimum	6.33E-13	4.40E-14	5.20E-15	5.96E-15
Maximum	12060.00	1656.00	115.00	11.56
Mean	496.73	55.44	5.58	0.74
SD	1305.72	167.11	13.23	1.54
Median	5.16	2.16	0.48	0.13
	September	**October**	**November**	**December**
Minimum	4.14E-16	1.76E-11	2.13E-12	3.59E-13
Maximum	665.30	6169.00	1625.00	204.20
Mean	6.27	122.85	68.81	14.63
SD	51.07	526.20	203.97	27.73
Median	0.02	5.17E-03	1.93E-03	0.01

Table 3.7-94. Monthly Concentration of 2,4-D (ng L^{-1}) Beneath the Root Zone from a 30 Year Simulation of an Established Kolekole Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	19.88	1.26	0.11	33130.00
Mean	1.80	0.14	0.01	752.76
SD	3.07	0.23	0.02	3281.21
Median	6.50E-05	1.23E-06	5.12E-06	5.76E-04
	May	**June**	**July**	**August**
Minimum	3.46E-13	2.40E-14	2.85E-15	4.99E-15
Maximum	14880.00	2070.00	143.70	13.80
Mean	659.44	72.10	7.32	0.93
SD	1667.93	209.61	16.66	1.83
Median	9.21	3.66	0.80	0.20
	September	**October**	**November**	**December**
Minimum	3.46E-16	1.31E-11	2.48E-12	4.18E-13
Maximum	1026.00	7413.00	1953.00	220.30
Mean	9.79	160.59	85.26	17.91
SD	79.11	647.59	240.80	32.07
Median	0.03	6.69E-03	2.23E-03	0.02

Table 3.7-95. Risk Level of Annual 2,4-D Transport from an Established USGA Green at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual 2,4-D Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff (g ha^{-1} yr^{-1})	2.66	9.12
Sediment (g ha^{-1} yr^{-1})	0.001	0.003
Leachate (g ha^{-1} yr^{-1})	19.00	40.53

Table 3.7-96. Risk Level of Annual 2,4-D Transport from an Established Wahiawa Fairway Soil at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual 2,4-D Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff (g ha^{-1} yr^{-1})	8.94	26.06
Sediment (g ha^{-1} yr^{-1})	0.02	0.05
Leachate (g ha^{-1} yr^{-1})	7.88	10.46

Table 3.7-97. Risk Level of Annual 2,4-D Transport from an Established Kolekole Fairway Soil at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual 2,4-D Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff (g ha^{-1} yr^{-1})	9.13	26.75
Sediment (g ha^{-1} yr^{-1})	0.02	0.06
Leachate (g ha^{-1} yr^{-1})	10.74	13.18

Figure 3.7-##a, b - Figure 3.7-##.

DCPA

Simulation Completed
Summary Statistics Completed
Tables Completed — Table 3.7-98
Graphs Completed
Discussion in Progress

Table 3.7-98. Mean Annual Flux of DCPA from a 30 Year Simulation of an Established USGA Green on the Proposed Galbraith Trust Estate, Wahlawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	0.00	0.00	0.000
Maximum	81127.78	2875.80	0.000
Mean	4354.87	185.53	0.000
SD	14689.00	520.42	0.000
Median	832.19	80.22	0.000

Table 3.7-99. Mean Annual Flux of DCPA from a 30 Year Simulation of an Established Wahiawa Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	3.90	3.16	2.84E-09
Maximum	29578.92	6593.38	7.04E-05
Mean	2046.35	564.89	1.40E-05
SD	5328.54	1190.94	1.90E-05
Median	1064.64	338.87	7.36E-06

Table 3.7-100. Mean Annual Flux of DCPA from a 30 Year Simulation of an Established Kolekole Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	13.50	10.96	1.53E-08
Maximum	40364.36	9041.96	5.80E-04
Mean	4634.01	1342.64	1.22E-04
SD	7733.72	1792.65	1.68E-04
Median	2813.70	1005.29	4.92E-05

Table 3.7-101. Monthly Concentration of DCPA (ng L^{-1}) Beneath the Root Zone from a 30 Year Simulation of an Established USGA Green on the Proposed Galbraith Trust Estate.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	0.00	0.00
Mean	0.00	0.00	0.00	0.00
SD	0.00	0.00	0.00	0.00
Median	0.00	0.00	0.00	0.00
	May	June	July	August
Minimum	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	0.00	0.00
Mean	0.00	0.00	0.00	0.00
SD	0.00	0.00	0.00	0.00
Median	0.00	0.00	0.00	0.00
	September	October	November	December
Minimum	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	0.00	0.00
Mean	0.00	0.00	0.00	0.00
SD	0.00	0.00	0.00	0.00
Median	0.00	0.00	0.00	0.00

Table 3.7-102. Monthly Concentration of DCPA (ng L^{-1}) Beneath the Root Zone from a 30 Year Simulation of an Established Wahiawa Fairway Soil on the Proposed Galbraith Trust Estate.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	6.43E-11	6.65E-10	6.33E-10	7.93E-10
Mean	5.39E-11	8.14E-11	9.13E-11	9.25E-11
SD	1.10E-10	1.39E-10	1.39E-10	1.21E-10
Median	1.29E-11	2.00E-11	2.56E-11	4.19E-11
	May	June	July	August
Minimum	1.99E-18	1.99E-18	0.00	0.00
Maximum	7.38E-10	7.38E-10	5.36E-10	3.70E-10
Mean	9.08E-11	9.08E-11	5.53E-11	4.52E-11
SD	1.29E-10	1.29E-10	8.81E-11	6.66E-11
Median	4.08E-11	4.08E-11	2.28E-11	1.79E-11
	September	October	November	December
Minimum	1.78E-16	1.23E-16	1.00E-16	1.38E-15
Maximum	2.56E-10	1.85E-10	4.32E-10	7.51E-10
Mean	3.39E-11	3.01E-11	4.07E-11	5.43E-11
SD	4.83E-11	4.19E-11	7.41E-11	1.14E-10
Median	1.25E-11	1.12E-11	1.04E-11	9.30E-12

Table 3.7-103. Monthly Concentration of DCPA (ng L[-1]) Beneath the Root Zone from a 30 Year Simulation of an Established Kolekole Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	7.45E-09	7.77E-09	7.42E-09	7.47E-09
Mean	5.89E-10	8.51E-10	9.56E-10	9.61E-10
SD	1.25E-09	1.53E-09	1.52E-09	1.28E-09
Median	1.24E-10	1.96E-10	2.92E-10	3.93E-10
	May	**June**	**July**	**August**
Minimum	9.54E-18	6.67E-18	4.61E-18	3.90E-18
Maximum	6.95E-09	5.96E-09	5.04E-09	3.48E-09
Mean	9.36E-10	7.18E-10	5.67E-10	4.68E-10
SD	1.29E-09	1.05E-09	8.64E-10	6.68E-10
Median	3.90E-10	3.04E-10	2.16E-10	1.63E-10
	September	**October**	**November**	**December**
Minimum	8.73E-16	6.03E-16	4.92E-16	7.20E-15
Maximum	2.41E-09	1.68E-09	4.91E-09	8.70E-09
Mean	3.52E-10	3.10E-10	4.34E-10	5.88E-10
SD	4.89E-10	4.18E-10	8.37E-10	1.31E-09
Median	1.13E-10	9.31E-11	9.83E-11	8.96E-11

[1]Detection limit for most pesticides under optimum research conditions is in the range of 1 ng L[-1].

Table 3.7-104. Risk Level of Annual DCPA Transport from an Established USGA Green at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual DCPA Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff (g ha^{-1} yr^{-1})	3.10	4.82
Sediment (g ha^{-1} yr^{-1})	0.15	0.27
Leachate (ug ha^{-1} yr^{-1})	0.00	0.00

Table 3.7-105. Risk Level of Annual DCPA Transport from an Established Wahiawa Fairway Soil at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual DCPA Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff (g ha^{-1} yr^{-1})	1.81	2.89
Sediment (g ha^{-1} yr^{-1})	0.62	0.98
Leachate (ug ha^{-1} yr^{-1})	2.08E-5	4.09E-5

Table 3.7-106. Risk Level of Annual DCPA Transport from an Established Kolekole Fairway Soil at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual DCPA Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff (g ha^{-1} yr^{-1})	4.89	7.35
Sediment (g ha^{-1} yr^{-1})	1.60	2.37
Leachate (ug ha^{-1} yr^{-1})	1.60E-4	4.11E-4

Figure 3.7-115a, b - Figure 3.7-126

Dicamba

Simulation Completed
Summary Statistics Completed
Tables Completed
Graphs Completed
Discussion in Progress

Table 3.7-107

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Table 3.7-107. Mean Annual Flux of Dicamba from a 30 Year Simulation of an Established USGA Green on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	0.00	0.00	407.25
Maximum	15037.69	0.53	40107865.41
Mean	732.78	0.04	8973297.43
SD	2760.54	0.10	11353565.51
Median	0.53	3.24E-05	5419891.48

Table 3.7-108. Mean Annual Flux of Dicamba from a 30 Year Simulation of an Established Wahiawa Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	1.94E-05	2.38E-08	5166.84
Maximum	22876.33	4.95	23993964.74
Mean	1715.89	0.55	4933021.56
SD	4413.03	1.11	6505305.43
Median	172.42	0.08	2569716.95

Table 3.7-109. Mean Annual Flux of Dicamba from a 30 Year Simulation of an Established Kolekole Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	Pesticide Runoff Loss (mg ha^{-1} yr^{-1})	Pesticide Sediment Loss (mg ha^{-1} yr^{-1})	Net Pesticide Loss Past the Maximum Root Zone (ug ha^{-1} yr^{-1})
Minimum	1.64E-05	1.98E-08	4977.30
Maximum	22609.24	4.89	24736208.14
Mean	1711.39	0.55	5223323.13
SD	4374.71	1.10	6808536.58
Median	168.64	0.08	2868549.04

Table 3.7-110. Monthly Concentration of Dicamba (ng L^{-1})[1] Beneath the Root Zone from a 30 Year Simulation of an Established USGA Green on the Proposed Galbraith Trust.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	73.04	14.09	1.12	32340.00
Mean	3.28	0.34	0.03	2240.97
SD	9.24	1.56	0.14	5965.67
Median	2.29E-03	1.04E-04	9.41E-07	9.86E-07
	May	June	July	August
Minimum	1.97E-16	3.99E-17	1.11E-17	3.17E-15
Maximum	16870.00	3392.00	690.60	133.40
Mean	3179.84	731.46	144.26	25.83
SD	3901.81	793.42	162.33	29.22
Median	1329.50	550.85	91.55	15.54
	September	October	November	December
Minimum	6.43E-16	4.04E-12	4.26E-09	2.53E-11
Maximum	15770.00	10370.00	2810.00	468.60
Mean	227.92	915.03	309.98	37.42
SD	1595.87	1878.39	511.71	74.84
Median	2.79	1.06	0.45	0.17

[1]Detection limit for most pesticides under optimum research conditions is in the range of 1 ng L^{-1}.

Table 3.7-111. Monthly Concentration of Dicamba (ng L^{-1}) Beneath the Root Zone from a 30 Year Simulation of an Established Wahiawa Fairway Soil on the Proposed Galbraith Trust Estate.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	84.76	16.12	3.12	13980.00
Mean	9.26	0.95	0.11	843.03
SD	16.36	2.44	0.34	2596.61
Median	0.02	1.39E-03	9.85E-05	3.15E-04
	May	June	July	August
Minimum	7.76E-13	1.56E-13	4.31E-14	3.32E-11
Maximum	9342.00	2260.00	513.00	99.55
Mean	1253.56	312.84	86.16	19.59
SD	1816.41	403.35	96.45	18.55
Median	339.75	179.00	53.71	15.38
	September	October	November	December
Minimum	6.66E-12	7.53E-10	3.70E-07	1.27E-07
Maximum	3053.00	4062.00	1930.00	409.50
Mean	45.98	318.52	218.94	70.52
SD	295.94	706.43	352.88	99.80
Median	3.73	1.30	0.47	4.19

Table 3.7-112. Monthly Concentration of Dicamba (ng L^{-1}) Beneath the Root Zone from a 30 Year Simulation of an Established Kolekole Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	88.70	16.87	3.09	14340.00
Mean	9.11	0.92	0.10	909.72
SD	16.48	12.46	0.33	2766.33
Median	0.02	1.26E-03	7.77E-05	2.28E-04
	May	**June**	**July**	**August**
Minimum	4.11E-13	8.24E-14	2.28E-14	2.29E-11
Maximum	9929.00	2326.00	523.80	103.00
Mean	1351.47	336.35	91.67	20.61
SD	1917.79	419.65	100.45	19.15
Median	404.50	203.50	58.88	16.56
	September	**October**	**November**	**December**
Minimum	4.60E-12	5.08E-10	3.24E-07	7.72E-08
Maximum	3434.00	4274.00	1996.00	423.30
Mean	51.95	346.63	231.27	71.56
SD	335.46	753.59	368.87	102.84
Median	3.96	1.33	0.48	5.06

Table 3.7-113. Risk Level of Annual Dicamba Transport from an Established USGA Green at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Dicamba Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff (g ha^{-1} yr^{-1})	0.24	0.90
Sediment (g ha^{-1} yr^{-1})	3.00E-05	8.00E-05
Leachate (g ha^{-1} yr^{-1})	12.68	27.84

Table 3.7-114. Risk Level of Annual Dicamba Transport from an Established Wahiawa Fairway Soil at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Dicamba Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff (g ha^{-1} yr^{-1})	1.22	3.57
Sediment (g ha^{-1} yr^{-1})	0.001	0.002
Leachate (g ha^{-1} yr^{-1})	8.19	14.40

Table 3.7-115. Risk Level of Annual Dicamba Transport from an Established Kolekole Fairway Soil at the 80% (5 year frequency of occurrence) and 90% (10 year frequency of occurrence) probability levels. Risk Levels were determined from the Cumulative Frequency Distribution of Annual Dicamba Flux from a 30 Year simulation for the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

Route of Transport	80% Probability Level	90% Probability Level
Runoff (g ha^{-1} yr^{-1})	1.22	3.57
Sediment (g ha^{-1} yr^{-1})	0.001	0.002
Leachate (g ha^{-1} yr^{-1})	8.42	15.20

Nitrogen Fate and Transport

Simulation in Progress
Summary in Progress
Tables in Progress
Graphs in Progress
Discussion in Progress

APPENDIX B

Simulated Pesticide Movement Summary Tables

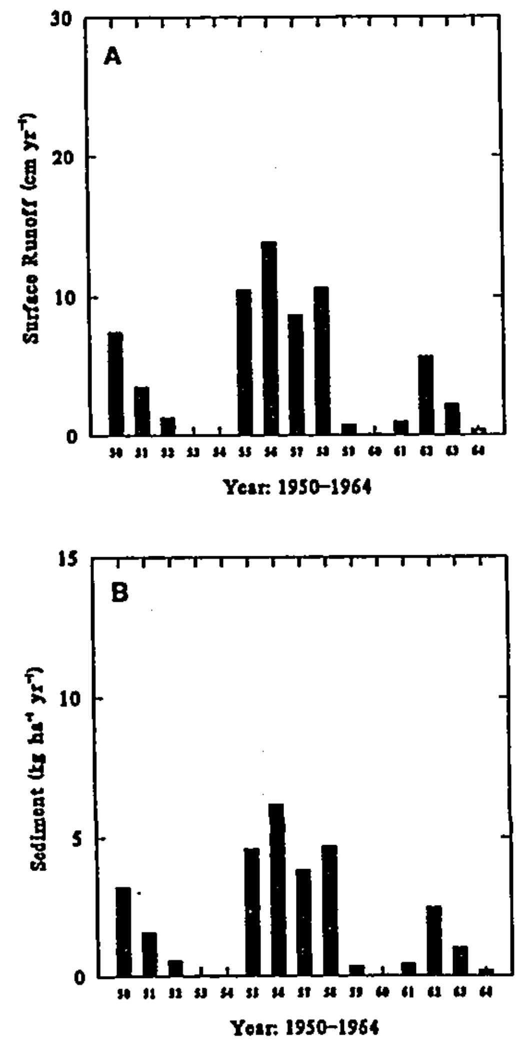


Figure B-1a. Annual runoff of (A) water and (B) sediment from a simulated USGA Green at the Galbraith Trust Estate: 1950-1964.

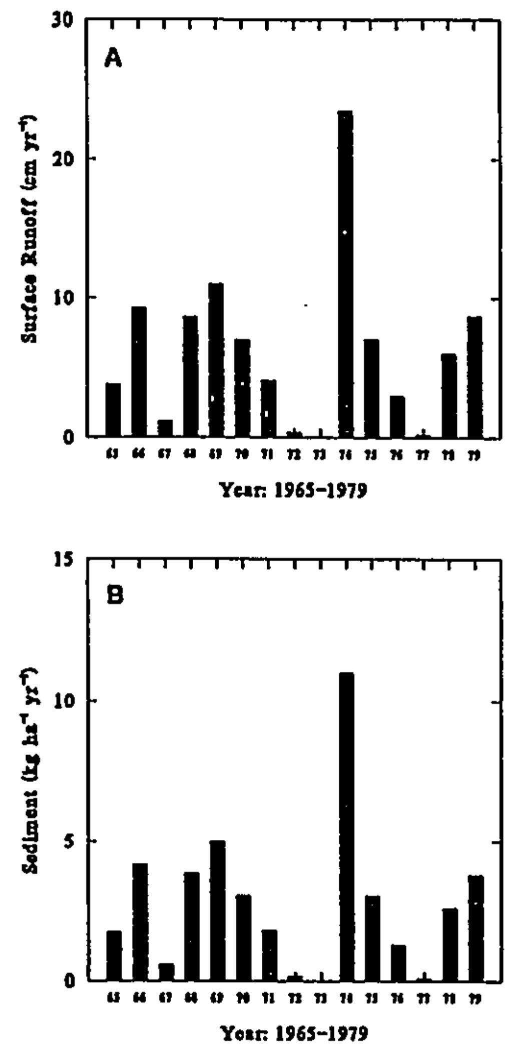


Figure B-1b. Annual runoff of (A) water and (B) sediment from a simulated USGA Green at the Galbraith Trust Estate: 1965-1979.

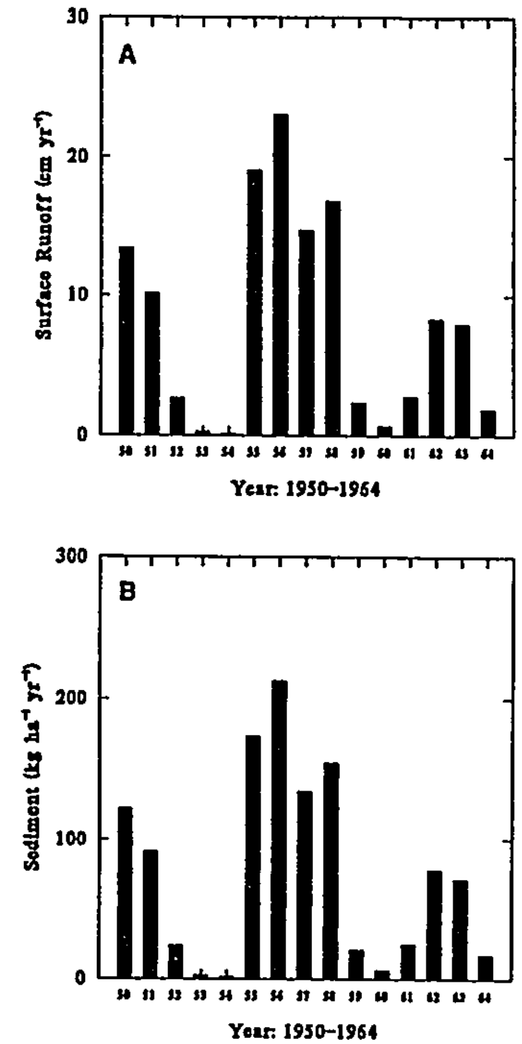


Figure B-2a. Annual runoff of (A) water and (B) sediment from a simulated Wahiawa fairway soil at the Galbraith Trust Estate: 1950-1964.

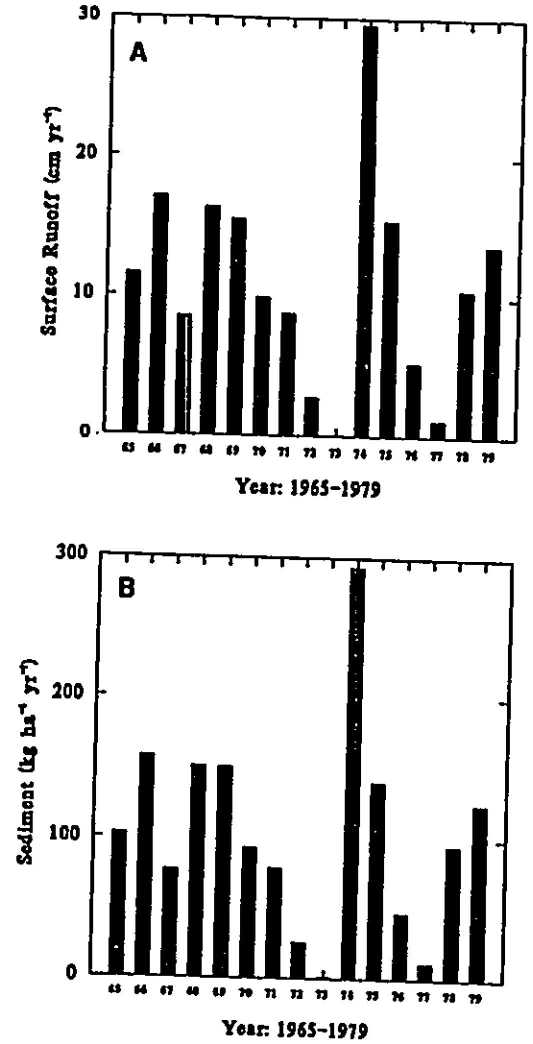


Figure B-2b. Annual runoff of (A) water and (B) sediment from a simulated Wahiawa fairway soil at the Galbraith Trust Estate: 1965-1979.

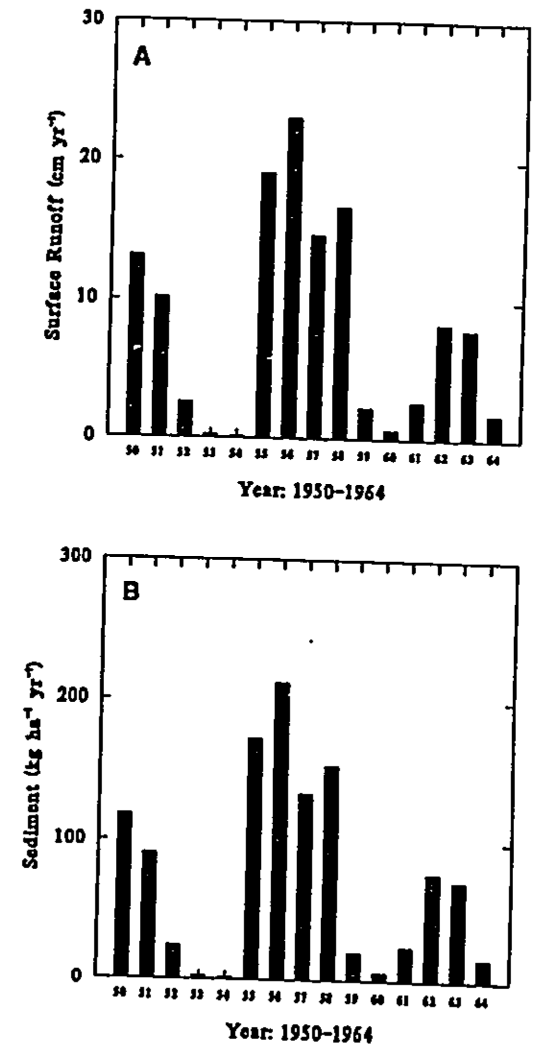


Figure B-3a. Annual runoff of (A) water and (B) sediment from a simulated Kolekole fairway soil at the Galbraith Trust Estate: 1950-1964.

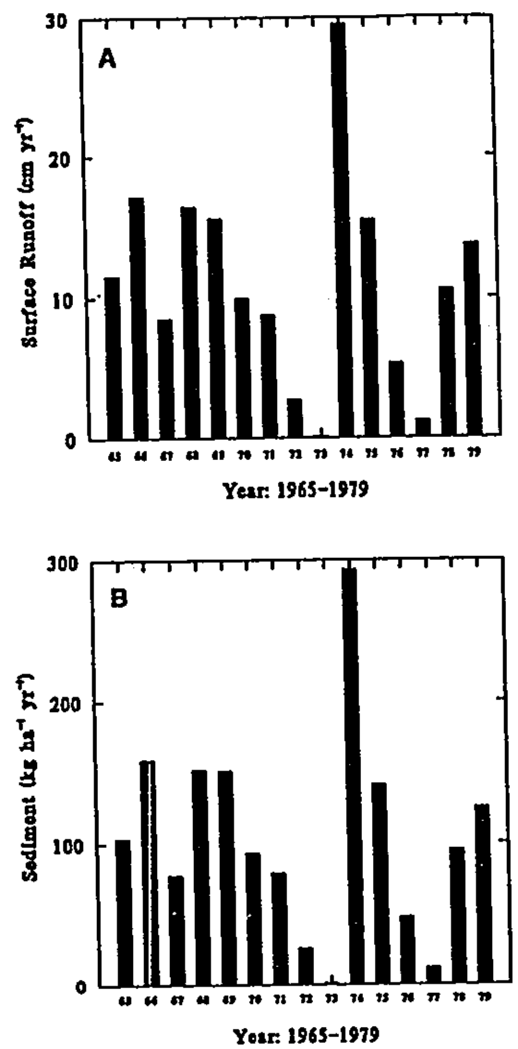


Figure B-3b. Annual runoff of (A) water and (B) sediment from a simulated Kolekole fairway soil at the Galbraith Trust Estate: 1965-1979.

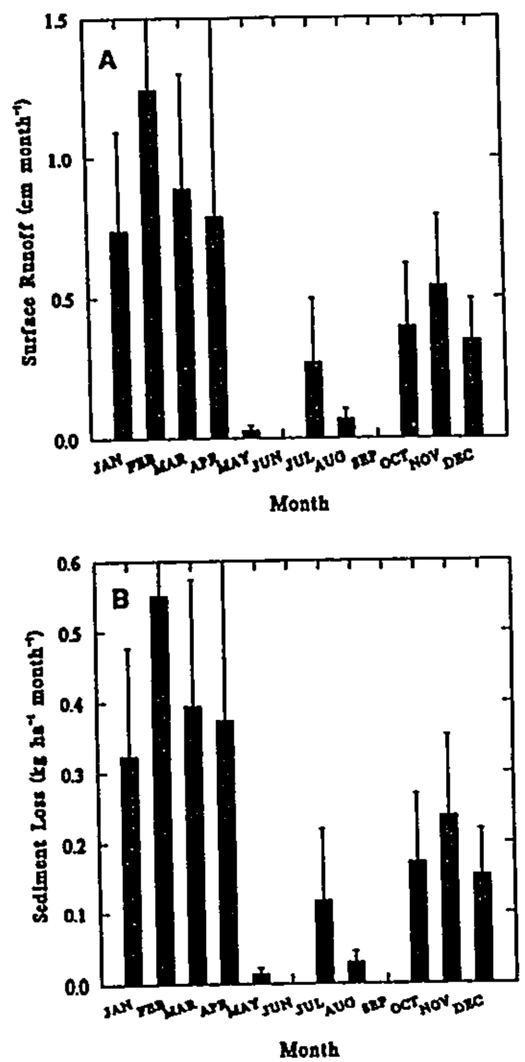


Figure B-4. Mean monthly runoff of (A) water and (B) sediment from a simulated USGA Green at the Galbraith Trust Estate. Error bars represent one standard error.

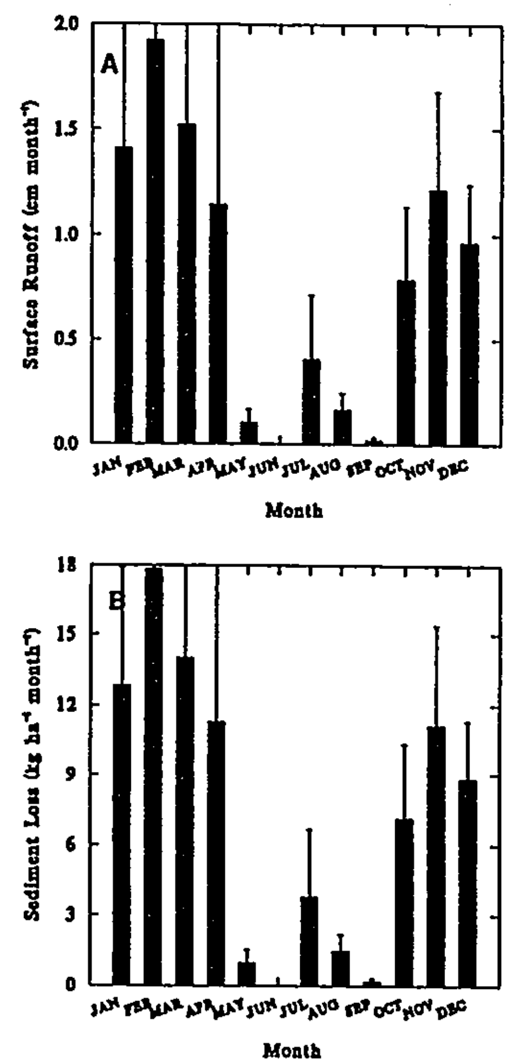


Figure B-5. Monthly mean runoff of (A) water and (B) sediment from a simulated Wahiawa fairway soil at the Galbraith Trust Estate. Error bars represent one standard error.

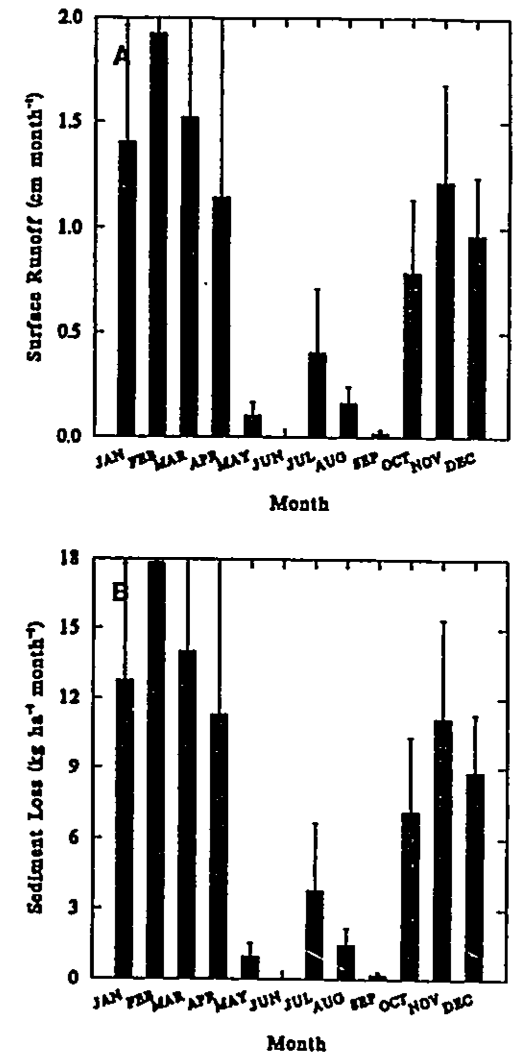


Figure B-6. Monthly mean runoff of (A) water and (B) sediment from a simulated Kolekole fairway soil at the Galbraith Trust Estate. Error bars represent one standard error.

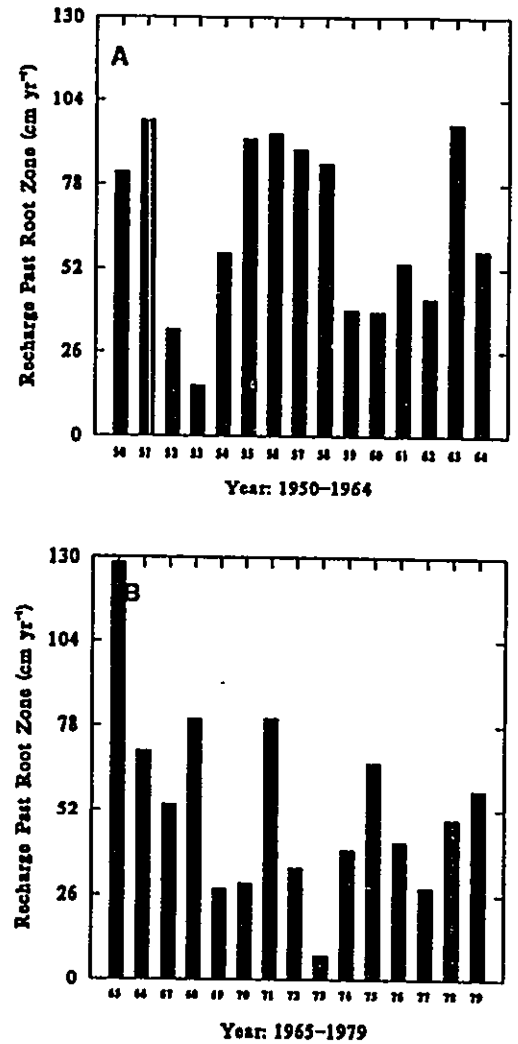


Figure B-7. Annual subsurface leaching of water beneath the root zone of a simulated USGA Green at the Galbraith Trust Estate for (A) 1950-1964 and (B) 1965-1979.

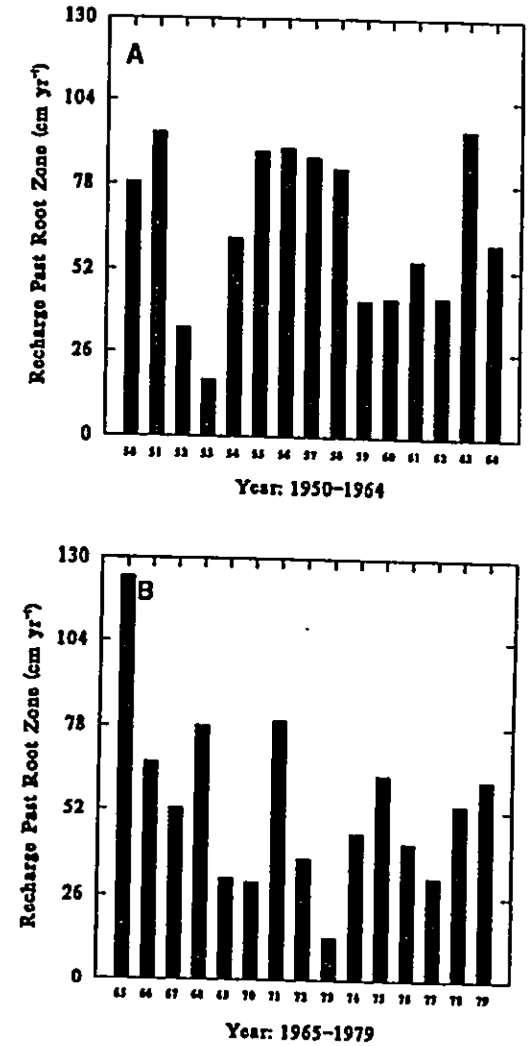


Figure B-8. Annual subsurface leaching of water beneath the root zone of a simulated Wahiawa fairway soil at the Galbraith Trust Estate for (A) 1950-1964 and (B) 1965-1979.

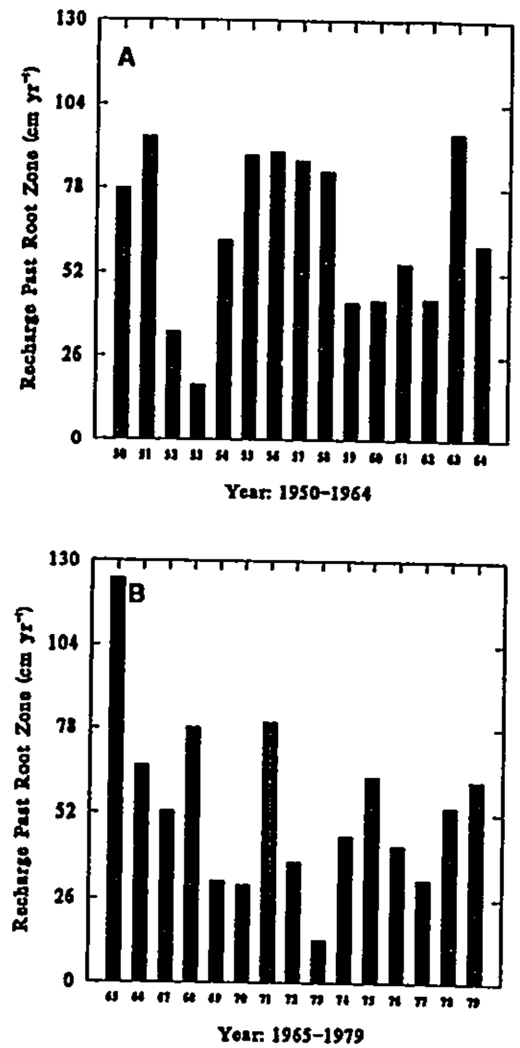


Figure B-9. Annual subsurface leaching of water beneath the root zone of a simulated Kolekole fairway soil at the Galbraith Trust Estate for (A) 1950-1964 and (B) 1965-1979.

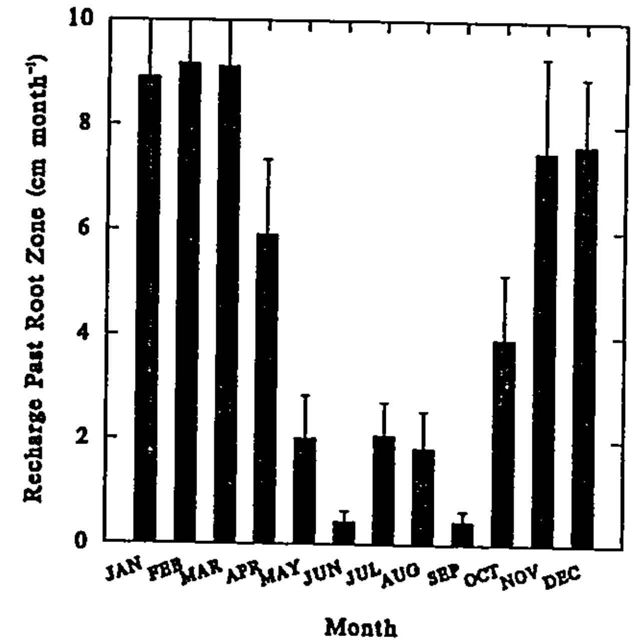


Figure B-10. Mean monthly subsurface movement of water beneath the root zone of a simulated USGA Green at the Galbraith Trust Estate. Error bars represent one standard error.

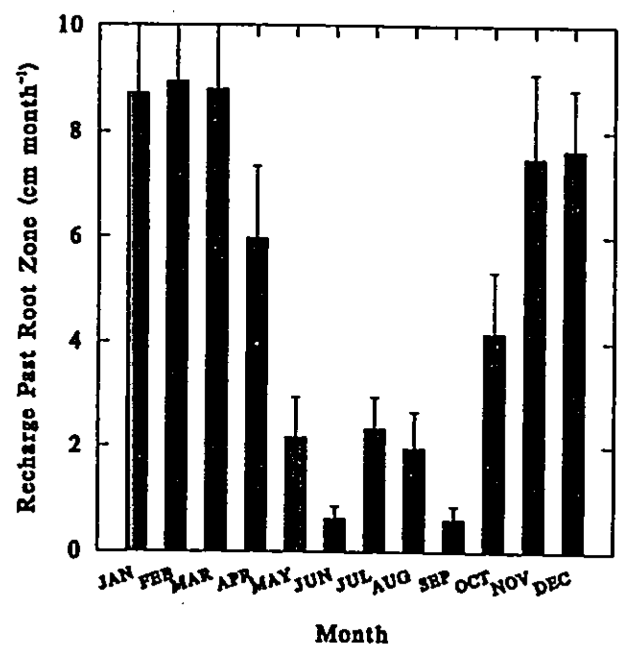


Figure B-11. Mean monthly subsurface movement of water beneath the root zone of a simulated Wahiawa fairway soil at the Galbraith Trust Estate. Error bars represent one standard error.

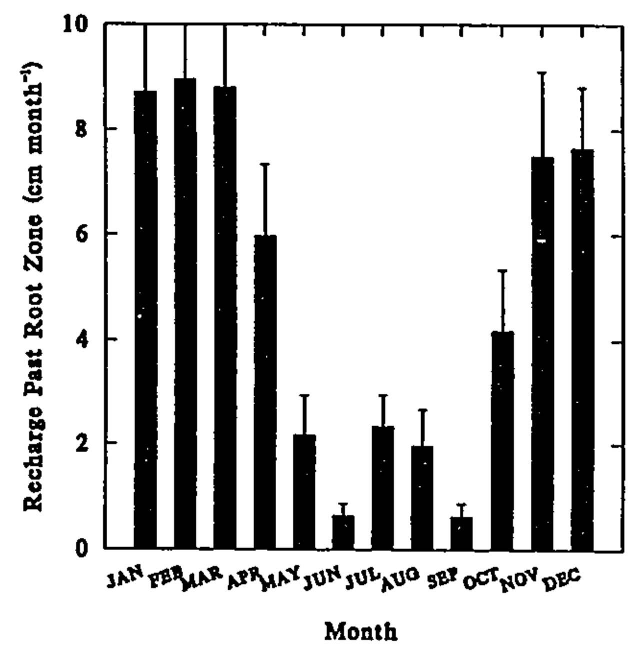


Figure B-12. Mean monthly subsurface movement of water beneath the root zone of a simulated Kolekole fairway soil at the Galbraith Trust Estate. Error bars represent one standard error.

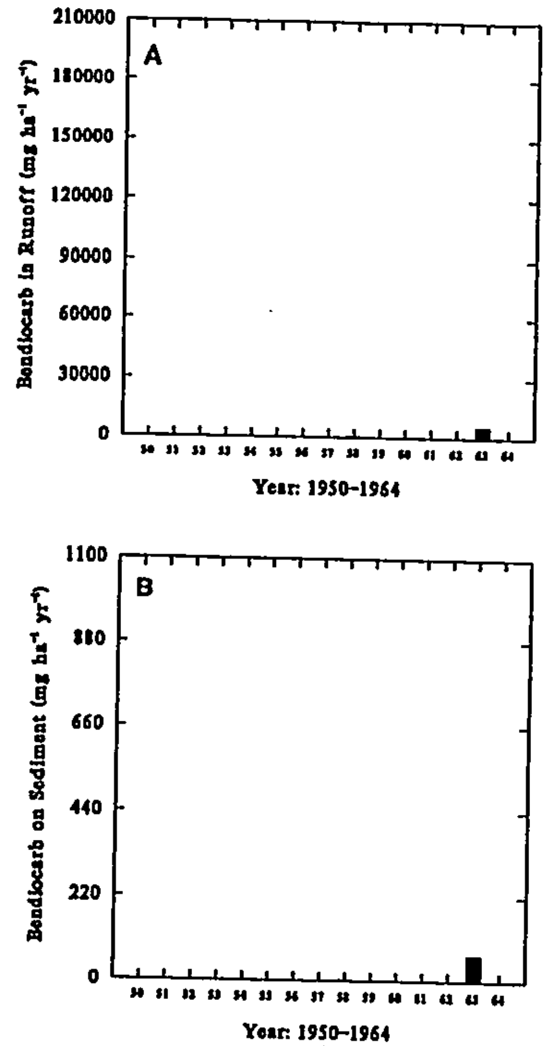


Figure B-13a. Annual surface loss of bendiocarb in runoff (A) water and (B) sediment from a simulated USGA Green at the Galbraith Trust Estate: 1950-1964.

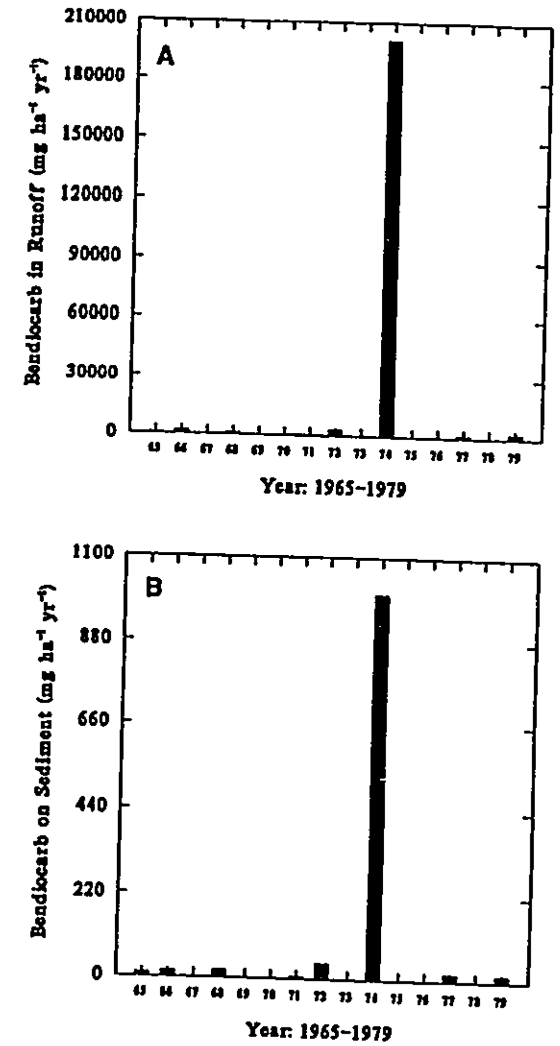


Figure B-13b. Annual surface loss of bendiocarb in runoff (A) water and (B) sediment from a simulated USGA Green at the Galbraith Trust Estate: 1965-1979.

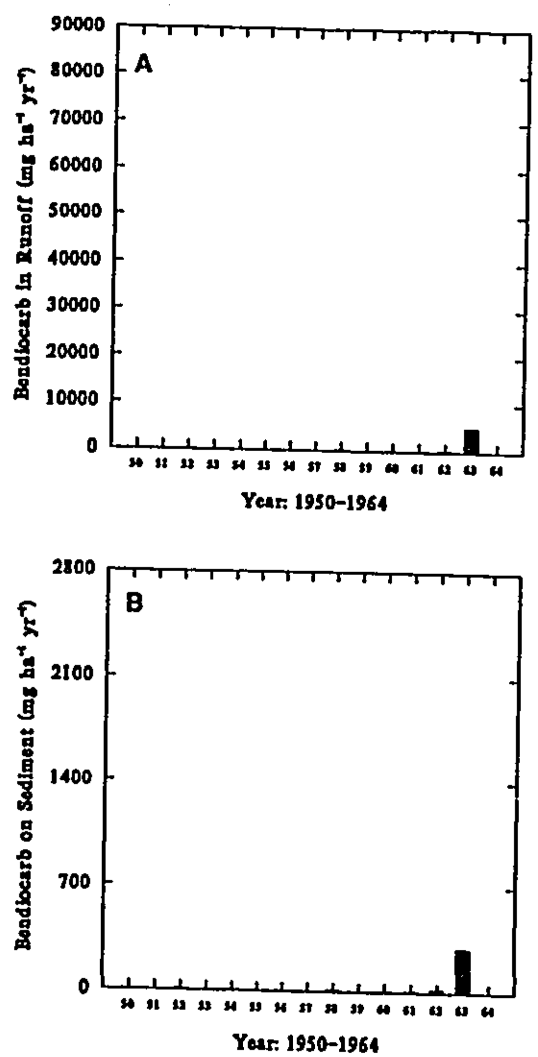


Figure B-14a. Annual surface loss of bendiocarb in runoff (A) water and (B) sediment from a simulated Wahlawa fairway soil at the Galbraith Trust Estate: 1950-1964.

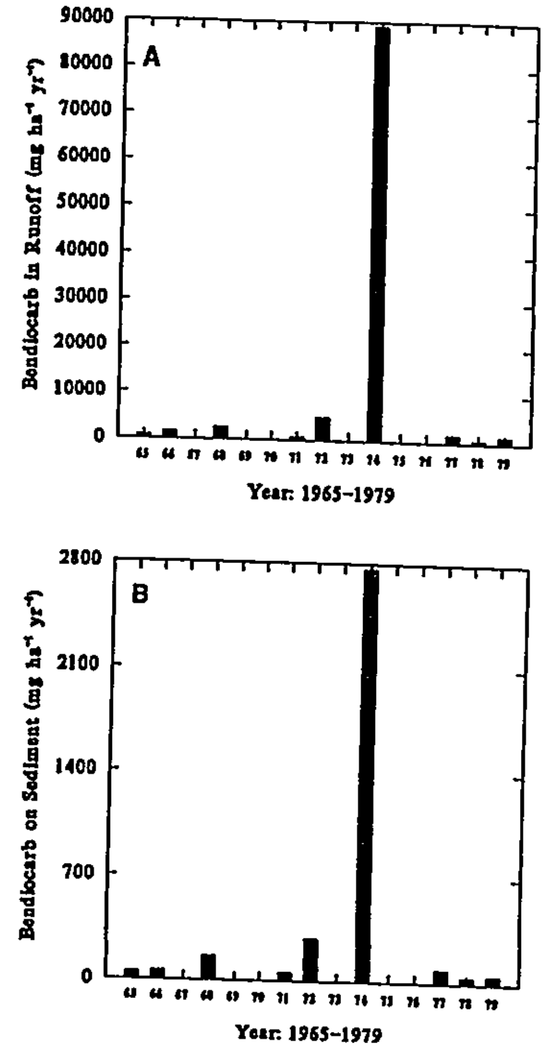


Figure B-14b. Annual surface loss of bendiocarb in runoff (A) water and (B) sediment from a simulated Wahlawa fairway soil at the Galbraith Trust Estate: 1965-1979.

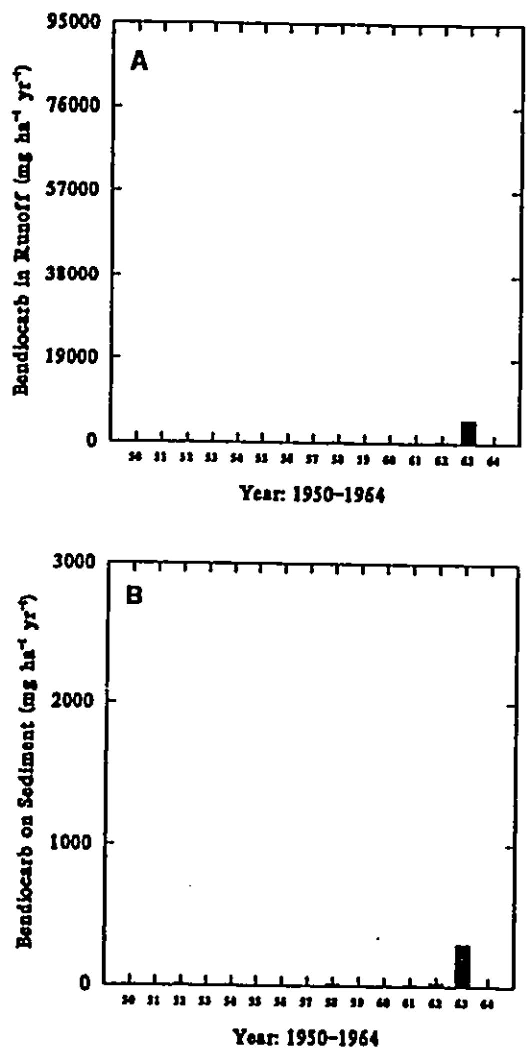


Figure B-15a. Annual surface loss of bendiocarb in runoff (A) water and (B) sediment from a simulated Kolekole fairway soil at the Galbraith Trust Estate: 1950-1964.

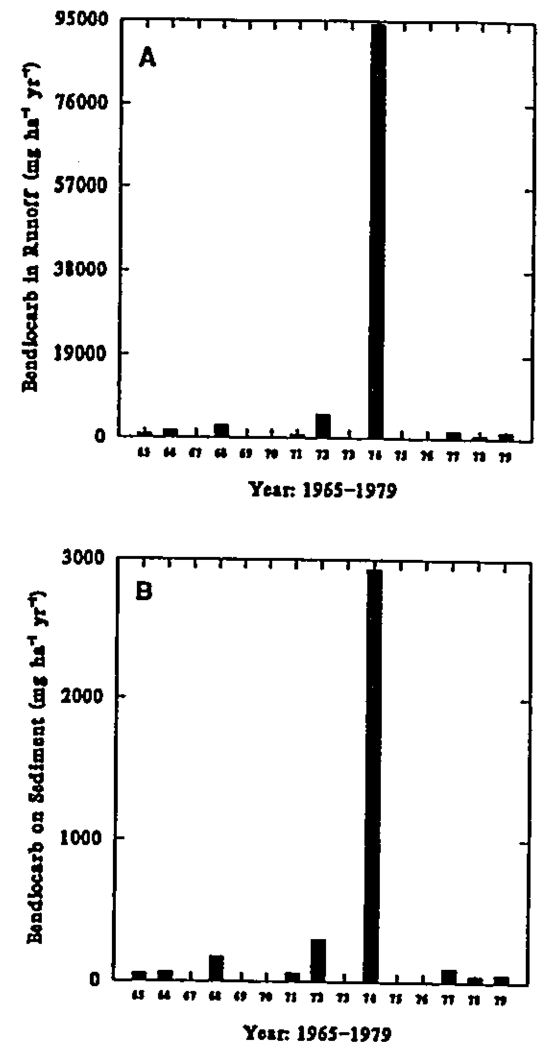


Figure B-15b. Annual surface loss of bendiocarb in runoff (A) water and (B) sediment from a simulated Kolekole fairway soil at the Galbraith Trust Estate: 1965-1979.

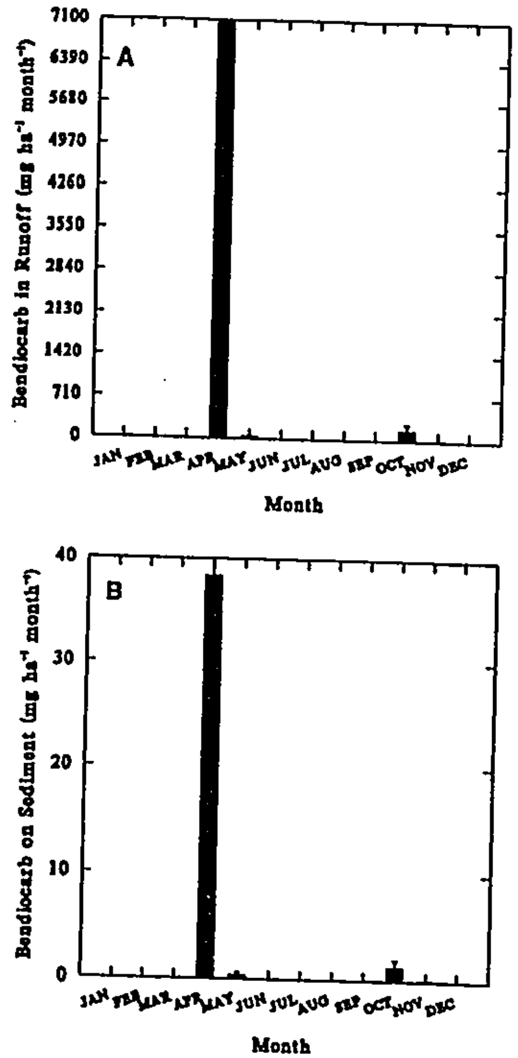


Figure B-16. Mean monthly loss of bendiocarb in runoff (A) water and (B) sediment from a simulated USGA Green at the Galbraith Trust Estate. Error bars represent one standard error.

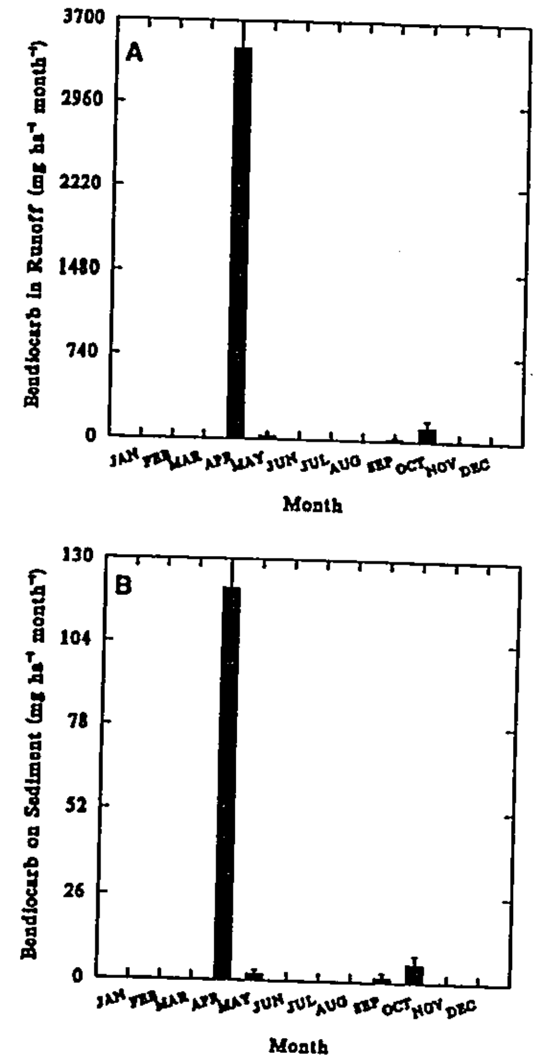


Figure B-17. Mean monthly loss of bendiocarb in runoff (A) water and (B) sediment from a simulated Wahiawa fairway soil at the Galbraith Trust Estate. Error bars represent one standard error.

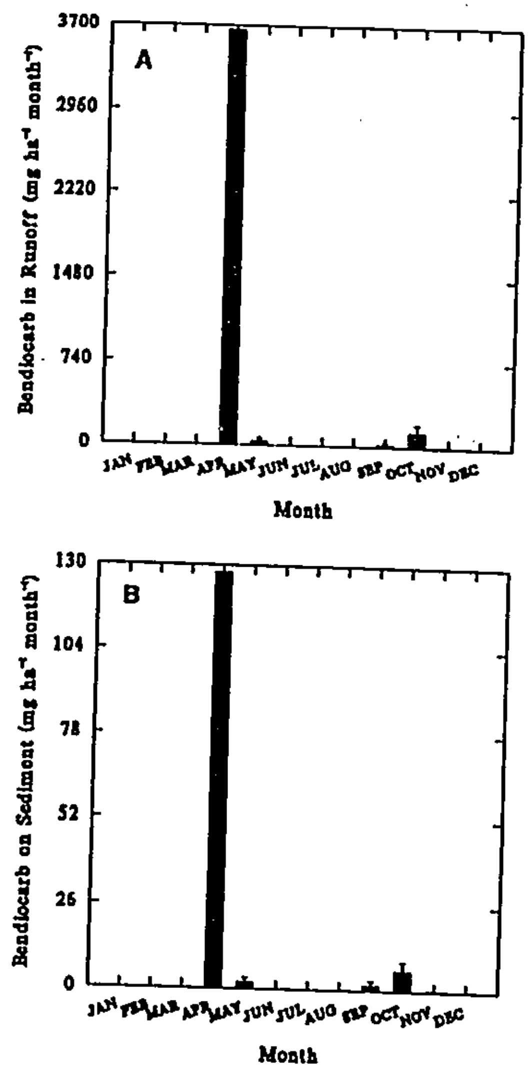


Figure B-18. Mean monthly loss of bendiocarb in runoff (A) water and (B) sediment from a simulated Kolekole fairway soil at the Galbraith Trust Estate. Error bars represent one standard error.

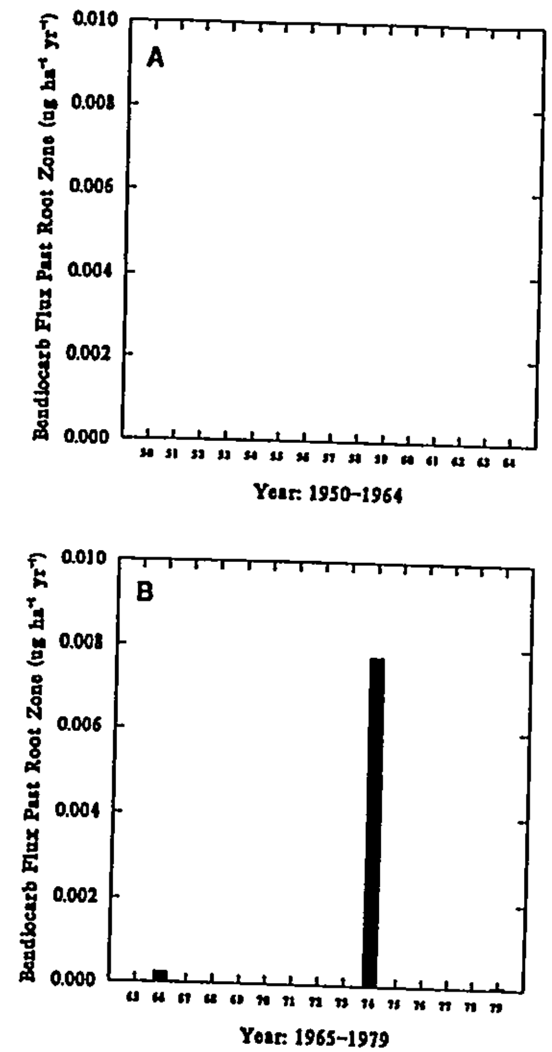


Figure B-19. Annual subsurface leaching of bendiocarb beneath the root zone of a simulated USGA Green at the Galbraith Trust Estate for (A) 1950-1964 and (B) 1965-1979.

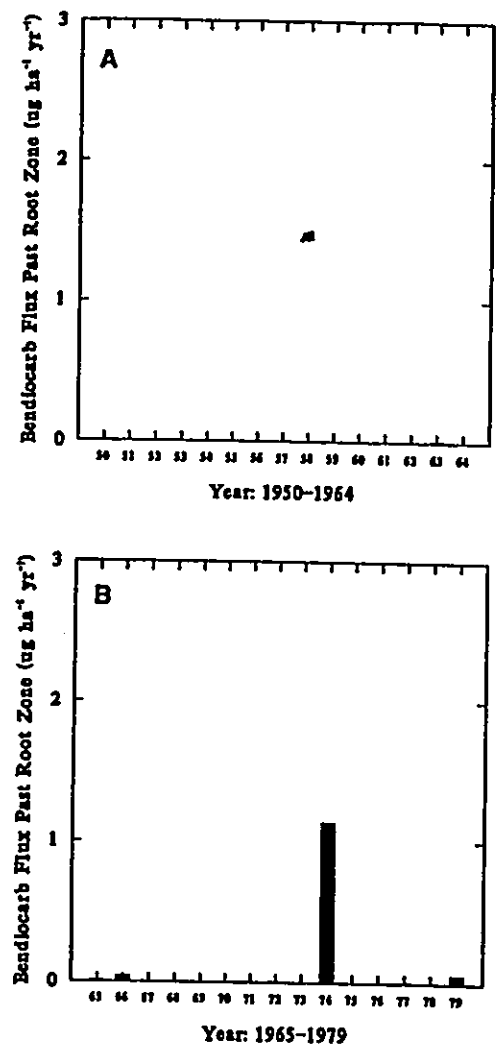


Figure B-20. Annual subsurface leaching of bendiocarb beneath the root zone of a simulated Wahiawa fairway soil at the Galbraith Trust Estate for (A) 1950-1964 and (B) 1965-1979.

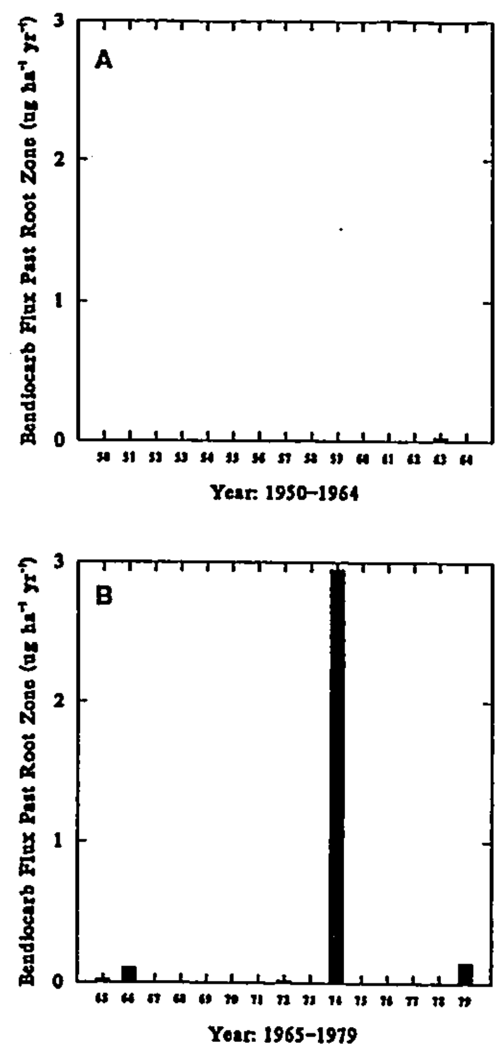


Figure B-21. Annual subsurface leaching of bendiocarb beneath the root zone of a simulated Kolekole fairway soil at the Galbraith Trust Estate for (A) 1950-1964 and (B) 1965-1979.

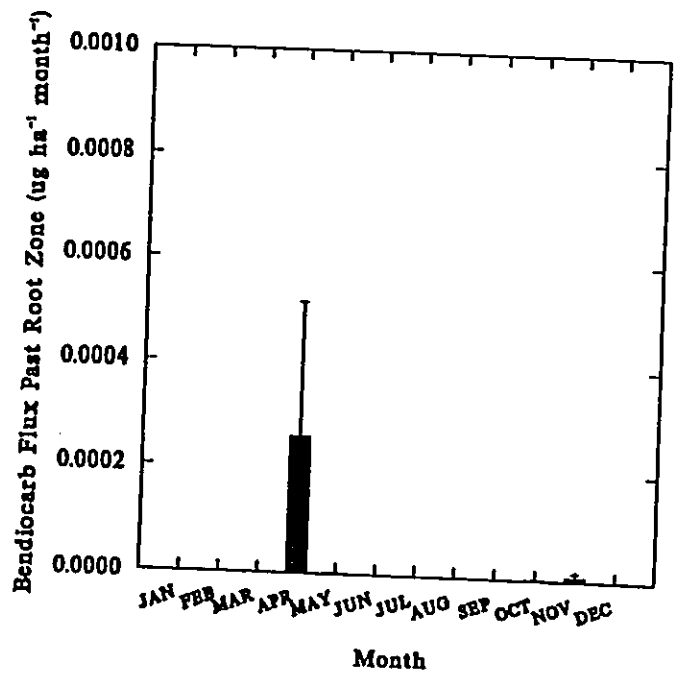


Figure B-22. Mean monthly subsurface movement of bendiocarb beneath the root zone of a simulated USGA Green at the Galbraith Trust Estate. Error bars represent one standard error.

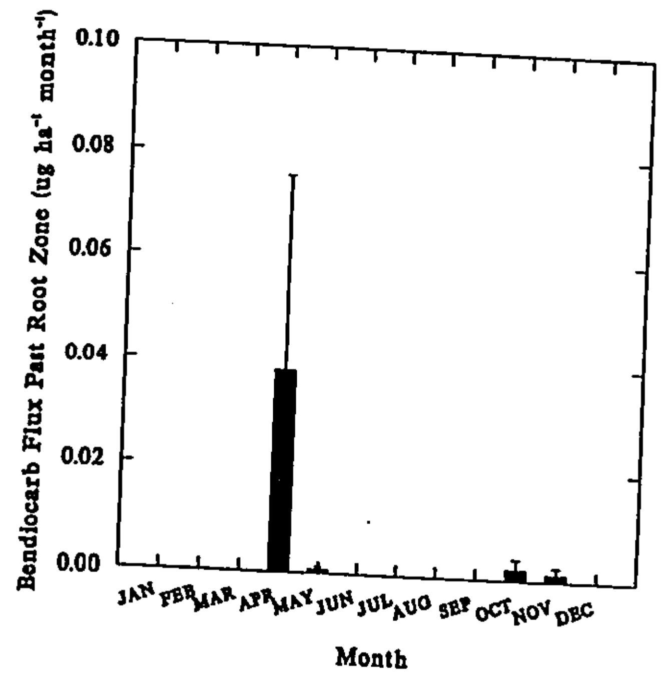


Figure B-23. Mean monthly subsurface movement of bendiocarb beneath the root zone of a simulated Wahiawa fairway soil at the Galbraith Trust Estate. Error bars represent one standard error.

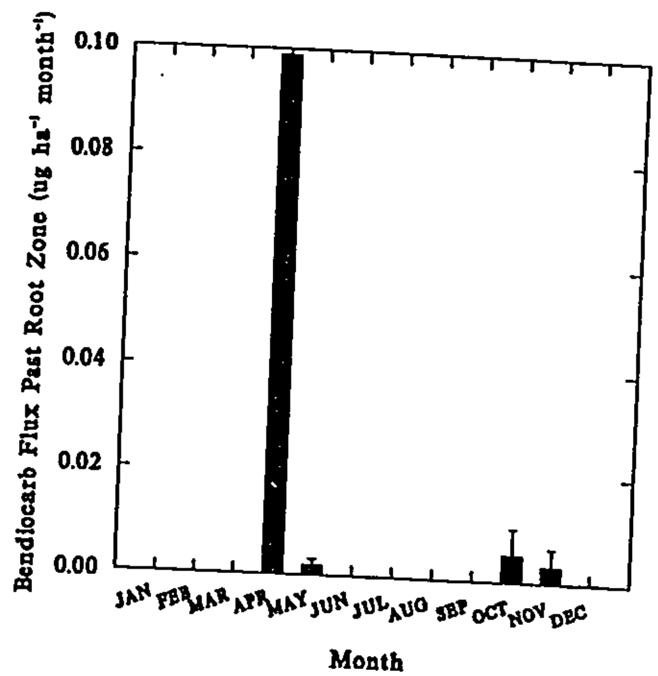


Figure B-24. Mean monthly subsurface movement of bendiocarb beneath the root zone of a simulated Kolekole fairway soil at the Galbraith Trust Estate. Error bars represent one standard error.

Table B-1. Monthly Concentration of Bendiocarb (ng L^{-1})[1] Beneath the Root Zone from a 30 Year Simulation of an Established USGA Green on the Proposed Galbraith Trust.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	2.90E-10	8.44E-11	3.36E-12	5.03E-05
Mean	3.90E-12	1.78E-12	7.86E-14	4.31E-08
SD	2.25E-11	7.36E-12	2.92E-13	3.91E-07
Median	0.00	0.00	0.00	0.00
	May	**June**	**July**	**August**
Minimum	0.00	0.00	0.00	0.00
Maximum	1.45E-06	3.45E-08	8.37E-10	3.60E-11
Mean	1.32E-08	3.21E-10	8.35E-12	3.05E-13
SD	1.01E-07	2.43E-09	5.93E-11	2.50E-12
Median	1.22E-18	0.00	0.00	0.00
	September	**October**	**November**	**December**
Minimum	0.00	0.00	0.00	0.00
Maximum	7.71E-13	4.04E-08	1.40E-07	9.27E-09
Mean	7.53E-15	3.23E-10	1.51E-09	8.67E-11
SD	5.44E-14	2.78E-09	1.06E-08	6.44E-10
Median	0.00	0.00	0.00	0.00

[1]Detection limit for most pesticides under optimum research conditions is in the range of 1 ng L^{-1}.

Table B-2. Monthly Concentration of Bendiocarb (ng L^{-1}) Beneath the Root Zone from a 30 Year Simulation of an Established Wahiawa Fairway Soil on the Proposed Galbraith Trust Estate.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	9.64E-09	8.81E-09	3.11E-10	9.49E-05
Mean	2.91E-10	1.27E-10	5.60E-12	8.89E-07
SD	1.13E-09	6.59E-10	2.31E-11	7.86E-06
Median	7.66E-17	6.90E-18	1.46E-18	7.08E-15
	May	**June**	**July**	**August**
Minimum	0.00	0.00	0.00	0.00
Maximum	3.11E-05	8.32E-07	2.14E-08	1.40E-09
Mean	3.04E-07	9.10E-09	2.78E-10	1.91E-11
SD	2.17E-06	5.90E-08	1.58E-09	1.00E-10
Median	6.50E-13	1.55E-13	2.85E-14	2.04E-14
	September	**October**	**November**	**December**
Minimum	0.00	0.00	0.00	0.00
Maximum	3.70E-09	6.07E-06	3.50E-06	2.50E-07
Mean	2.64E-11	5.17E-08	4.68E-08	3.10E-09
SD	2.51E-10	4.18E-07	2.72E-07	1.76E-08
Median	1.78E-15	1.13E-15	4.23E-15	6.51E-15

Table B-3. Monthly Concentration of Bendiocarb (ng L^{-1}) Beneath the Root Zone from a 30 Year Simulation of an Established Kolekole Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	2.86E-08	2.60E-08	9.19E-10	2.88E-04
Mean	8.86E-10	3.77E-10	1.66E-11	2.70E-06
SD	3.42E-09	1.95E-09	6.83E-11	2.38E-05
Median	2.30E-16	2.00E-17	4.45E-18	2.29E-14

	May	June	July	August
Minimum	0.00	0.00	0.00	0.00
Maximum	9.44E-05	2.53E-06	6.51E-08	4.27E-09
Mean	9.24E-07	2.79E-08	8.53E-10	5.93E-11
SD	6.59E-06	1.79E-07	4.79E-09	3.07E-10
Median	2.26E-12	5.38E-13	9.82E-14	6.78E-14

	September	October	November	December
Minimum	0.00	0.00	0.00	0.00
Maximum	1.25E-08	1.88E-05	1.07E-05	7.60E-07
Mean	8.92E-11	1.61E-07	1.43E-07	9.50E-09
SD	8.48E-10	1.29E-06	8.27E-07	5.33E-08
Median	5.92E-15	3.75E-15	1.37E-14	1.91E-14

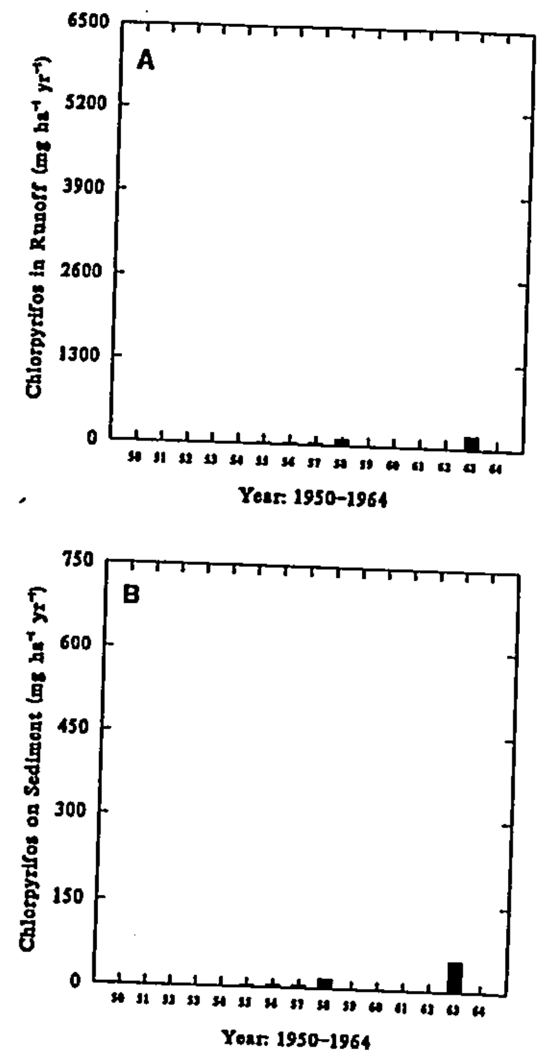


Figure B-25a. Annual surface loss of chlorpyrifos in runoff (A) water and (B) sediment from a simulated USGA Green at the Galbraith Trust Estate: 1950-1964.

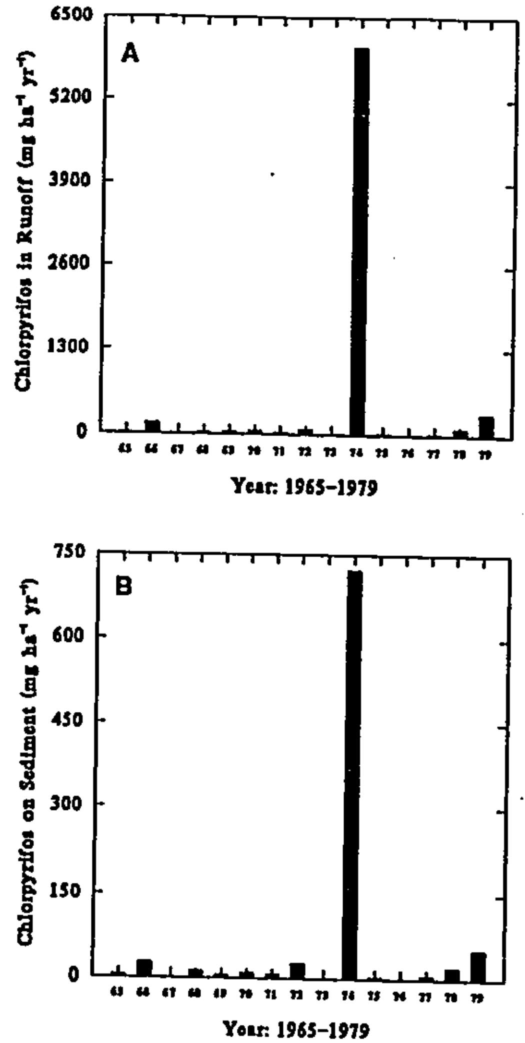


Figure B-25b. Annual surface loss of chlorpyrifos in runoff (A) water and (B) sediment from a simulated USGA Green at the Galbraith Trust Estate: 1965-1979.

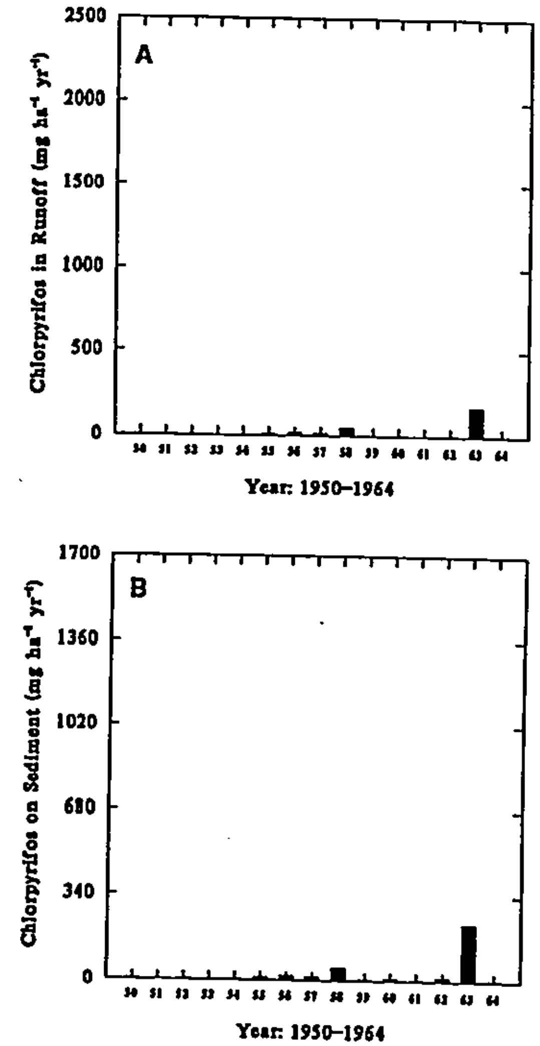


Figure B-26a. Annual surface loss of chlorpyrifos in runoff (A) water and (B) sediment from a simulated Wahiawa fairway soil at the Galbraith Trust Estate: 1950-1964.

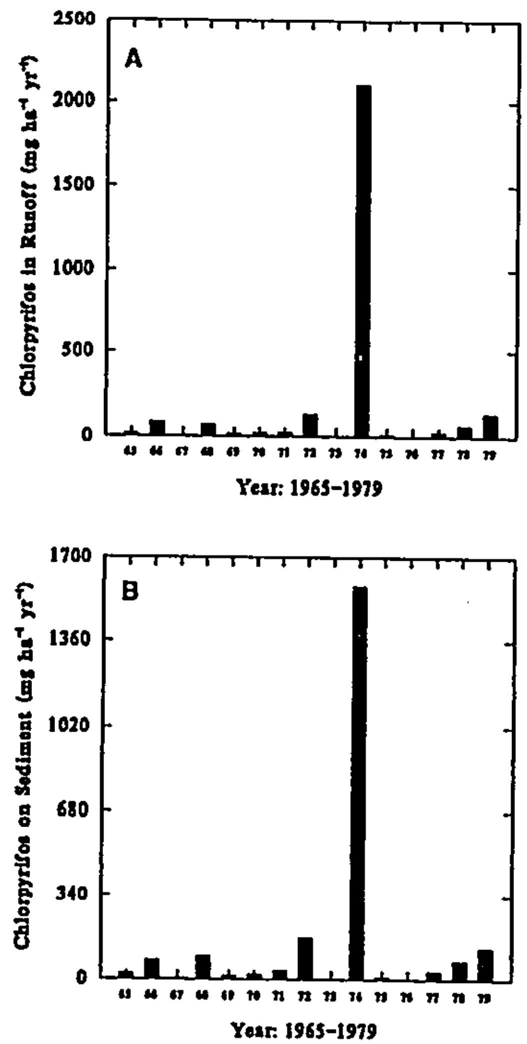


Figure B-26b. Annual surface loss of chlorpyrifos in runoff (A) water and (B) sediment from a simulated Wahiawa fairway soil at the Galbraith Trust Estate: 1965-1979.

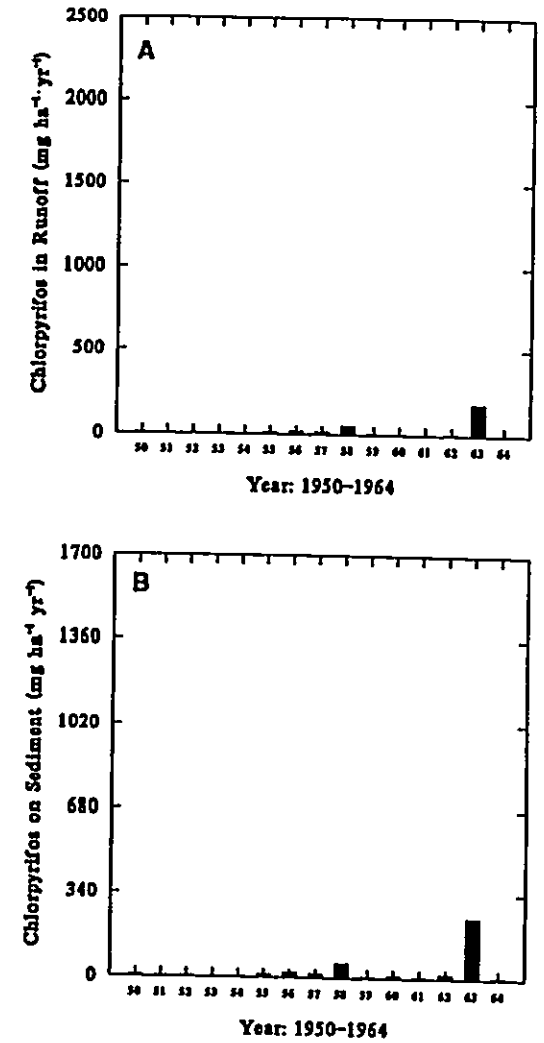


Figure B-27a. Annual surface loss of chlorpyrifos in runoff (A) water and (B) sediment from a simulated Kolekole fairway soil at the Galbraith Trust Estate: 1950-1964.

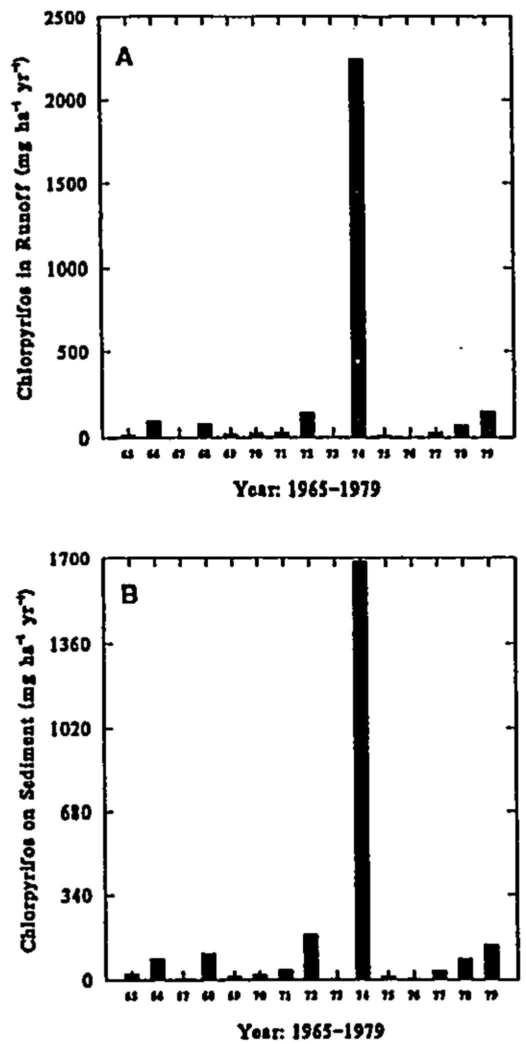


Figure B-27b. Annual surface loss of chlorpyrifos in runoff (A) water and (B) sediment from a simulated Kolekole fairway soil at the Galbraith Trust Estate: 1965-1979.

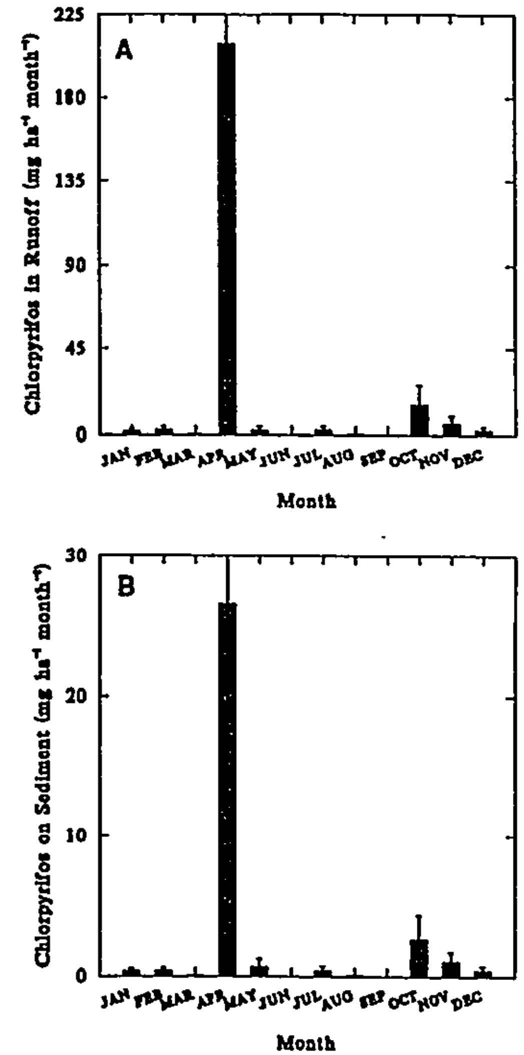


Figure B-28. Mean monthly loss of chlorpyrifos in runoff (A) water and (B) sediment from a simulated USGA Green at the Galbraith Trust Estate. Error bars represent one standard error.

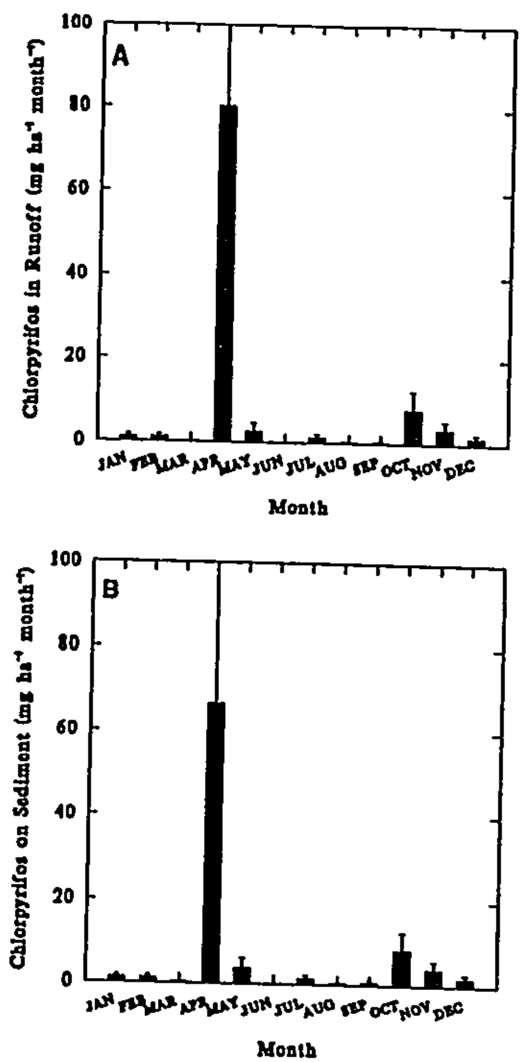


Figure B-29. Mean monthly loss of chlorpyrifos in runoff (A) water and (B) sediment from a simulated Wahiawa fairway soil at the Galbraith Trust Estate. Error bars represent one standard error.

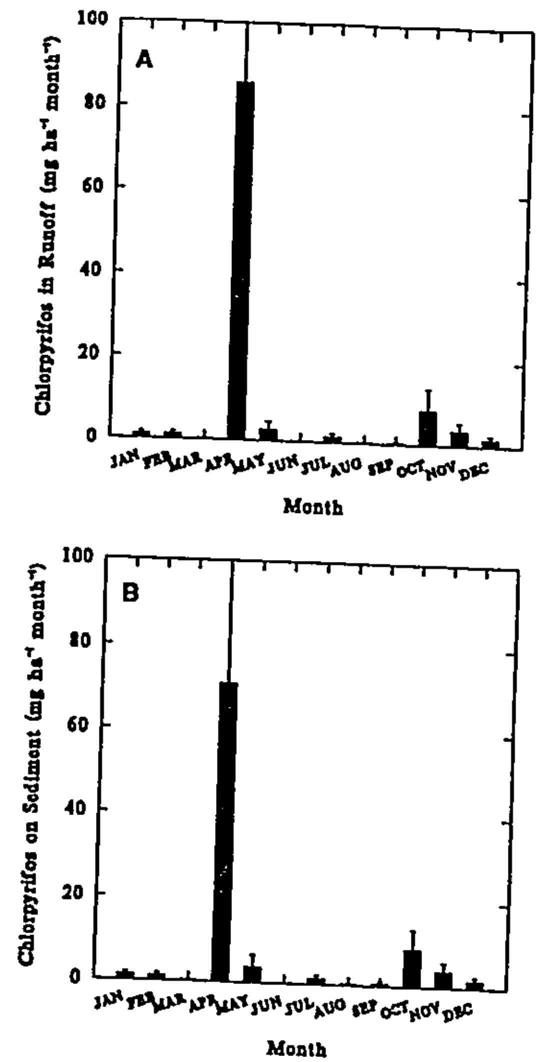


Figure B-30. Mean monthly loss of chlorpyrifos in runoff (A) water and (B) sediment from a simulated Kolekole fairway soil at the Galbraith Trust Estate. Error bars represent one standard error.

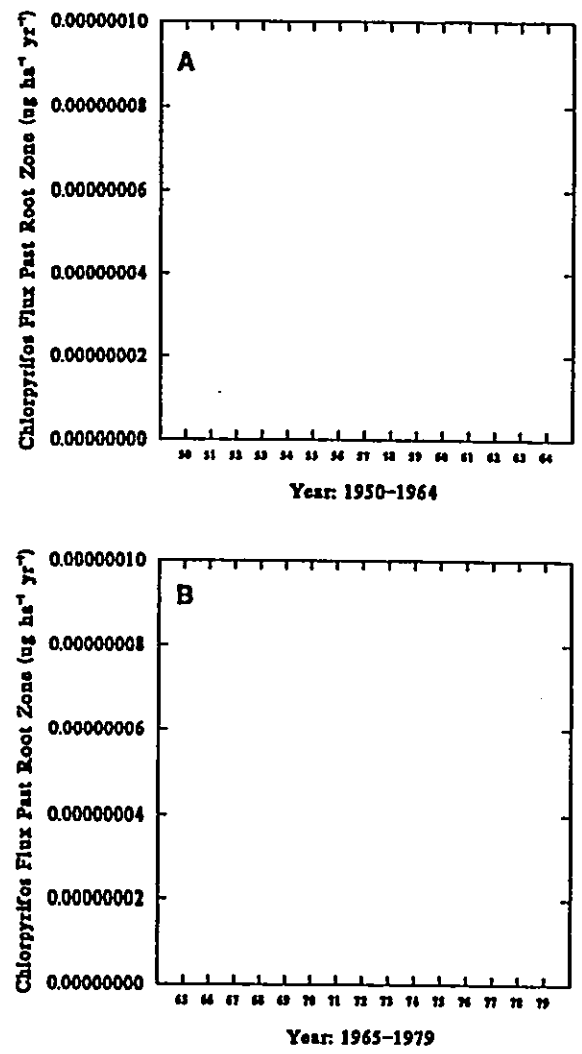


Figure B-31. Annual subsurface leaching of chlorpyrifos beneath the root zone of a simulated USGA Green at the Galbraith Trust Estate for (A) 1950-1964 and (B) 1965-1979.

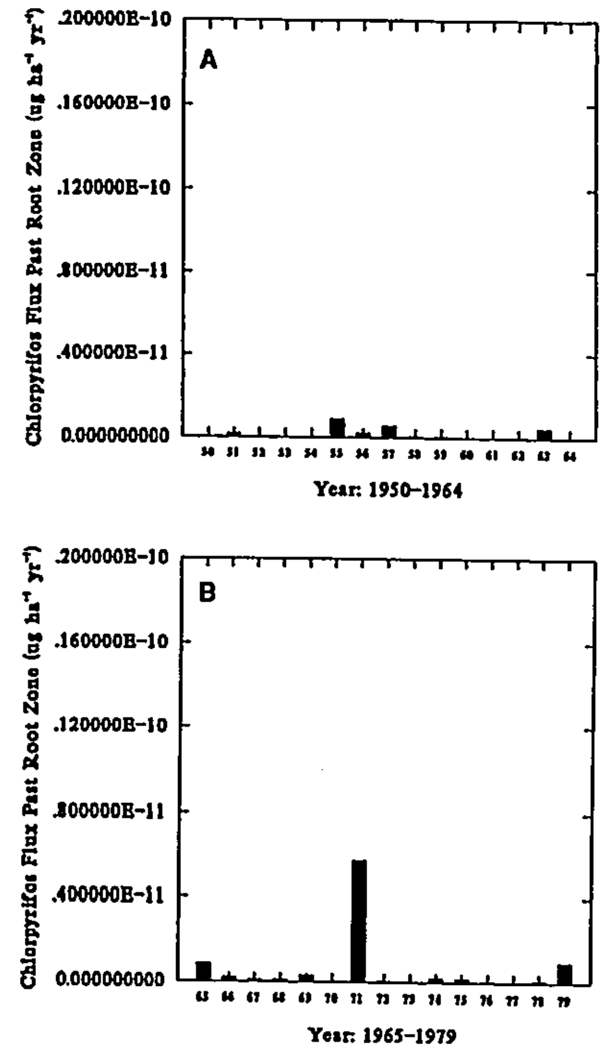


Figure B-32. Annual subsurface leaching of chlorpyrifos beneath the root zone of a simulated Wahiawa fairway soil at the Galbraith Trust Estate for (A) 1950-1964 and (B) 1965-1979.

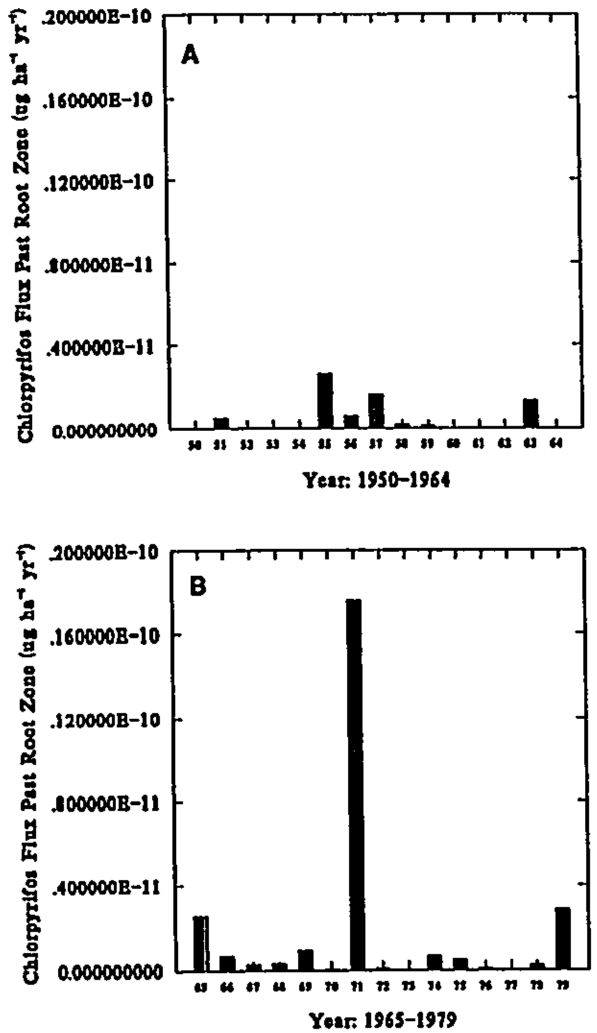


Figure B-33. Annual subsurface leaching of chlorpyrifos beneath the root zone of a simulated Kolekole fairway soil at the Galbraith Trust Estate for (A) 1950-1964 and (B) 1965-1979.

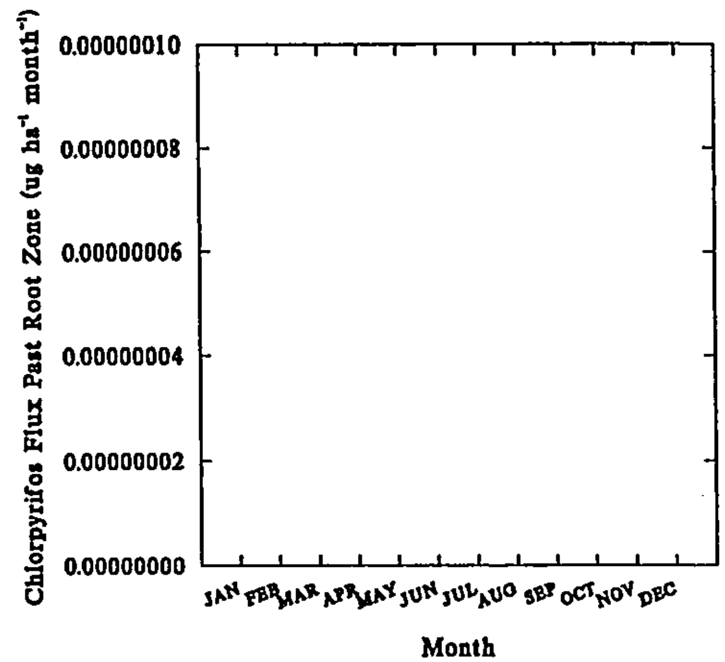


Figure B-34. Mean monthly subsurface movement of chlorpyrifos beneath the root zone of a simulated USGA Green at the Galbraith Trust Estate. Error bars represent one standard error.

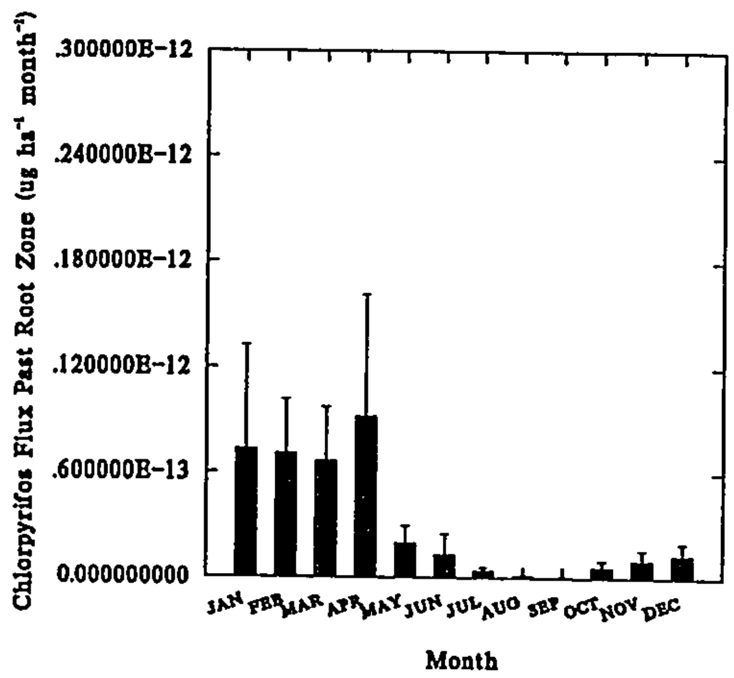


Figure B-35. Mean monthly subsurface movement of chlorpyrifos beneath the root zone of a simulated Wahiawa fairway soil at the Galbraith Trust Estate. Error bars represent one standard error.

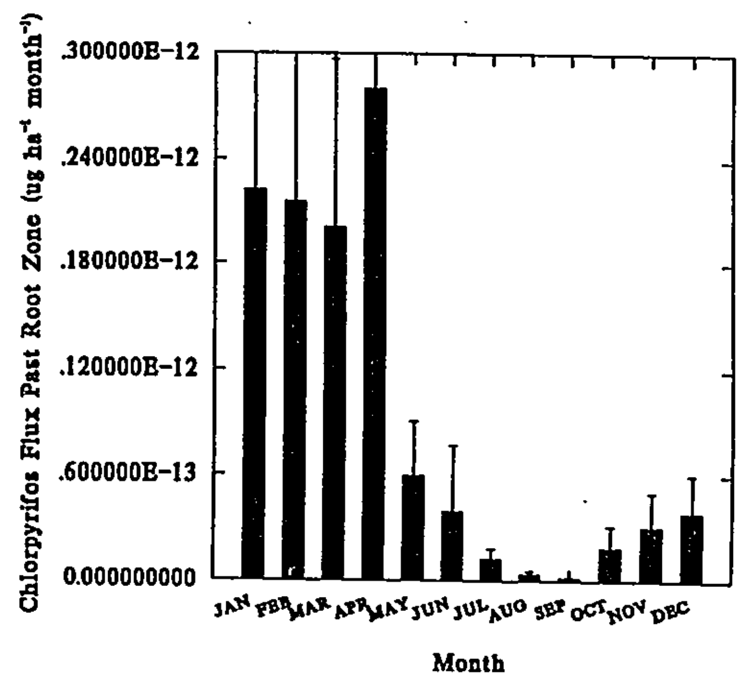


Figure B-36. Mean monthly subsurface movement of chlorpyrifos beneath the root zone of a simulated Kolekole fairway soil at the Galbraith Trust Estate. Error bars represent one standard error.

Table 3.7-20. Monthly Concentration of Chlorpyrifos (ng L^{-1})[1] Beneath the Root Zone from a 30 Year Simulation of an Established USGA Green on the Proposed Galbraith Trust.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	0.00	0.00
Mean	0.00	0.00	0.00	0.00
SD	0.00	0.00	0.00	0.00
Median	0.00	0.00	0.00	0.00
	May	**June**	**July**	**August**
Minimum	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	0.00	0.00
Mean	0.00	0.00	0.00	0.00
SD	0.00	0.00	0.00	0.00
Median	0.00	0.00	0.00	0.00
	September	**October**	**November**	**December**
Minimum	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	0.00	0.00
Mean	0.00	0.00	0.00	0.00
SD	0.00	0.00	0.00	0.00
Median	0.00	0.00	0.00	0.00

Table 3.7-21. Monthly Concentration of Chlorpyrifos (ng L^{-1}) Beneath the Root Zone from a 30 Year Simulation of an Established Wahiawa Fairway Soil on the Proposed Galbraith Trust Estate.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	9.41E-18	1.27E-17	7.70E-18	1.53E-17
Mean	6.54E-20	3.57E-19	2.55E-19	3.38E-19
SD	6.43E-19	1.78E-18	1.17E-18	1.58E-18
Median	0.00	0.00	0.00	0.00
	May	**June**	**July**	**August**
Minimum	0.00	0.00	0.00	0.00
Maximum	1.34E-17	7.06E-18	5.13E-18	2.54E-18
Mean	3.38E-19	2.02E-19	1.24E-19	6.13E-20
SD	1.80E-18	1.09E-18	6.83E-19	3.37E-19
Median	0.00	0.00	0.00	0.00
	September	**October**	**November**	**December**
Minimum	0.00	0.00	0.00	0.00
Maximum	1.25E-18	0.00	0.00	0.00
Mean	1.26E-20	0.00	0.00	0.00
SD	1.19E-19	0.00	0.00	0.00
Median	0.00	0.00	0.00	0.00

Table 3.7-22. Monthly Concentration of Chlorpyrifos (ng L^{-1}) Beneath the Root Zone from a 30 Year Simulation of an Established Kolekole Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	3.43E-17	4.61E-17	2.81E-17	5.57E-17
Mean	3.76E-19	1.67E-18	1.45E-18	1.68E-18
SD	2.42E-18	6.51E-18	4.47E-18	5.86E-18
Median	0.00	0.00	0.00	0.00
	May	**June**	**July**	**August**
Minimum	0.00	0.00	0.00	0.00
Maximum	4.86E-17	2.57E-17	1.87E-17	9.22E-18
Mean	1.74E-18	1.03E-18	5.65E-19	2.24E-19
SD	6.55E-18	3.99E-18	2.49E-18	1.23E-18
Median	0.00	0.00	0.00	0.00
	September	**October**	**November**	**December**
Minimum	0.00	0.00	0.00	0.00
Maximum	4.55E-18	2.30E-18	2.28E-18	5.11E-18
Mean	1.11E-19	8.59E-20	7.17E-20	1.19E-19
SD	6.11E-19	3.83E-19	3.32E-19	6.71E-19
Median	0.00	0.00	0.00	0.00

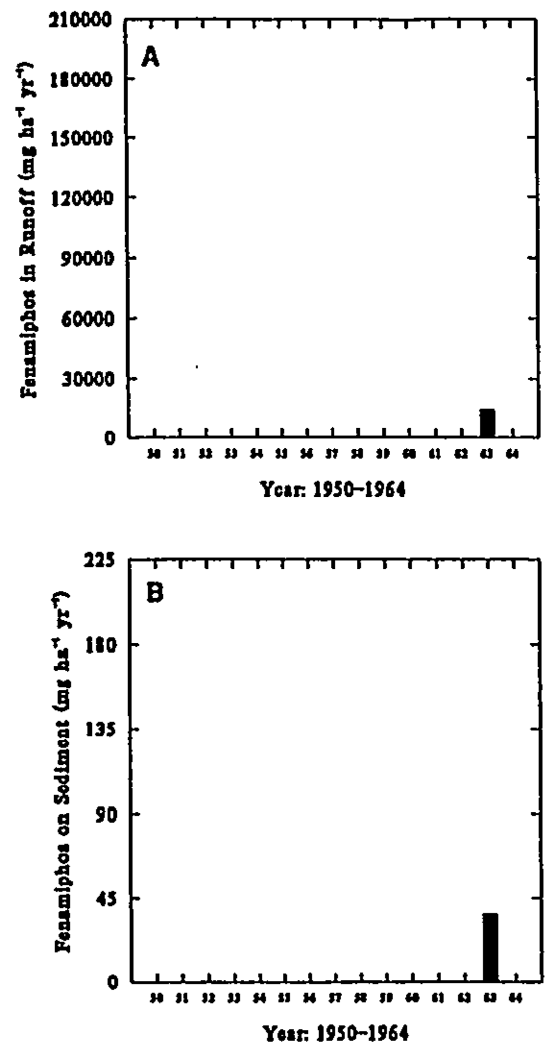


Figure B-37a. Annual surface loss of fenamiphos in runoff (A) water and (B) sediment from a simulated USGA Green at the Galbraith Trust Estate: 1950-1964.

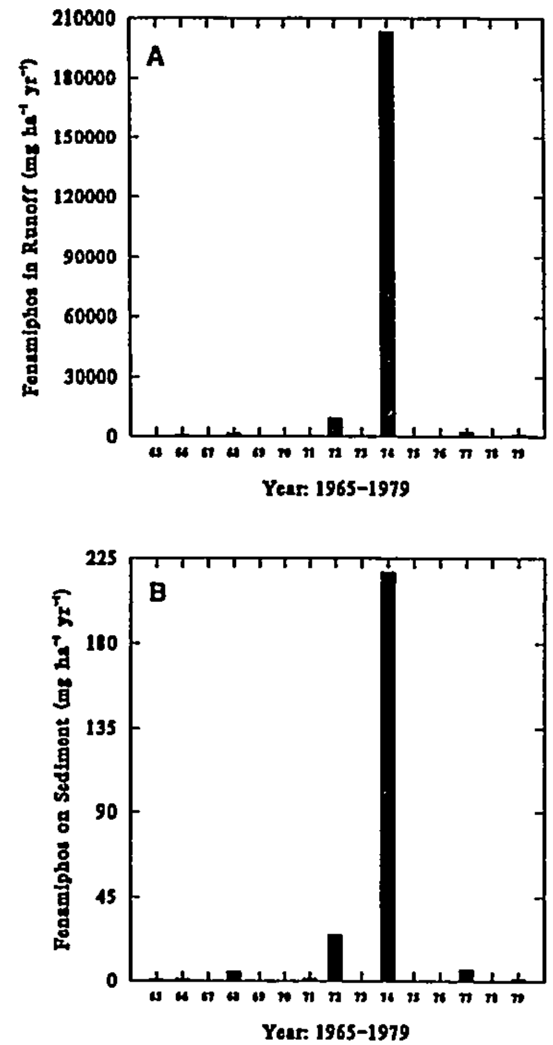


Figure B-37b. Annual surface loss of fenamiphos in runoff (A) water and (B) sediment from a simulated USGA Green at the Galbraith Trust Estate: 1965-1979.

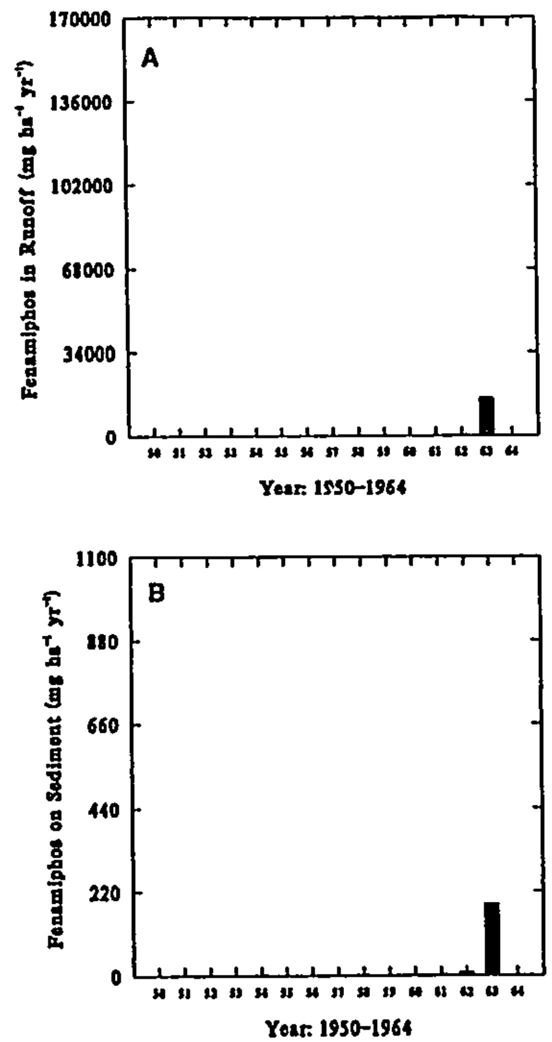


Figure B-38a. Annual surface loss of fenamiphos in runoff (A) water and (B) sediment from a simulated Wahiawa fairway soil at the Galbraith Trust Estate: 1950-1964.

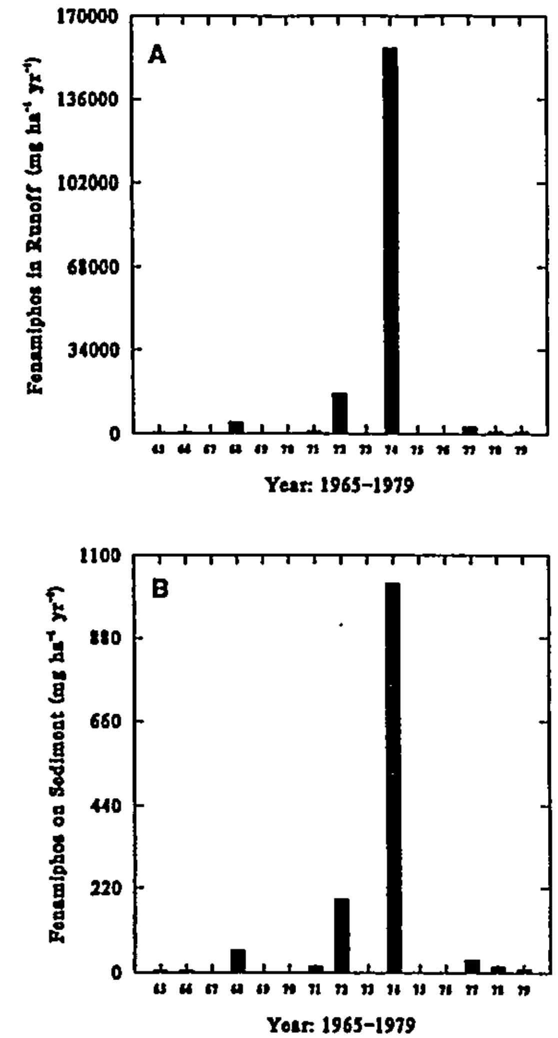


Figure B-38b. Annual surface loss of fenamiphos in runoff (A) water and (B) sediment from a simulated Wahiawa fairway soil at the Galbraith Trust Estate: 1965-1979.

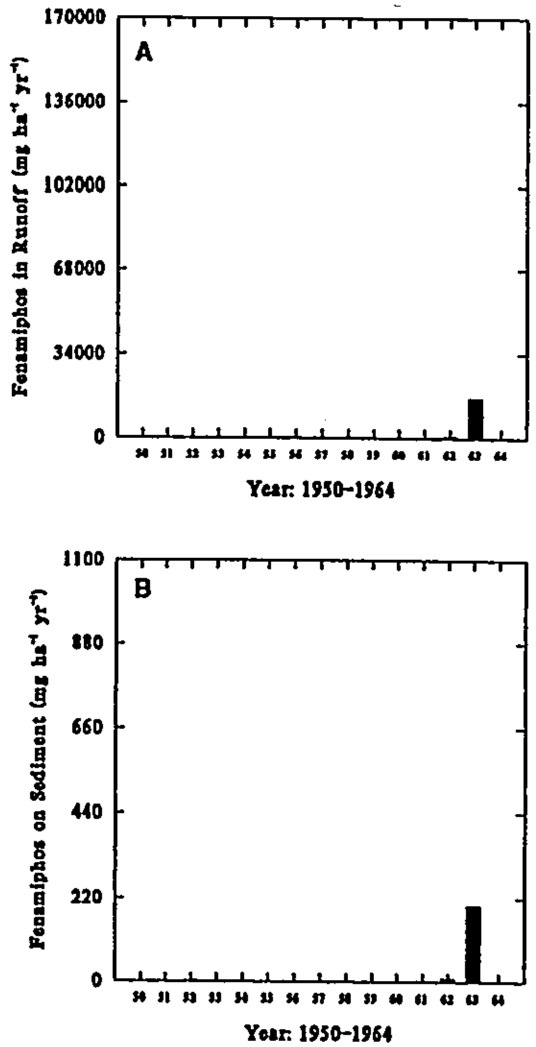


Figure B-39a. Annual surface loss of fenamiphos in runoff (A) water and (B) sediment from a simulated Kolekole fairway soil at the Galbraith Trust Estate: 1950-1964.

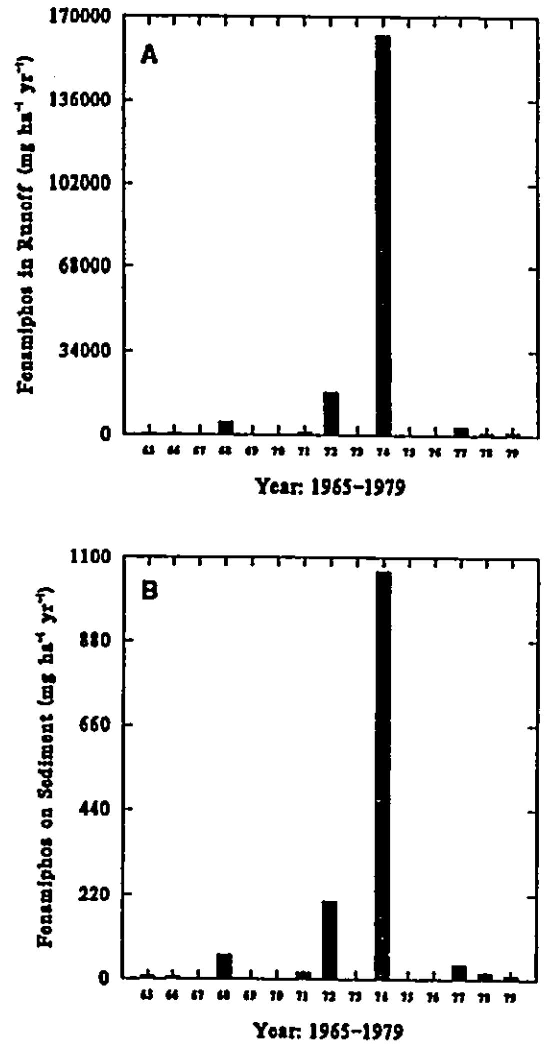


Figure B-39b. Annual surface loss of fenamiphos in runoff (A) water and (B) sediment from a simulated Kolekole fairway soil at the Galbraith Trust Estate: 1965-1979.

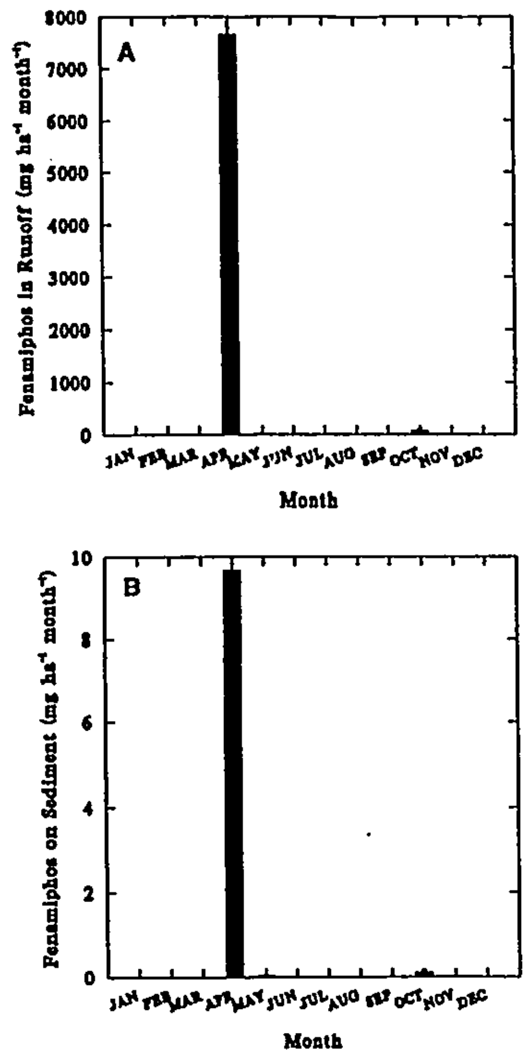


Figure B-40. Mean monthly loss of fenamiphos in runoff (A) water and (B) sediment from a simulated USGA Green at the Galbraith Trust Estate. Error bars represent one standard error.

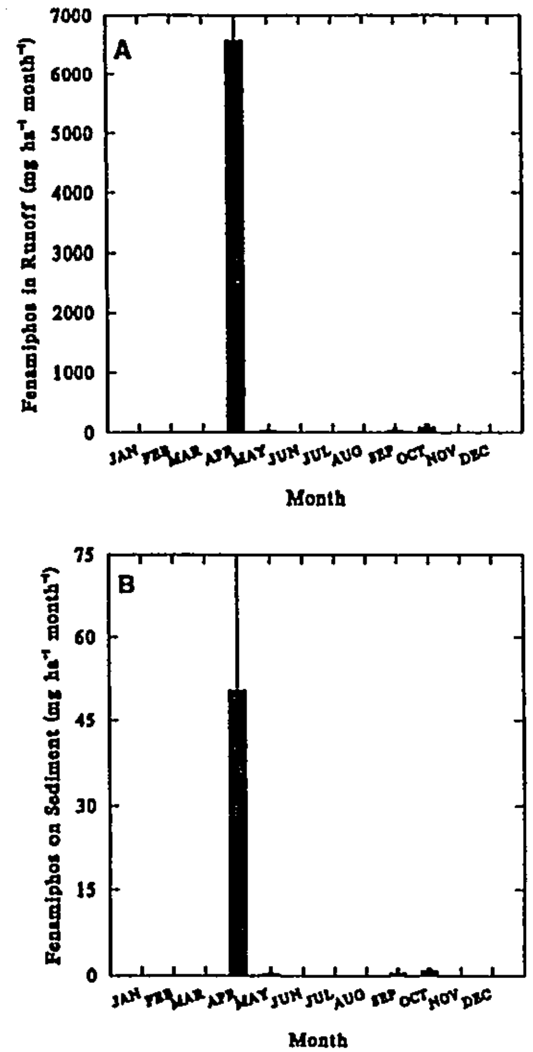


Figure B-41. Mean monthly loss of fenamiphos in runoff (A) water and (B) sediment from a simulated Wahiawa fairway soil at the Galbraith Trust Estate. Error bars represent one standard error.

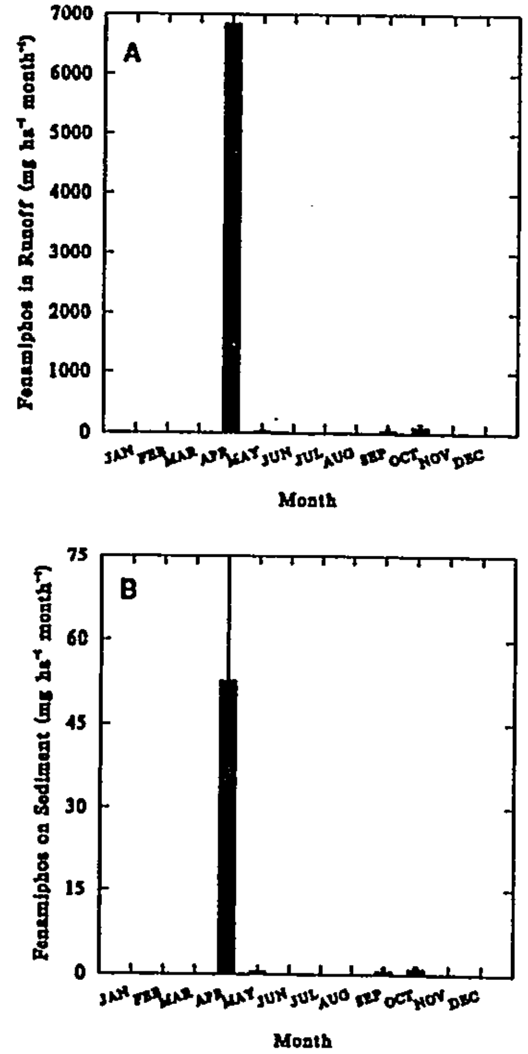


Figure B-42. Mean monthly loss of fenamiphos in runoff (A) water and (B) sediment from a simulated Kolekole fairway soil at the Galbraith Trust Estate. Error bars represent one standard error.

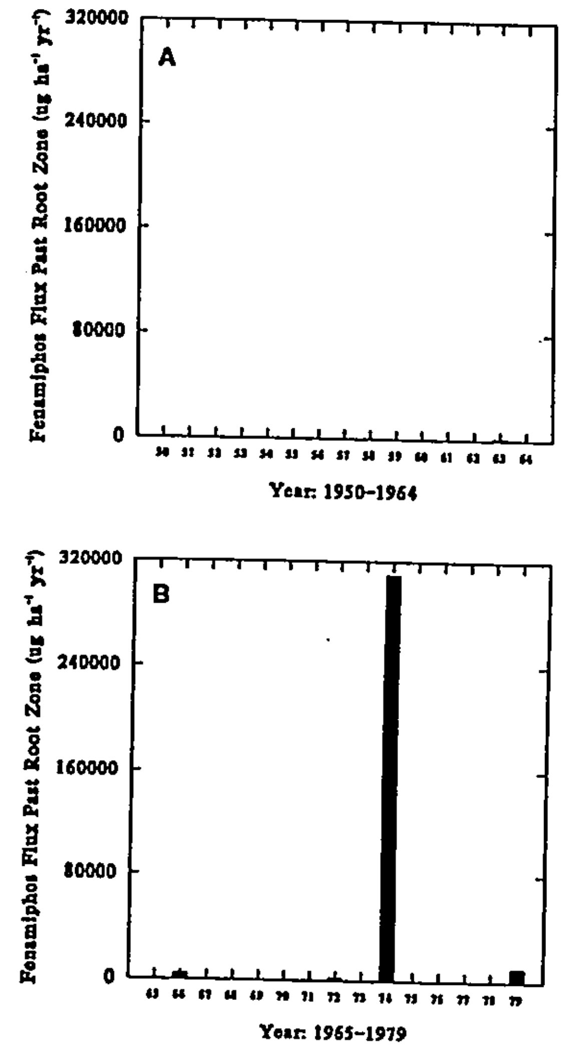


Figure B-43. Annual subsurface leaching of fenamiphos beneath the root zone of a simulated USGA Green at the Galbraith Trust Estate for (A) 1950-1964 and (B) 1965-1979.

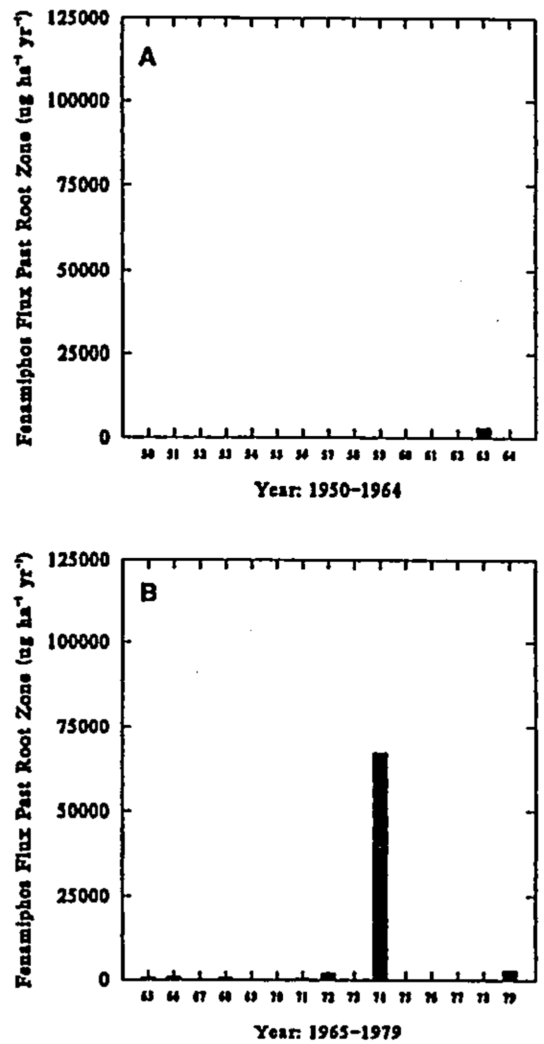


Figure B-44. Annual subsurface leaching of fenamiphos beneath the root zone of a simulated Wahiawa fairway soil at the Galbraith Trust Estate for (A) 1950-1964 and (B) 1965-1979.

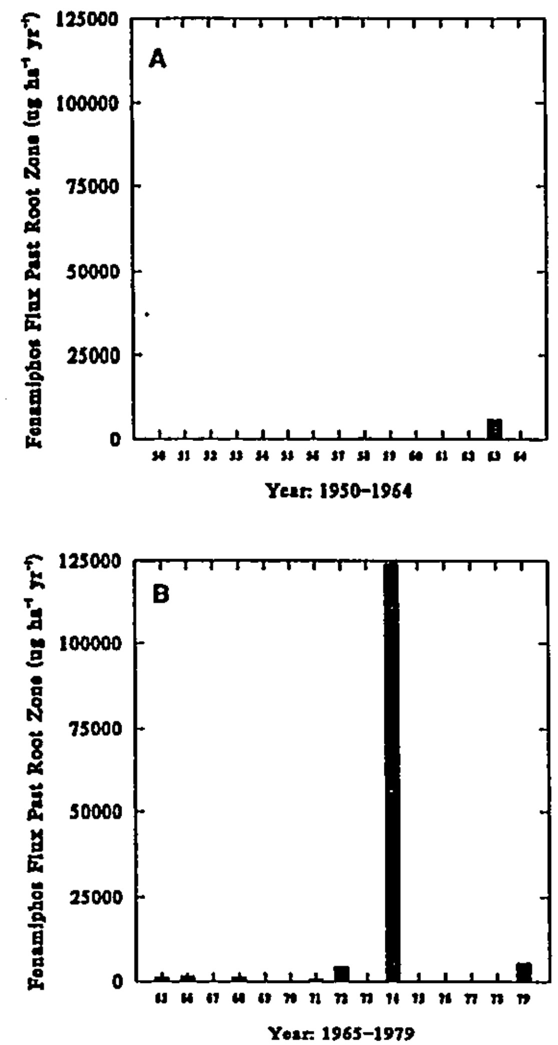


Figure B-45. Annual subsurface leaching of fenamiphos beneath the root zone of a simulated Kolekole fairway soil at the Galbraith Trust Estate for (A) 1950-1964 and (B) 1965-1979.

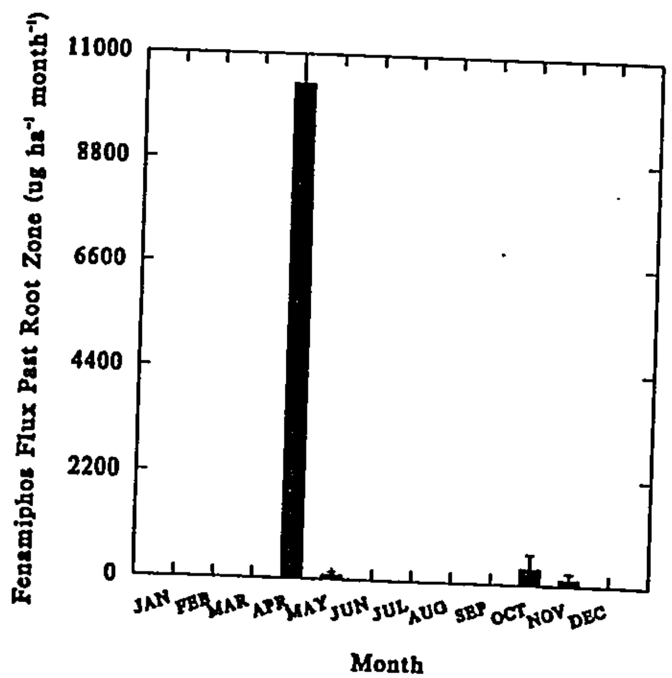


Figure B-46. Mean monthly subsurface movement of fenamiphos beneath the root zone of a simulated USGA Green at the Galbraith Trust Estate. Error bars represent one standard error.

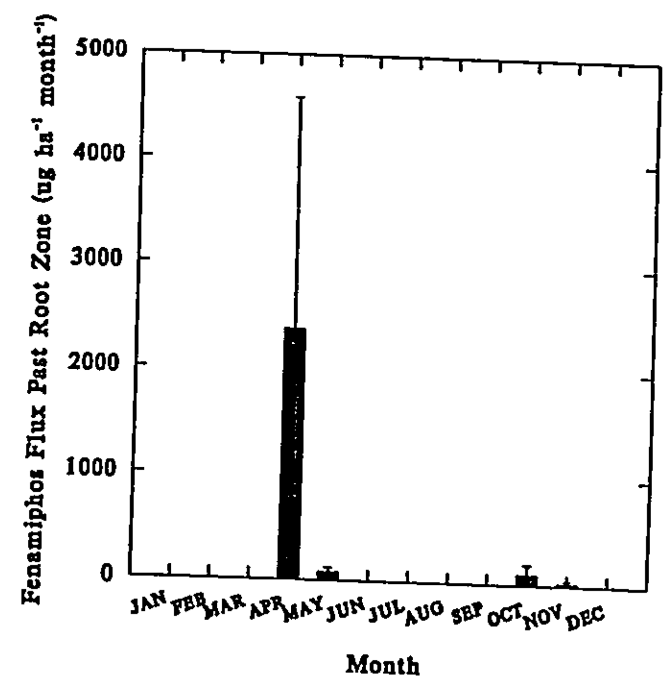


Figure B-47. Mean monthly subsurface movement of fenamiphos beneath the root zone of a simulated Wahiawa fairway soil at the Galbraith Trust Estate. Error bars represent one standard error.

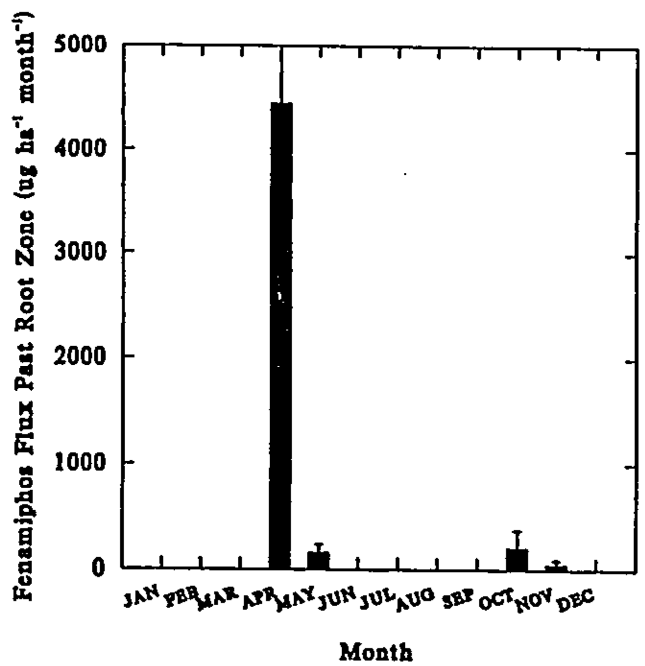


Figure B-48. Mean monthly subsurface movement of fenamiphos beneath the root zone of a simulated Kolekole fairway soil at the Galbraith Trust Estate. Error bars represent one standard error.

Table B-7. Monthly Concentration of Fenamiphos (ng L-1)[1] Beneath the Root Zone from a 30 Year Simulation of an Established USGA Green on the Proposed Galbraith Trust.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	7.89E-03	1.47E-03	6.72E-05	199.20
Mean	2.21E-04	4.70E-05	3.09E-06	1.84
SD	8.19E-04	1.40E-04	8.10E-06	16.25
Median	1.30E-10	1.02E-11	1.29E-12	1.57E-09
	May	**June**	**July**	**August**
Minimum	1.12E-18	0.00	0.00	0.00
Maximum	66.49	2.22	0.07	4.92E-03
Mean	0.68	0.02	9.15E-04	6.03E-05
SD	4.81	0.16	5.57E-03	3.57E-04
Median	2.06E-08	1.18E-09	2.47E-10	6.15E-09
	September	**October**	**November**	**December**
Minimum	0.00	0.00	0.00	0.00
Maximum	6.91E-04	7.46	2.11	0.18
Mean	6.99E-06	0.07	0.04	3.22E-03
SD	4.93E-05	0.53	0.19	0.01
Median	1.45E-09	3.49E-10	5.70E-10	2.02E-09

Table B-8. Monthly Concentration of Fenamiphos (ng L-1) Beneath the Root Zone from a 30 Year Simulation of an Established Wahiawa Fairway Soil on the Proposed Galbraith Trust Estate.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	1.62E-03	6.15E-04	2.79E-05	18.31
Mean	4.71E-05	1.16E-05	6.71E-07	0.19
SD	1.57E-04	4.80E-05	2.22E-06	1.53
Median	2.63E-11	1.61E-12	6.84E-13	9.95E-09
	May	**June**	**July**	**August**
Minimum	1.08E-18	0.00	0.00	0.00
Maximum	6.60	0.25	8.91E-03	8.27E-04
Mean	0.08	3.38E-03	1.46E-04	1.19E-05
SD	0.48	0.02	7.06E-04	6.09E-05
Median	2.27E-06	7.55E-07	1.52E-07	6.50E-08
	September	**October**	**November**	**December**
Minimum	0.00	0.00	0.00	0.00
Maximum	5.02E-03	0.96	0.19	0.02
Mean	3.76E-05	8.84E-03	4.31E-03	4.53E-04
SD	3.51E-04	0.07	0.02	1.58E-03
Median	6.04E-09	2.18E-09	6.52E-09	2.47E-09

Table B-9. Monthly Concentration of Fenamiphos (ng L^{-1}) Beneath the Root Zone from a 30 Year Simulation of an Established Kolekole Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	3.27E-03	1.03E-03	4.63E-05	37.40
Mean	9.39E-05	2.07E-05	1.19E-06	0.39
SD	3.07E-04	8.08E-05	3.75E-06	3.12
Median	5.50E-11	3.04E-12	1.06E-12	2.00E-08
	May	**June**	**July**	**August**
Minimum	2.26E-18	0.00	0.00	0.00
Maximum	13.49	0.51	0.02	1.69E-03
Mean	0.16	7.18E-03	3.09E-04	2.51E-05
SD	0.98	0.04	1.46E-03	1.25E-04
Median	6.64E-06	2.16E-06	4.19E-07	1.71E-07
	September	**October**	**November**	**December**
Minimum	0.00	0.00	0.00	0.00
Maximum	0.01	2.01	0.37	0.03
Mean	9.99E-05	0.02	8.89E-03	9.48E-04
SD	9.30E-04	0.14	0.04	3.25E-03
Median	1.56E-08	2.23E-09	1.49E-08	4.93E-09

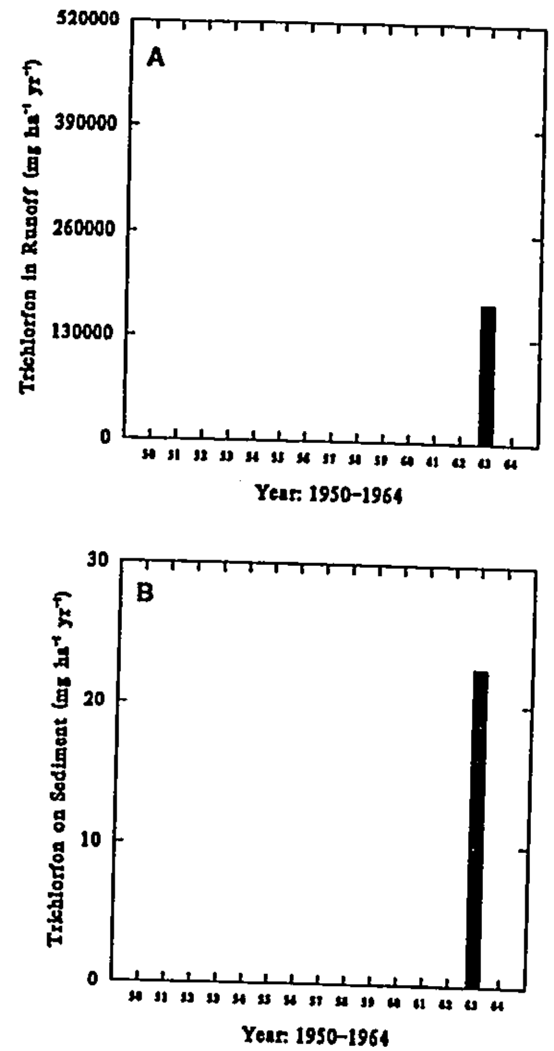


Figure B-49a. Annual surface loss of trichlorfon in runoff (A) water and (B) sediment from a simulated USGA Green at the Galbraith Trust Estate: 1950-1964.

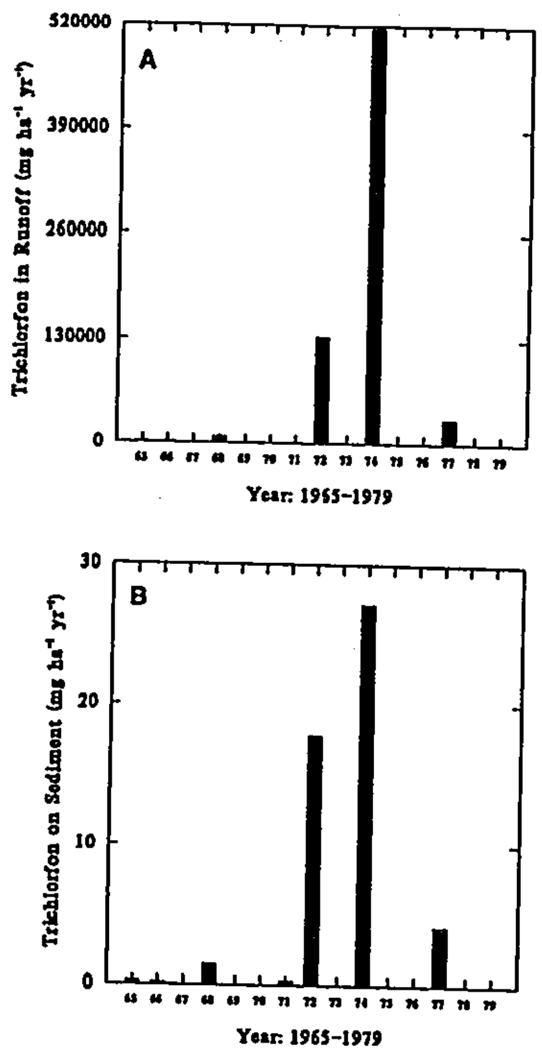


Figure B-49b. Annual surface loss of trichlorfon in runoff (A) water and (B) sediment from a simulated USGA Green at the Galbraith Trust Estate: 1965-1979.

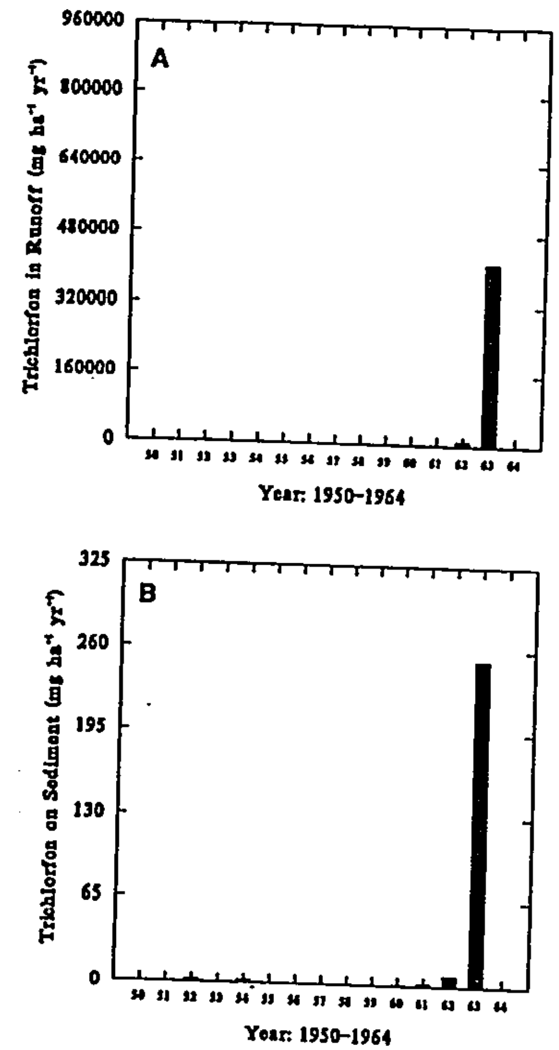


Figure B-50a. Annual surface loss of trichlorfon in runoff (A) water and (B) sediment from a simulated Wahiawa fairway soil at the Galbraith Trust Estate: 1950-1964.

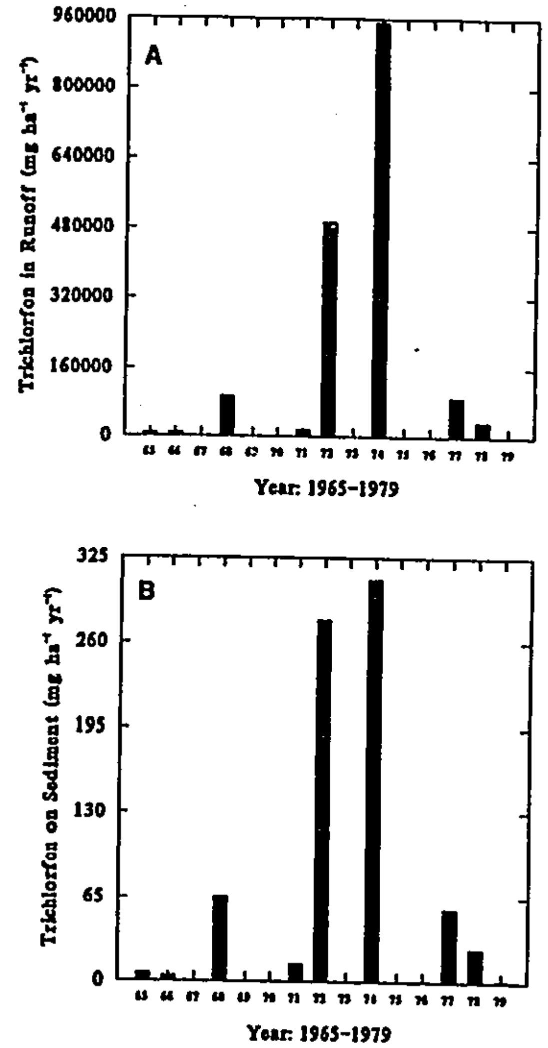


Figure B-50b. Annual surface loss of trichlorfon in runoff (A) water and (B) sediment from a simulated Wahiawa fairway soil at the Galbraith Trust Estate: 1965-1979.

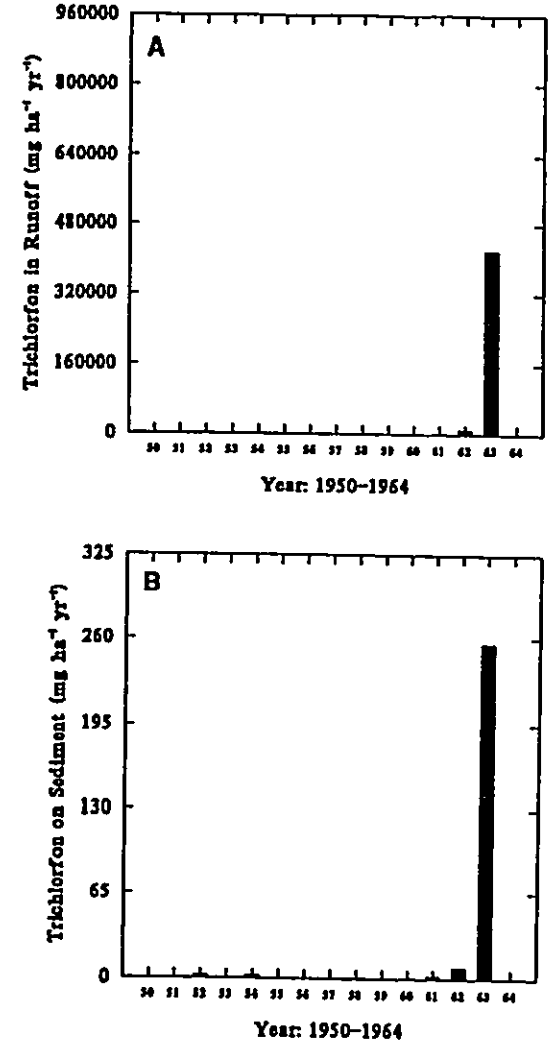


Figure B-51a. Annual surface loss of trichlorfon in runoff (A) water and (B) sediment from a simulated Kolekole fairway soil at the Galbraith Trust Estate: 1950-1964.

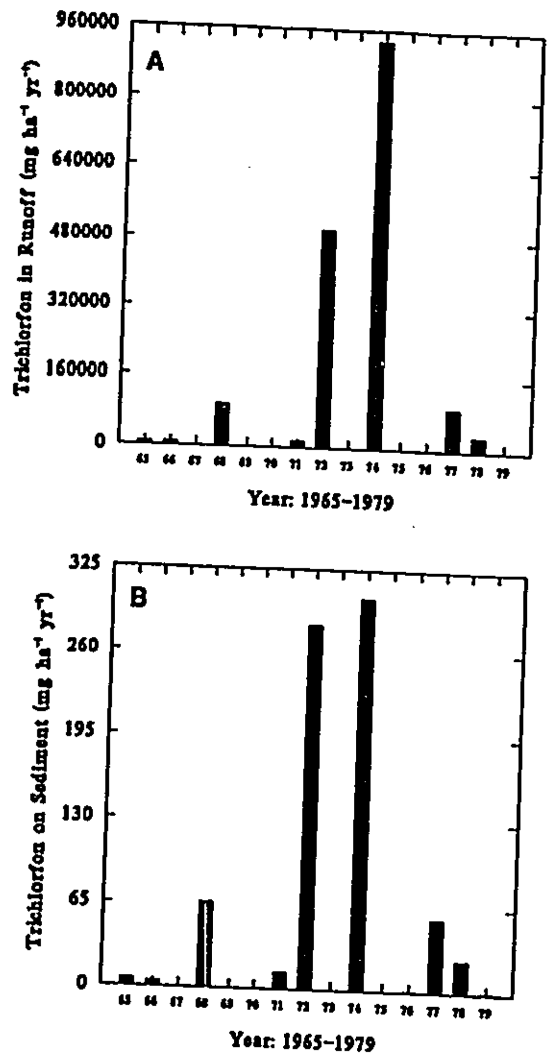


Figure B-51b. Annual surface loss of trichlorfon in runoff (A) water and (B) sediment from a simulated Kolekole fairway soil at the Galbraith Trust Estate: 1965-1979.

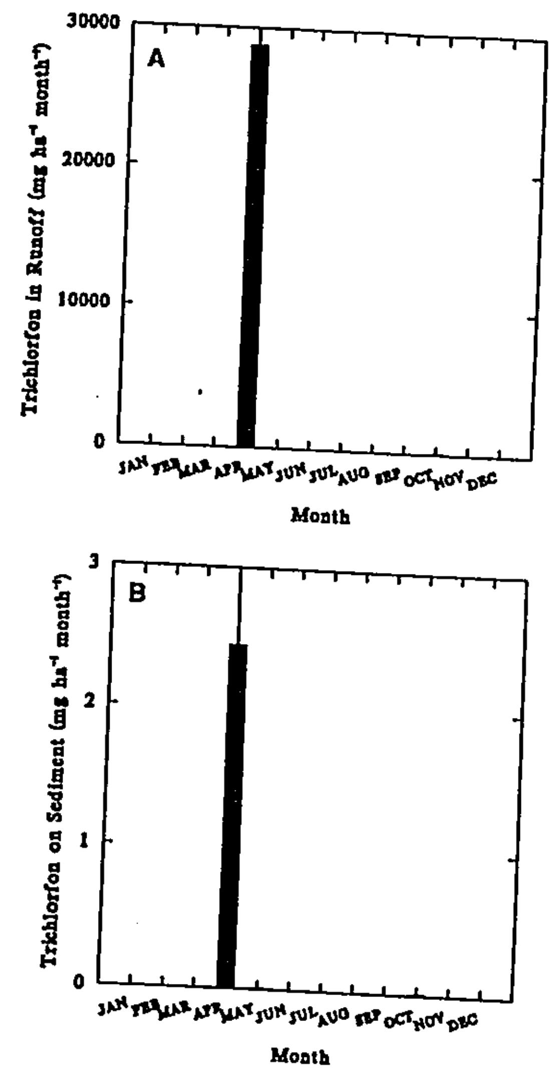


Figure B-52. Mean monthly loss of trichlorfon in runoff (A) water and (B) sediment from a simulated USGA Green at the Galbraith Trust Estate. Error bars represent one standard error.

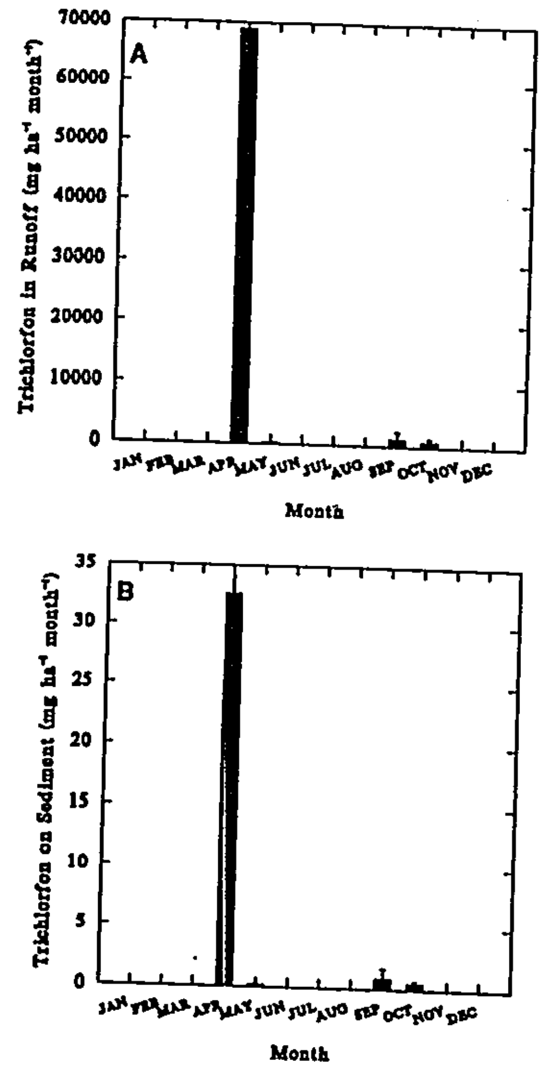


Figure B-53. Mean monthly loss of trichlorfon in runoff (A) water and (B) sediment from a simulated Wahiawa fairway soil at the Galbraith Trust Estate. Error bars represent one standard error.

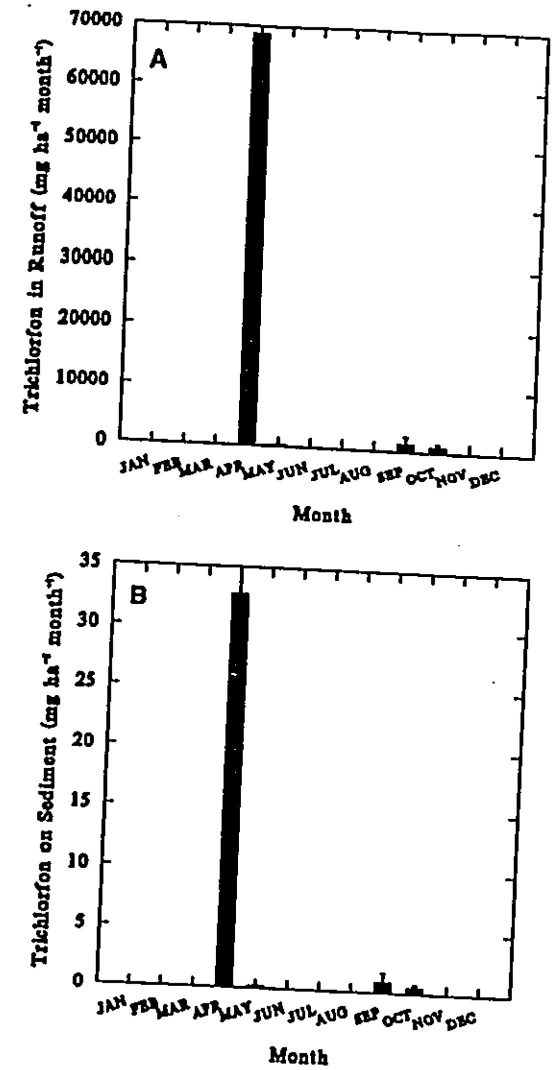


Figure B-54. Mean monthly loss of trichlorfon in runoff (A) water and (B) sediment from a simulated Kolekole fairway soil at the Galbraith Trust Estate. Error bars represent one standard error.

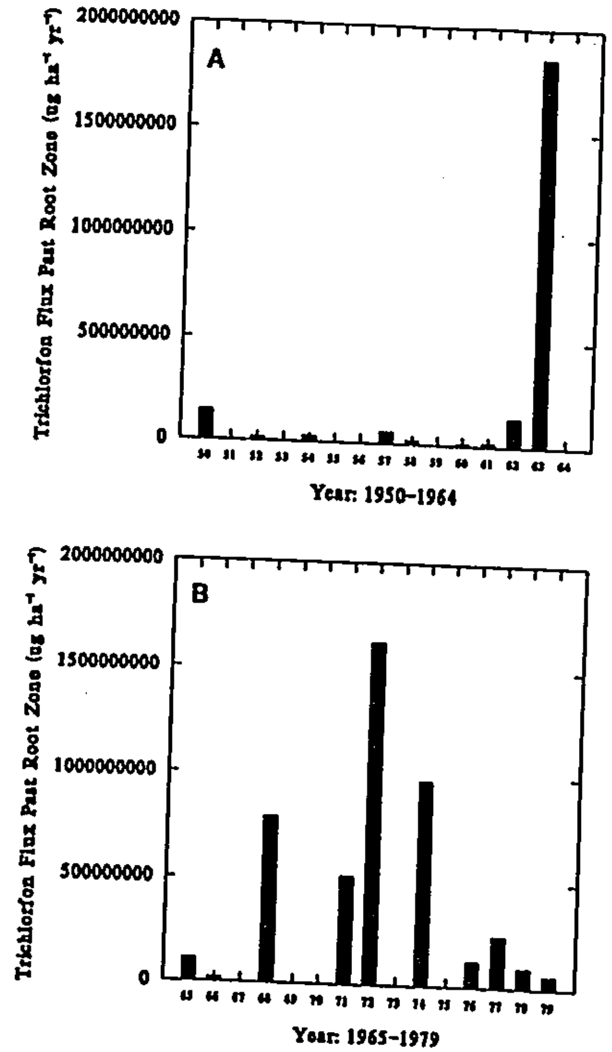


Figure B-55. Annual subsurface leaching of trichlorfon beneath the root zone of a simulated USGA Green at the Galbraith Trust Estate for (A) 1950-1964 and (B) 1965-1979.

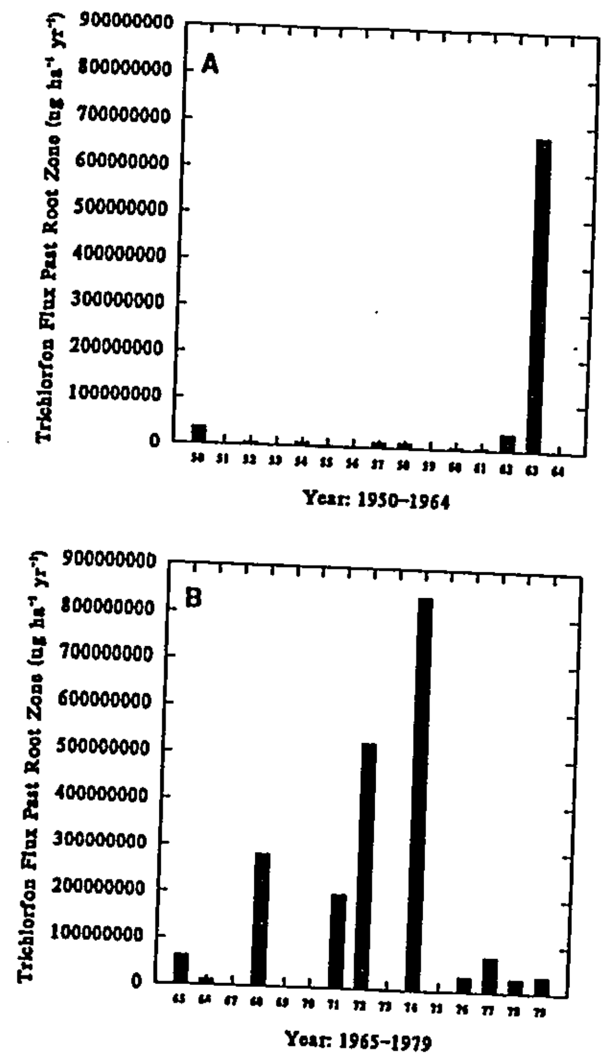


Figure B-56. Annual subsurface leaching of trichlorfon beneath the root zone of a simulated Wahiawa fairway soil at the Galbraith Trust Estate for (A) 1950-1964 and (B) 1965-1979.

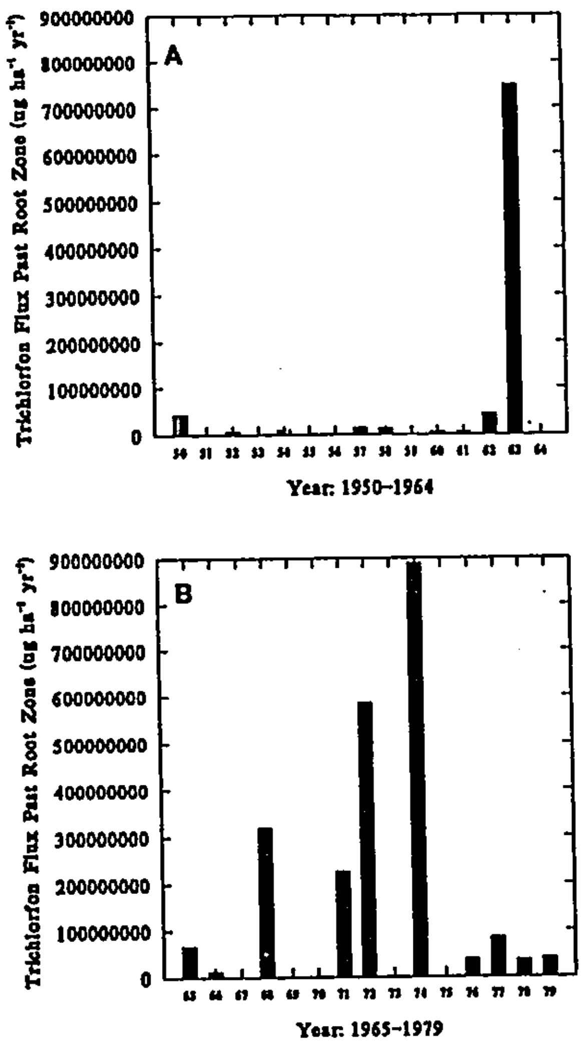


Figure B-57. Annual subsurface leaching of trichlorfon beneath the root zone of a simulated Kolekole fairway soil at the Galbraith Trust Estate for (A) 1950-1964 and (B) 1965-1979.

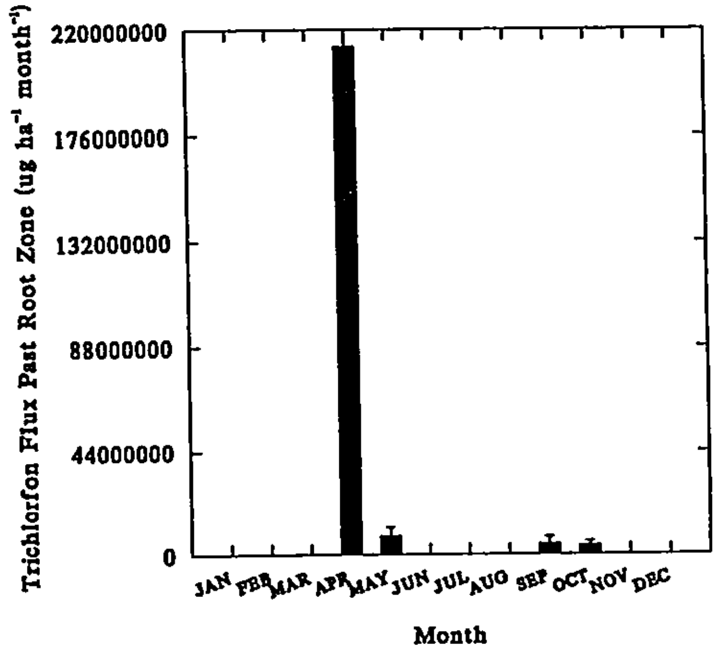


Figure B-58. Mean monthly subsurface movement of trichlorfon beneath the root zone of a simulated USGA Green at the Galbraith Trust Estate. Error bars represent one standard error.

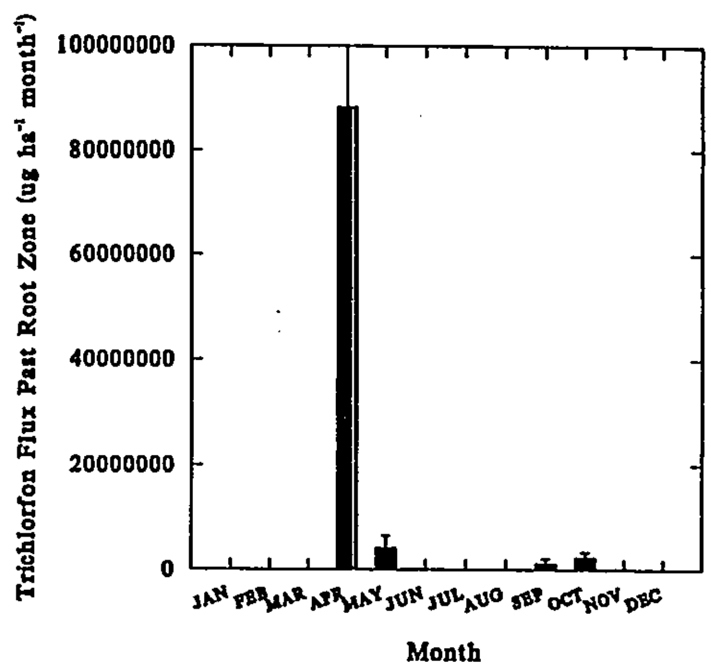


Figure B-59. Mean monthly subsurface movement of trichlorfon beneath the root zone of a simulated Wahiawa fairway soil at the Galbraith Trust Estate. Error bars represent one standard error.

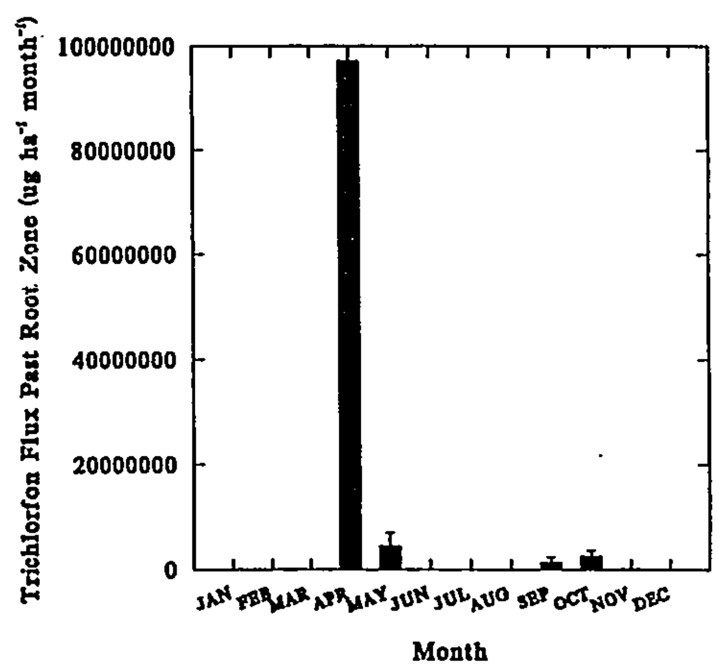


Figure B-60. Mean monthly subsurface movement of trichlorfon beneath the root zone of a simulated Kolekole fairway soil at the Galbraith Trust Estate. Error bars represent one standard error.

Table B-10. Monthly Concentration of Trichlorfon (ng L^{-1})[1] Beneath the Root Zone from a 30 Year Simulation of an Established USGA Green on the Proposed Galbraith Trust.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	1.27	0.03	5.13E-04	1.79E+06
Mean	0.04	5.17E-04	5.92E-06	5.89E+04
SD	0.13	2.68E-03	3.68E-05	1.99E+05
Median	3.8E-09	4.38E-11	8.65E-14	9.16E-14
	May	**June**	**July**	**August**
Minimum	0.00	0.00	0.00	0.00
Maximum	3.43E+05	7634.00	208.80	5.05
Mean	2.21E+04	616.86	17.16	0.39
SD	4.54E+04	1100.45	29.68	0.69
Median	3.12E+03	152.30	3.78	0.10
	September	**October**	**November**	**December**
Minimum	0.00	0.00	0.00	0.00
Maximum	2.94E+05	8.91E+04	2.53E+03	69.14
Mean	2.89E+03	2.99E+03	164.41	3.62
SD	2.22E+04	9.37E+03	374.05	8.90
Median	2.83E-03	1.93E-04	1.71E-05	3.50E-04

Table B-11. Monthly Concentration of Trichlorfon (ng L^{-1}) Beneath the Root Zone from a 30 Year Simulation of an Established Wahiawa Fairway Soil on the Proposed Galbraith Trust Estate.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	1.94	0.03	9.85E-04	5.85E+05
Mean	0.10	1.41E-03	2.48E-05	1.95E+04
SD	0.23	3.65E-03	8.24E-05	7.13E+04
Median	4.15E-05	3.04E-10	1.45E-09	2.55E-08
	May	**June**	**July**	**August**
Minimum	0.00	0.00	0.00	0.00
Maximum	1.53E+05	5.36E+03	156.40	4.09
Mean	7.46E+03	241.62	8.09	0.23
SD	1.75E+04	554.07	16.38	0.41
Median	500.05	39.92	1.93	0.08
	September	**October**	**November**	**December**
Minimum	0.00	0.00	1.80E-18	0.00
Maximum	4.74E+04	2.47E+04	2.53E+03	71.28
Mean	453.08	813.66	102.71	5.53
SD	3.50E+03	2.39E+03	267.18	10.48
Median	2.99E-03	2.38E-04	2.28E-05	0.10

Table B-12. Monthly Concentration of Trichlorfon (ng L^{-1}) Beneath the Root Zone from a 30 Year Simulation of an Established Kolekole Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	1.95	0.03	1.01E-03	6.54E+05
Mean	0.10	1.35E-03	2.28E-05	2.18E+04
SD	0.23	3.64E-03	8.09E-05	7.87E+04
Median	2.88E-05	2.69E-10	8.55E-10	1.72E-08
	May	**June**	**July**	**August**
Minimum	0.00	0.00	0.00	0.00
Maximum	1.61E+05	5.68E+03	164.90	4.27
Mean	8.35E+03	267.45	8.90	0.25
SD	1.93E+04	592.71	17.42	0.43
Median	644.85	49.11	2.21	0.09
	September	**October**	**November**	**December**
Minimum	0.00	0.00	1.58E-18	0.00
Maximum	5.65E+04	2.83E+04	2.70E+03	75.85
Mean	547.44	932.80	111.49	5.76
SD	4.20E+03	2.71E+03	282.98	11.00
Median	3.26E-03	2.55E-04	2.40E-05	0.14

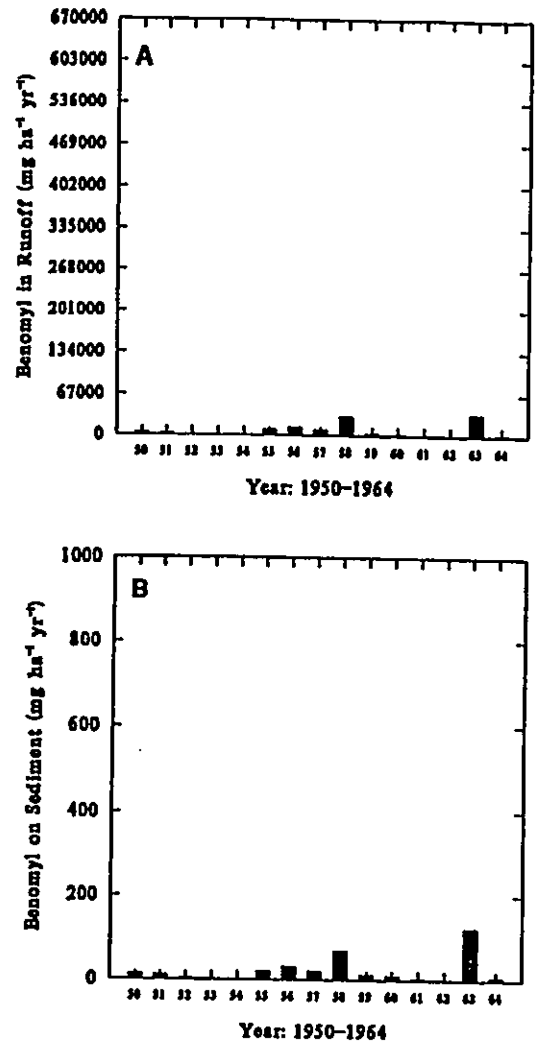


Figure B-61a. Annual surface loss of benomyl in runoff (A) water and (B) sediment from a simulated USGA Green at the Galbraith Trust Estate: 1950-1964.

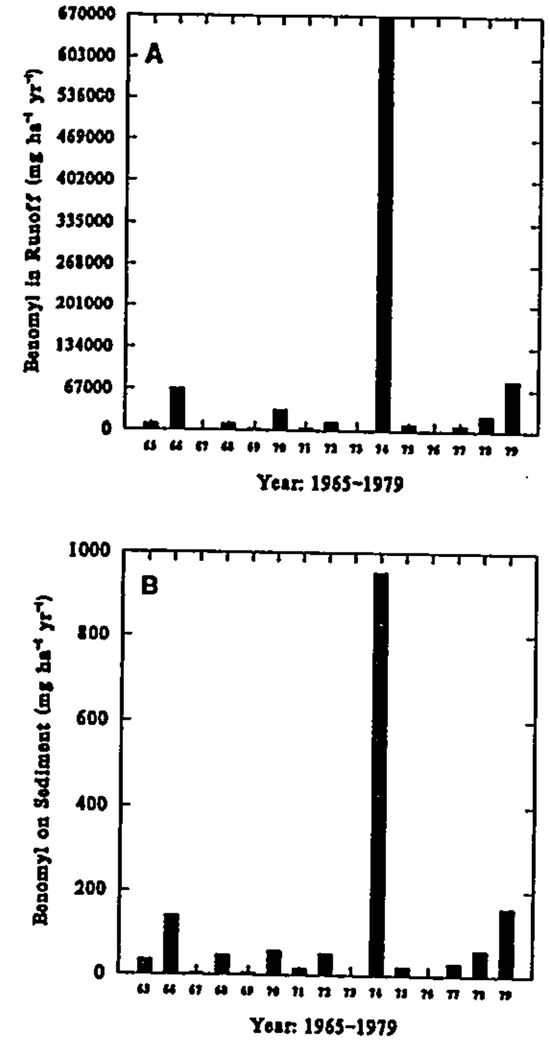


Figure B-61b. Annual surface loss of benomyl in runoff (A) water and (B) sediment from a simulated USGA Green at the Galbraith Trust Estate: 1965-1979.

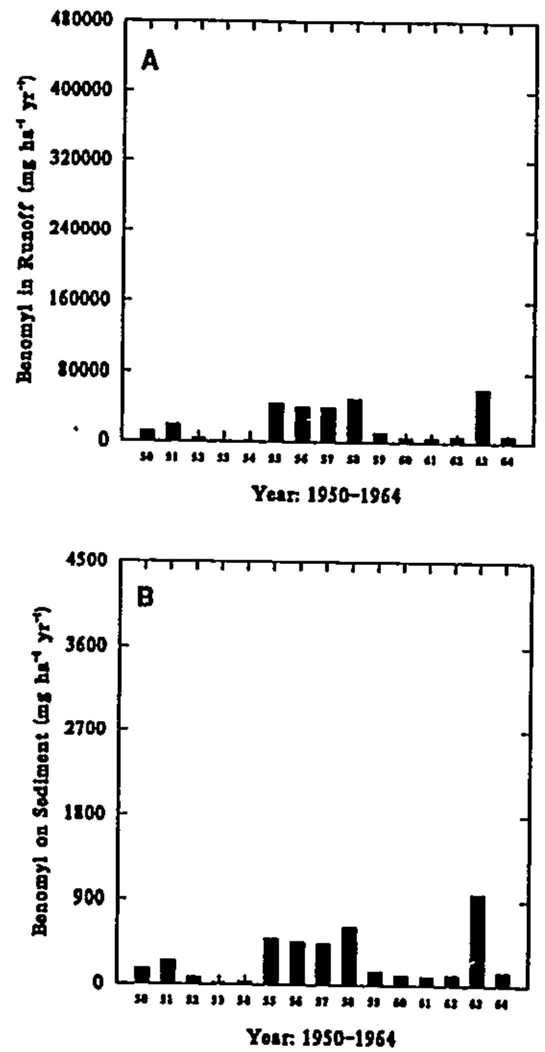


Figure B-62a. Annual surface loss of benomyl in runoff (A) water and (B) sediment from a simulated Wahiawa fairway soil at the Galbraith Trust Estate: 1950-1964.

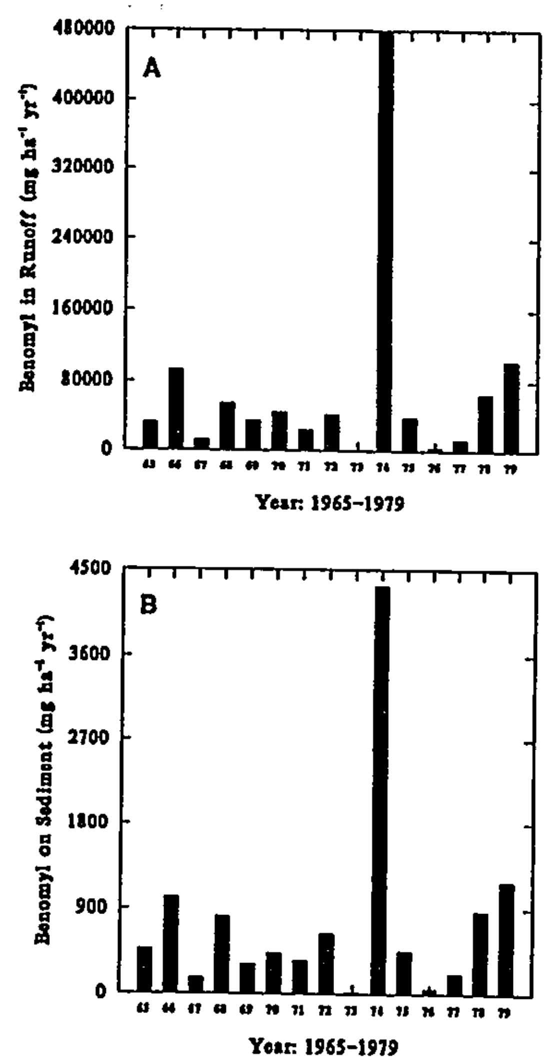


Figure B-62b. Annual surface loss of benomyl in runoff (A) water and (B) sediment from a simulated Wahiawa fairway soil at the Galbraith Trust Estate: 1965-1979.

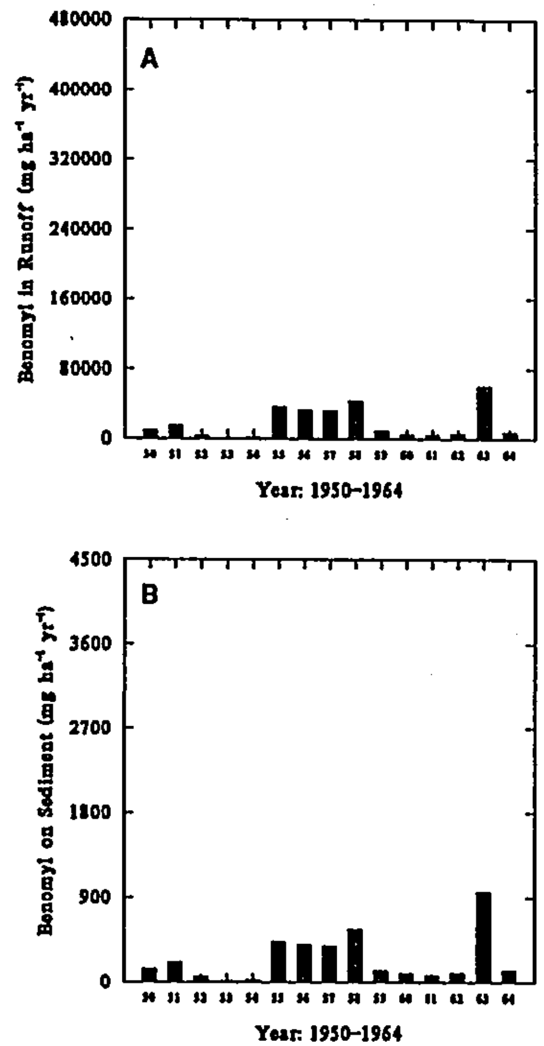


Figure B-63a. Annual surface loss of benomyl in runoff (A) water and (B) sediment from a simulated Kolekole fairway soil at the Galbraith Trust Estate: 1950-1964.

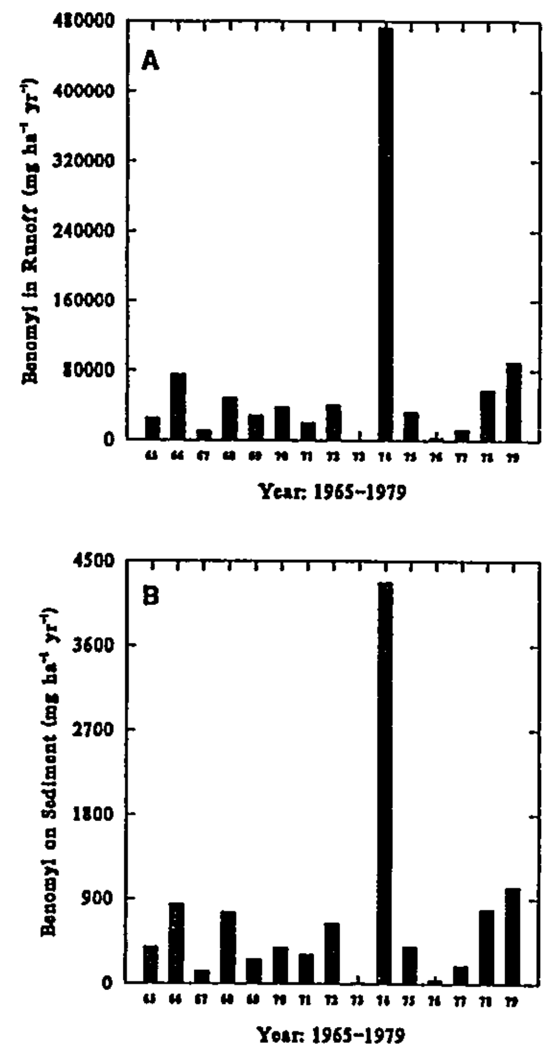


Figure B-63b. Annual surface loss of benomyl in runoff (A) water and (B) sediment from a simulated Kolekole fairway soil at the Galbraith Trust Estate: 1965-1979.

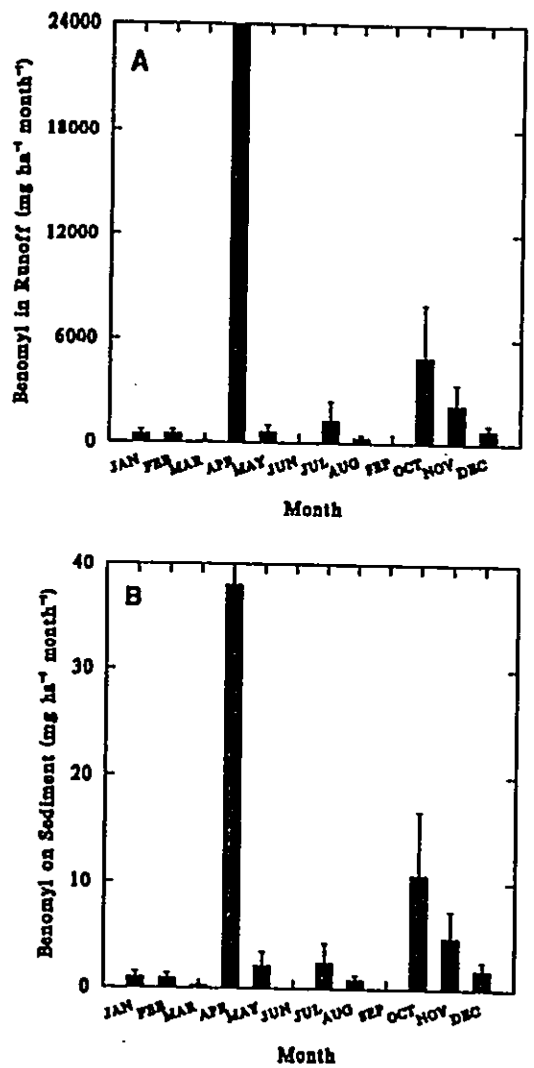


Figure B-64. Mean monthly loss of benomyl in runoff (A) water and (B) sediment from a simulated USGA Green at the Galbraith Trust Estate. Error bars represent one standard error.

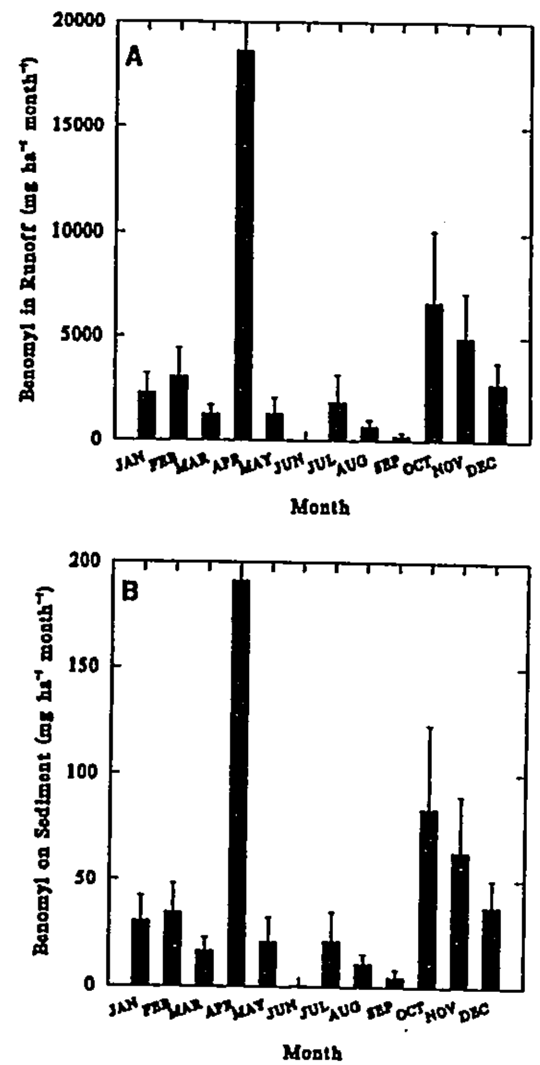


Figure B-65. Mean monthly loss of benomyl in runoff (A) water and (B) sediment from a simulated Wahiawa fairway soil at the Galbraith Trust Estate. Error bars represent one standard error.

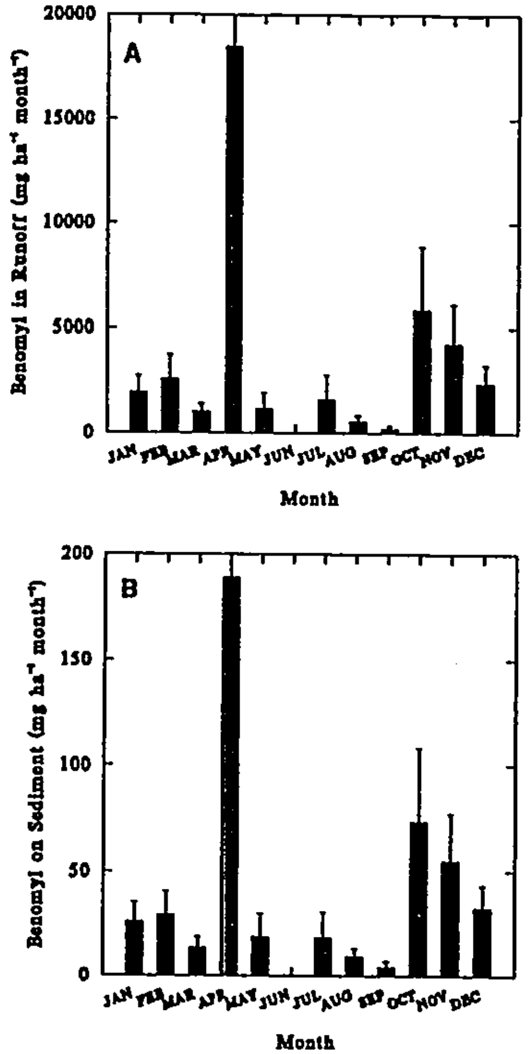


Figure B-66. Mean monthly loss of benomyl in runoff (A) water and (B) sediment from a simulated Kolekole fairway soil at the Galbraith Trust Estate. Error bars represent one standard error.

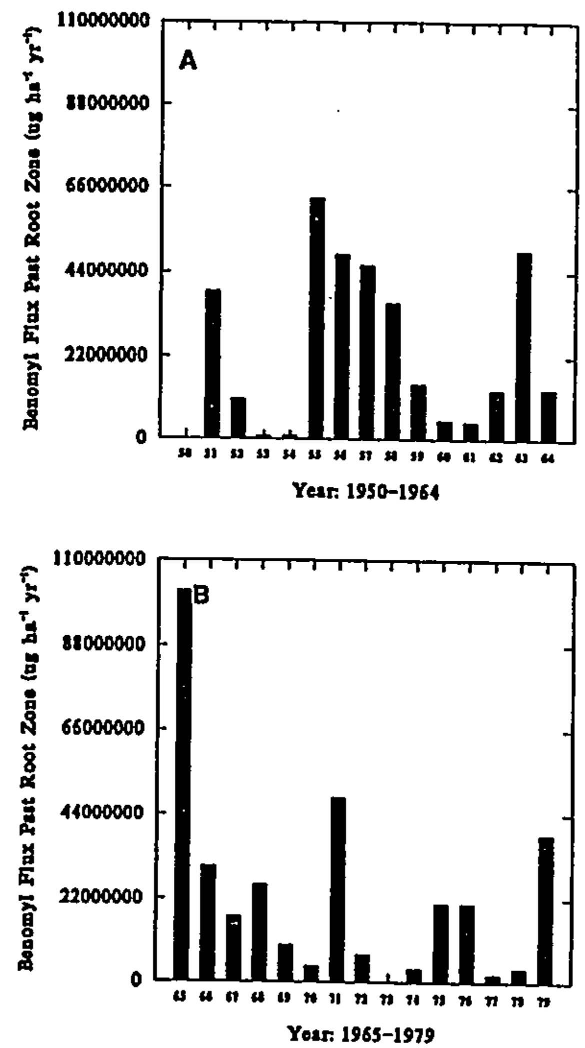


Figure B-67. Annual subsurface leaching of benomyl beneath the root zone of a simulated USGA Green at the Galbraith Trust Estate for (A) 1950-1964 and (B) 1965-1979.

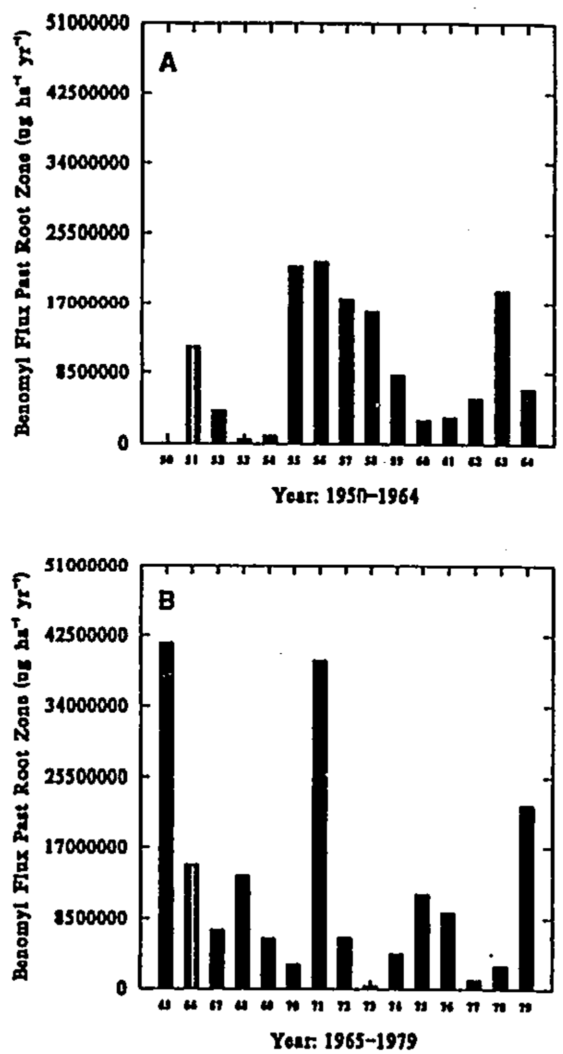


Figure B-68. Annual subsurface leaching of benomyl beneath the root zone of a simulated Wahiawa fairway soil at the Galbraith Trust Estate for (A) 1950-1964 and (B) 1965-1979.

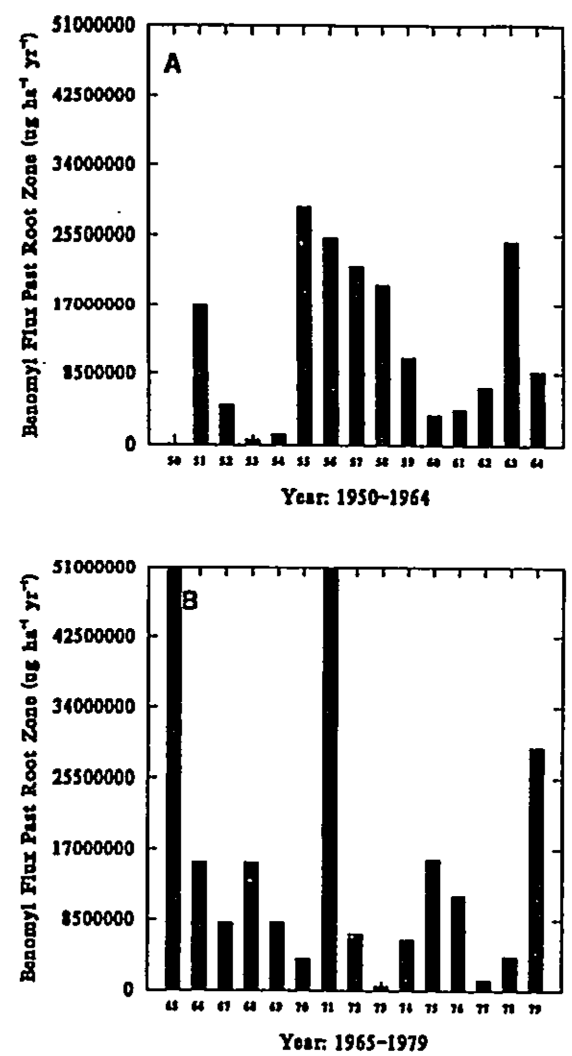


Figure B-69. Annual subsurface leaching of benomyl beneath the root zone of a simulated Kolekole fairway soil at the Galbraith Trust Estate for (A) 1950-1964 and (B) 1965-1979.

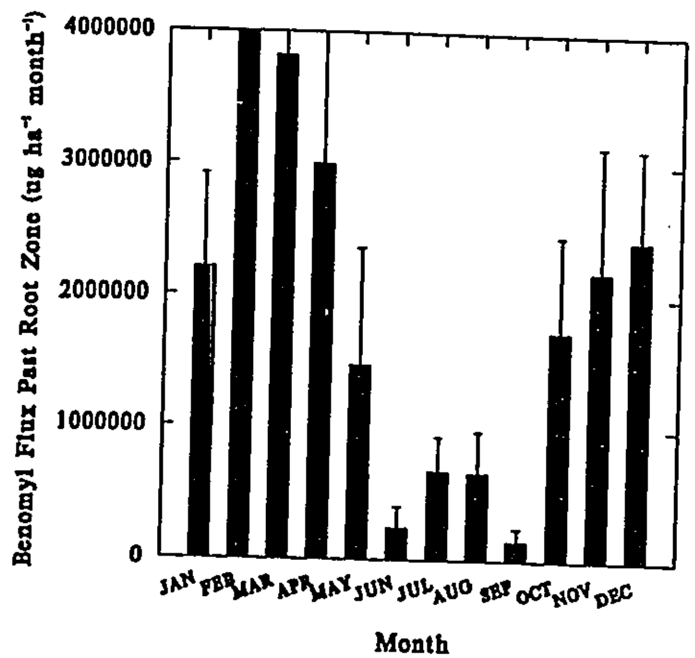


Figure B-70. Mean monthly subsurface movement of benomyl beneath the root zone of a simulated USGA Green at the Galbraith Trust Estate. Error bars represent one standard error.

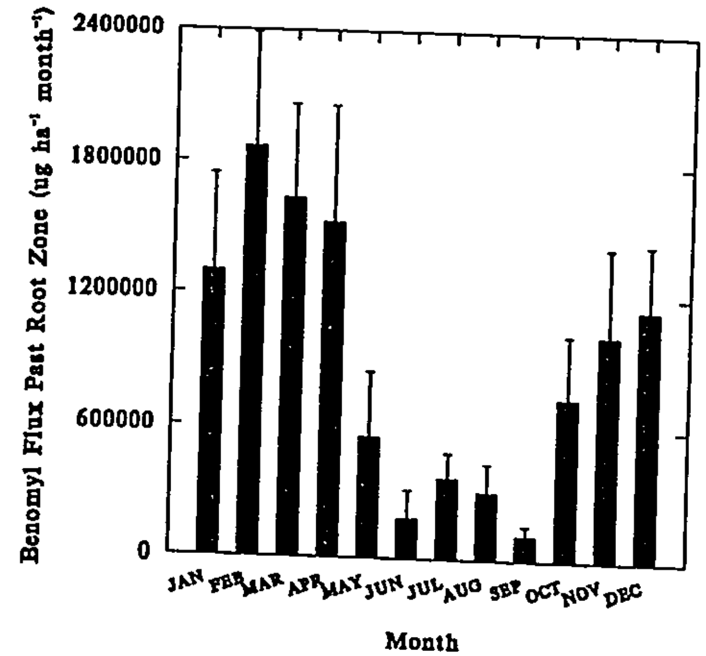


Figure B-71. Mean monthly subsurface movement of benomyl beneath the root zone of a simulated Wahiawa fairway soil at the Galbraith Trust Estate. Error bars represent one standard error.

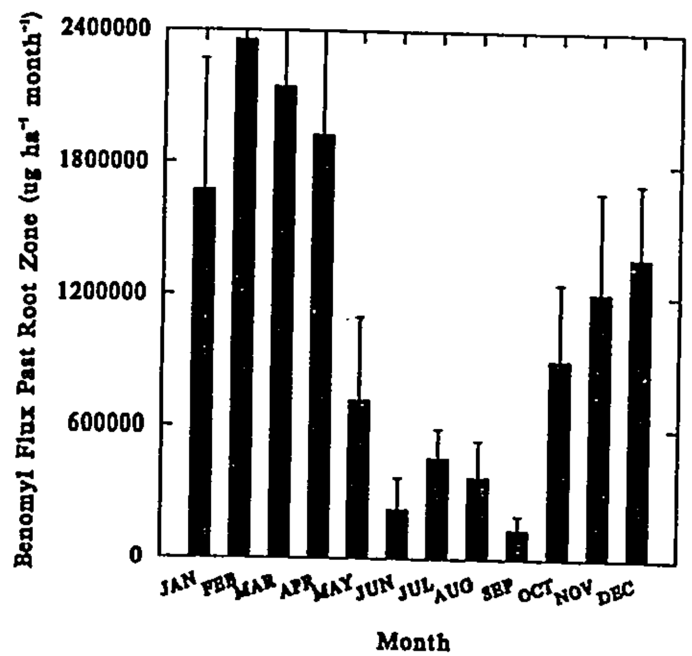


Figure B-72. Mean monthly subsurface movement of benomyl beneath the root zone of a simulated Kolekole fairway soil at the Galbraith Trust Estate. Error bars represent one standard error.

Table B-13. Monthly Concentration of Benomyl (ng L^{-1}) Beneath the Root Zone from a 30 Year Simulation of an Established USGA Green on the Proposed Galbraith Trust Estate.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	10110.00	10290.00	16300.00	15640.00
Mean	2268.22	2985.57	3545.70	4190.36
SD	2147.96	2591.04	3131.72	3700.46
Median	1525.00	2441.00	3489.50	3650.00
	May	June	July	August
Minimum	6.65E-7	5.56E-7	4.62E-7	4.25E-7
Maximum	14970.00	13570.00	11390.00	10020.00
Mean	4281.14	3724.37	3224.73	2878.75
SD	4035.33	3627.47	3129.95	2686.26
Median	3259.00	2718.00	2333.50	1942.50
	September	October	November	December
Minimum	0.01	0.01	0.00	0.05
Maximum	8330.00	8114.00	9401.00	10930.00
Mean	2477.73	2226.07	2232.31	2373.25
SD	2295.27	2161.27	2271.98	2296.17
Median	1619.00	1364.50	1230.00	1477.00

Table B-14. Monthly Concentration of Benomyl (ng L^{-1}) Beneath the Root Zone from a 30 Year Simulation of an Established Wahiawa Fairway Soil on the Proposed Galbraith Trust Estate.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	3478.00	3641.00	3618.00	5670.00
Mean	744.55	959.96	1069.85	1189.50
SD	680.44	860.74	868.75	942.38
Median	628.25	752.90	1009.50	1149.50
	May	June	July	August
Minimum	0.00	9.06E-4	7.53E-4	6.92E-4
Maximum	5470.00	4891.00	4498.00	3737.00
Mean	1192.13	1039.31	914.91	820.53
SD	1037.93	940.99	838.37	717.40
Median	1006.50	841.10	702.05	633.05
	September	October	November	December
Minimum	0.08	0.06	0.06	0.71
Maximum	3104.00	2594.00	3200.00	3762.00
Mean	708.35	652.84	686.04	753.44
SD	611.24	590.28	658.24	718.52
Median	530.45	455.05	452.75	487.55

Table B-15. Monthly Concentration of Benomyl (ng L^{-1}) Beneath the Root Zone from a 30 Year Simulation of an Established Kolekole Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	4585.00	5365.00	5219.00	7659.00
Mean	972.13	1282.91	1437.90	1611.89
SD	843.01	1150.34	1172.05	1309.91
Median	922.10	1049.00	1299.50	1564.00
	May	June	July	August
Minimum	0.003	0.003	0.002	0.002
Maximum	7389.00	6448.00	5930.00	4926.00
Mean	1605.39	1396.20	1226.07	1097.07
SD	1418.40	1275.47	1125.00	957.30
Median	1413.00	1192.00	1014.50	893.75
	September	October	November	December
Minimum	0.20	0.16	0.15	1.77
Maximum	4093.00	3437.00	3860.00	4398.00
Mean	946.09	865.49	895.01	975.50
SD	815.53	784.31	842.29	882.68
Median	752.35	646.15	589.20	691.20

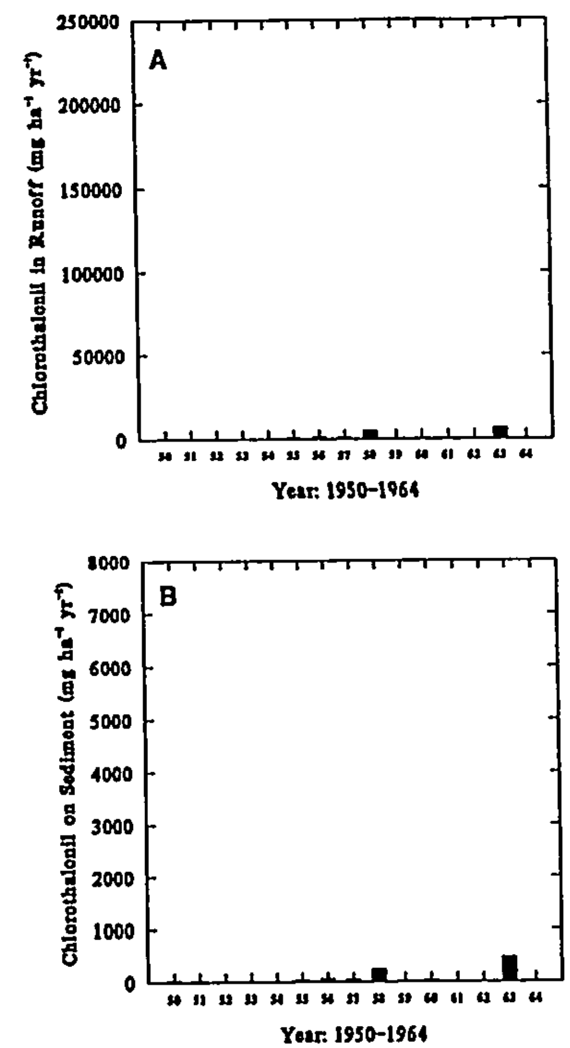


Figure B-73a. Annual surface loss of chlorothalonil in runoff (A) water and (B) sediment from a simulated USGA Green at the Galbraith Trust Estate: 1950-1964.

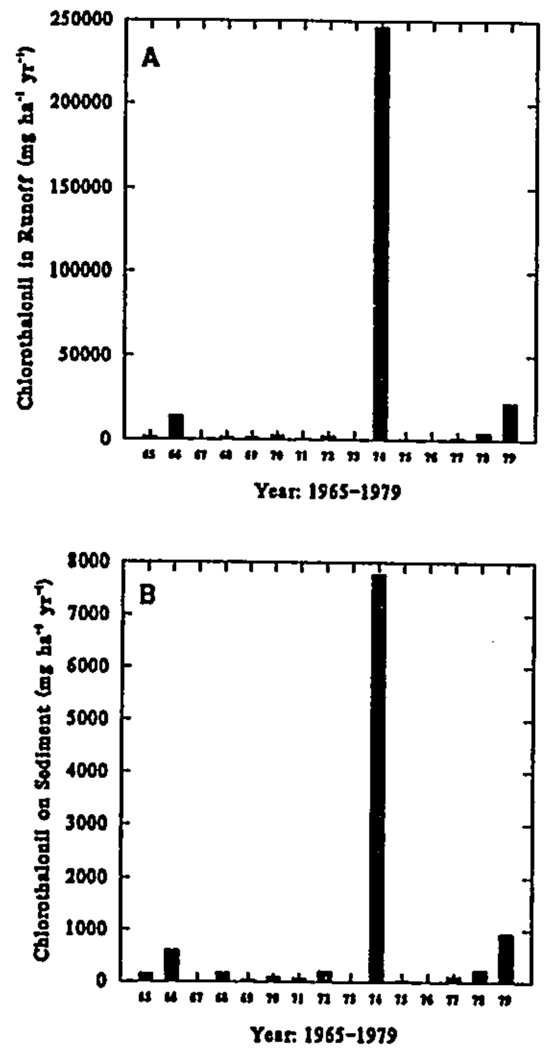


Figure B-73b. Annual surface loss of chlorothalonil in runoff (A) water and (B) sediment from a simulated USGA Green at the Galbraith Trust Estate: 1965-1979.

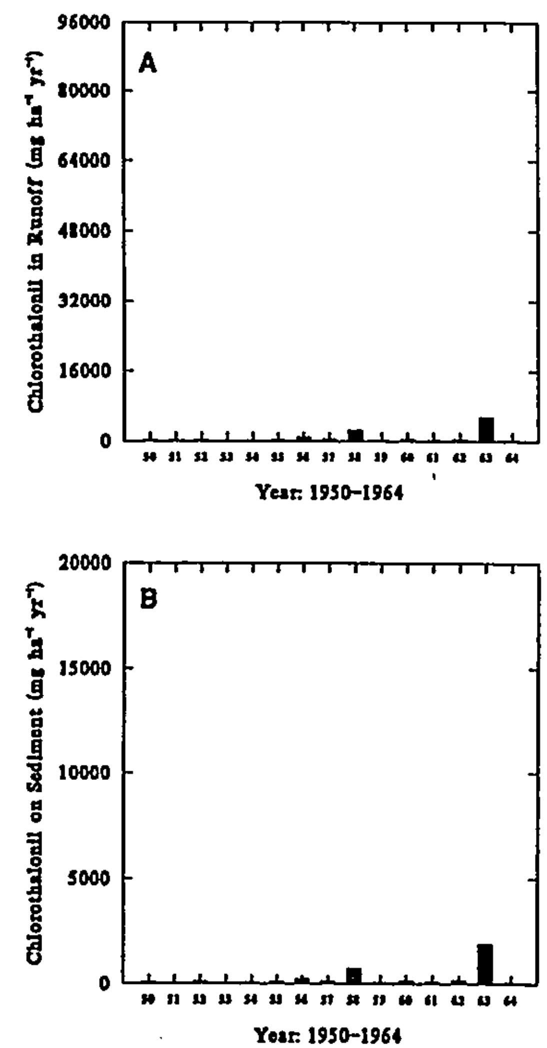


Figure B-74a. Annual surface loss of chlorothalonil in runoff (A) water and (B) sediment from a simulated Wahiawa fairway soil at the Galbraith Trust Estate: 1950-1964.

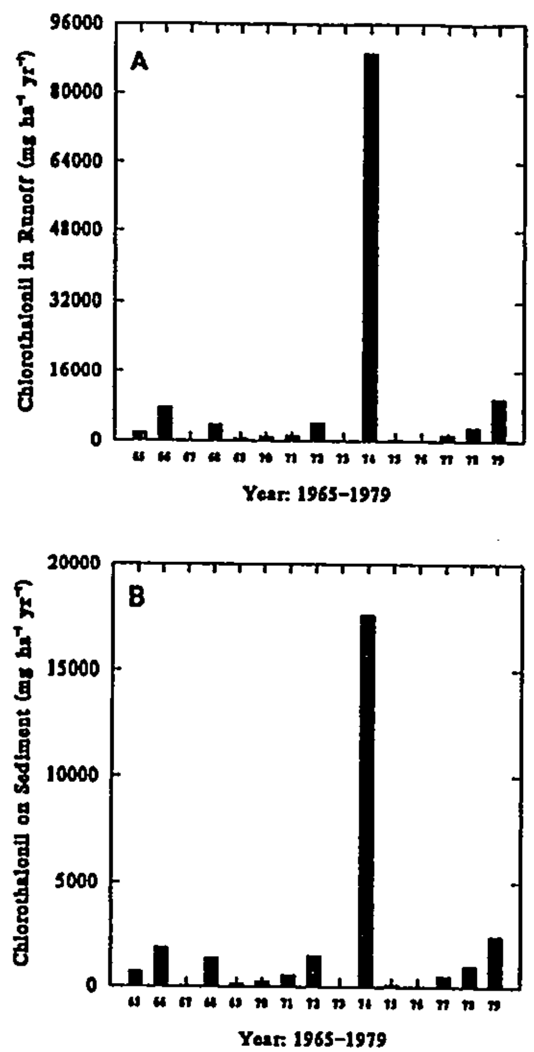


Figure B-74b. Annual surface loss of chlorothalonil in runoff (A) water and (B) sediment from a simulated Wahiawa fairway soil at the Galbraith Trust Estate: 1965-1979.

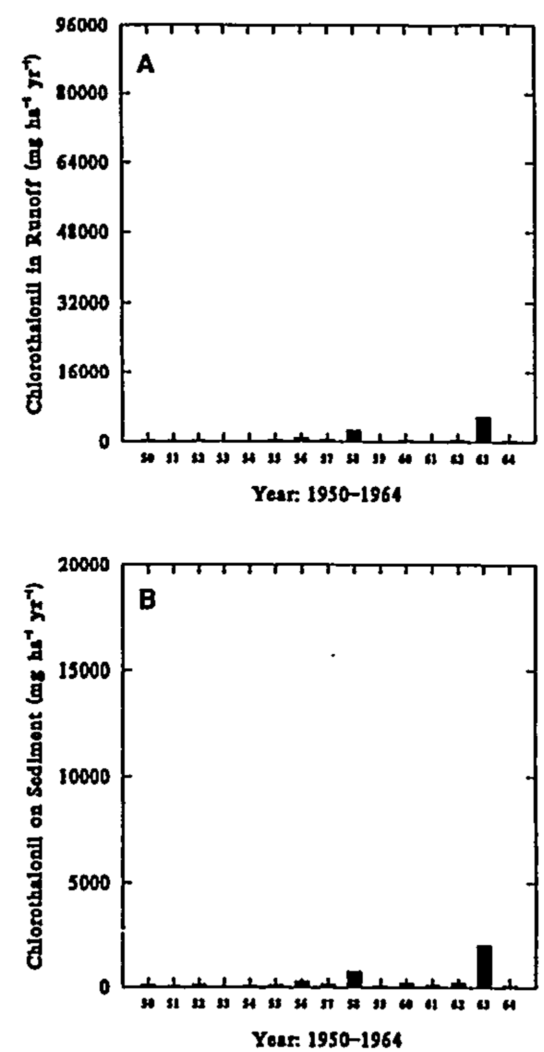


Figure B-75a. Annual surface loss of chlorothalonil in runoff (A) water and (B) sediment from a simulated Kolekole fairway soil at the Galbraith Trust Estate: 1950-1964.

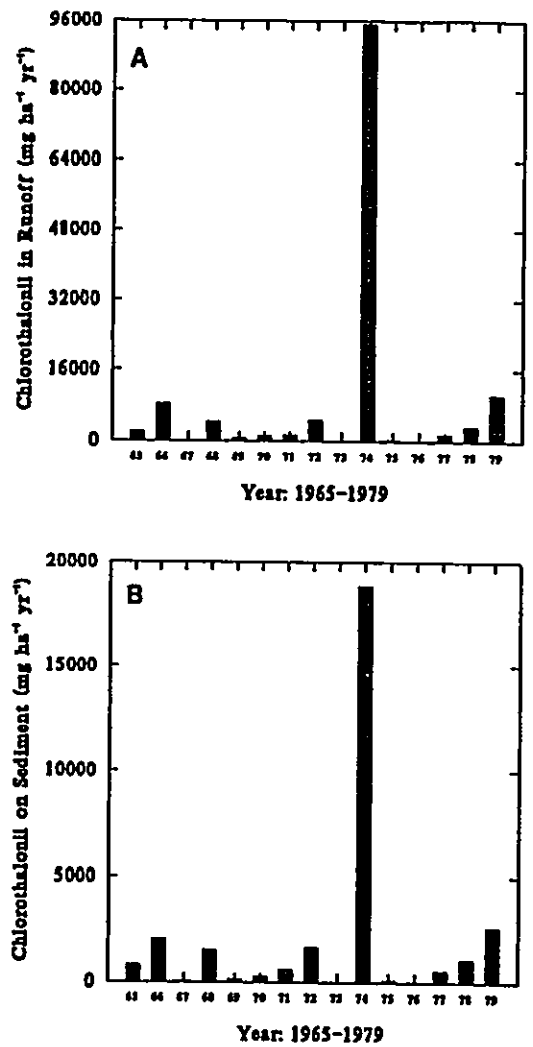


Figure B-75b. Annual surface loss of chlorothalonil in runoff (A) water and (B) sediment from a simulated Kolekole fairway soil at the Galbraith Trust Estate: 1965-1979.

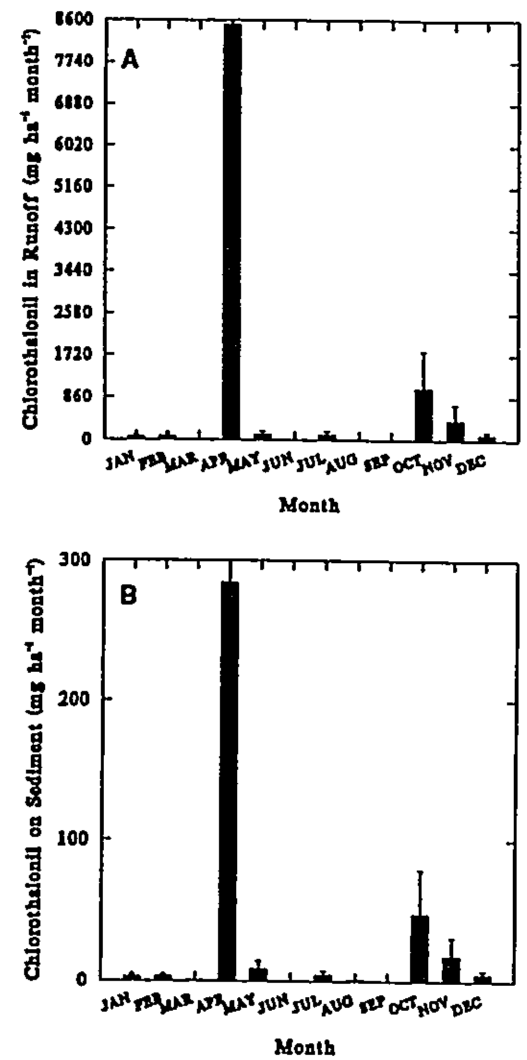


Figure B-76. Mean monthly loss of chlorothalonil in runoff (A) water and (B) sediment from a simulated USGA Green at the Galbraith Trust Estate. Error bars represent one standard error.

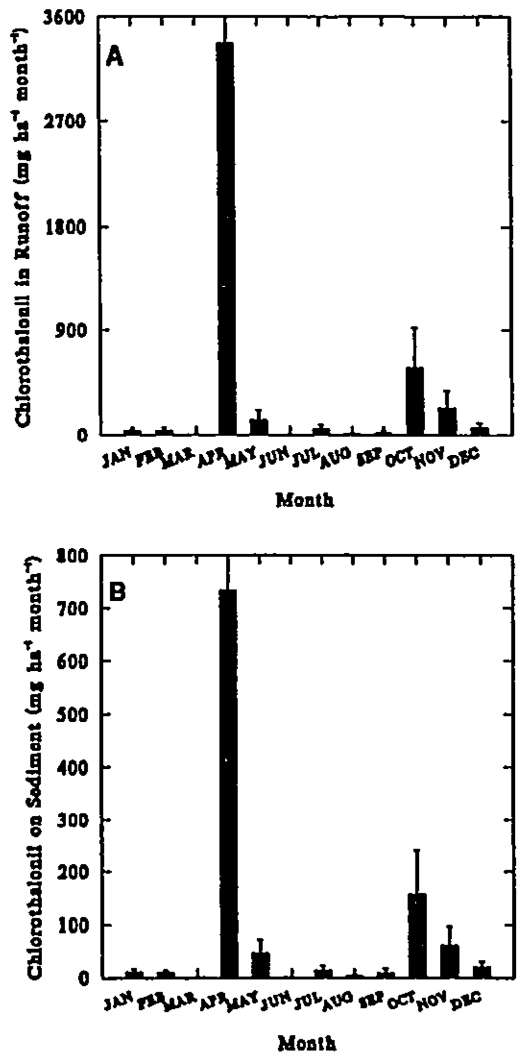


Figure B-77. Mean monthly loss of chlorothalonil in runoff (A) water and (B) sediment from a simulated Wahiawa fairway soil at the Galbraith Trust Estate. Error bars represent one standard error.

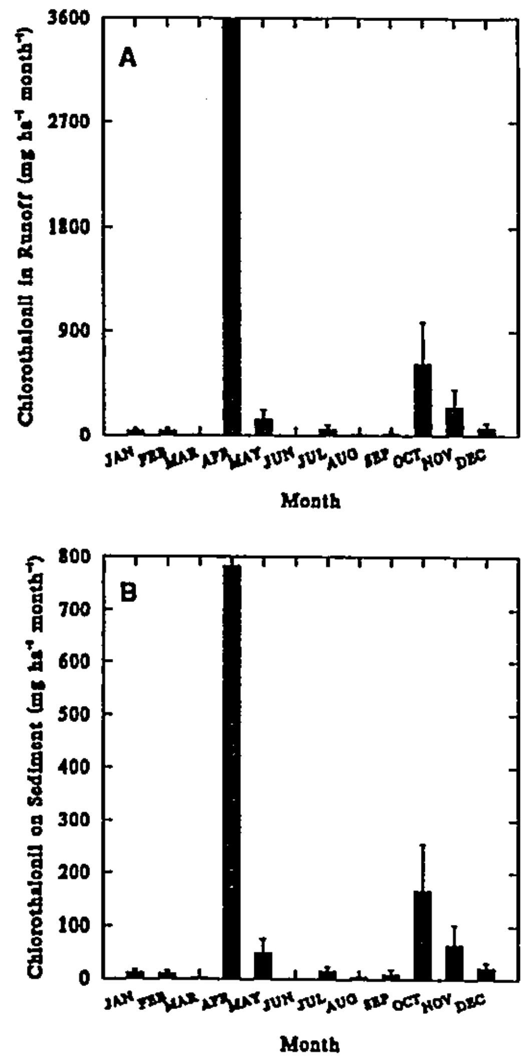


Figure B-78. Mean monthly loss of chlorothalonil in runoff (A) water and (B) sediment from a simulated Kolekole fairway soil at the Galbraith Trust Estate. Error bars represent one standard error.

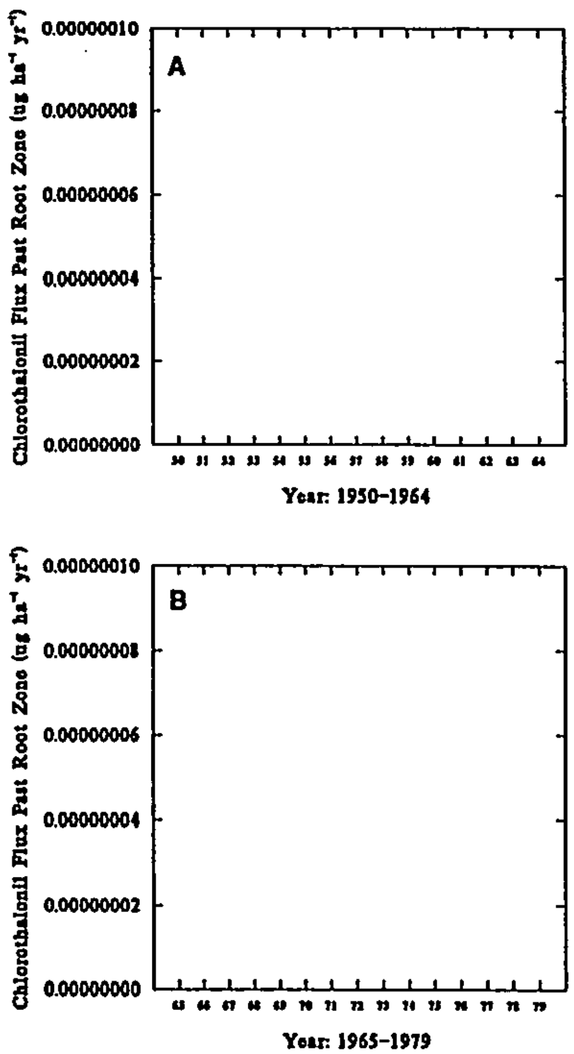


Figure B-79. Annual subsurface leaching of chlorothalonil beneath the root zone of a simulated USGA Green at the Galbraith Trust Estate for (A) 1950-1964 and (B) 1965-1979.

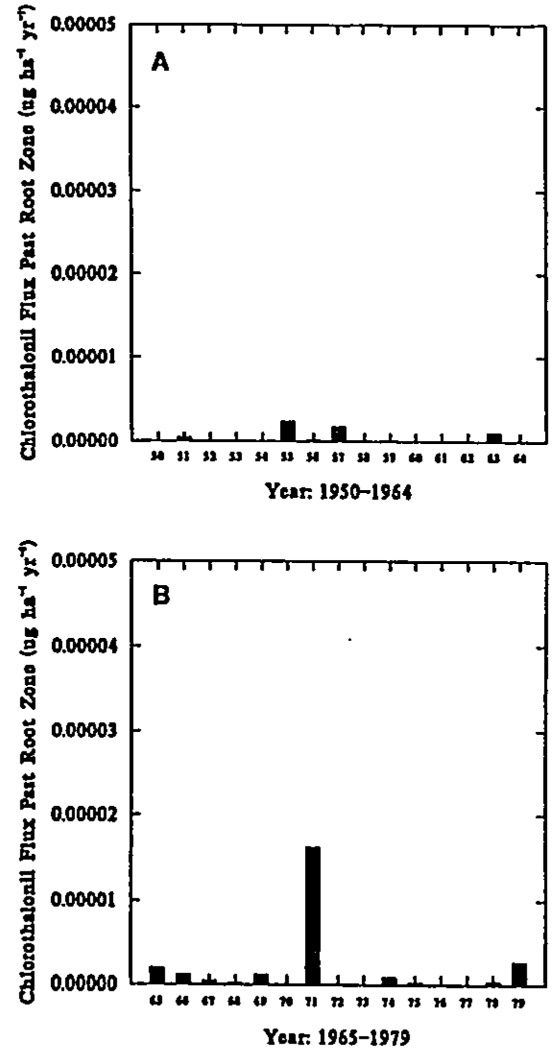


Figure B-80. Annual subsurface leaching of chlorothalonil beneath the root zone of a simulated Wahiawa fairway soil at the Galbraith Trust Estate for (A) 1950-1964 and (B) 1965-1979.

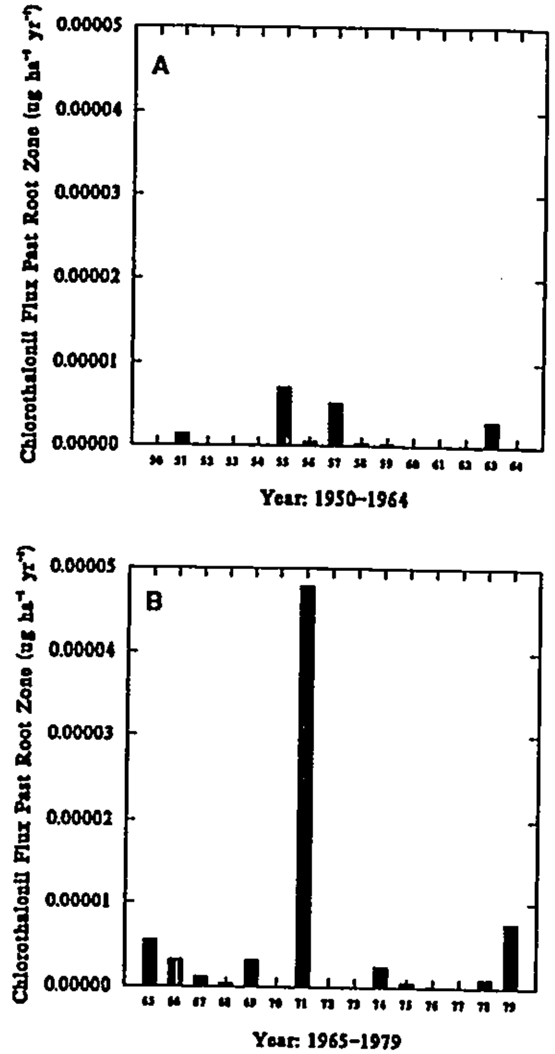


Figure B-81. Annual subsurface leaching of chlorothalonil beneath the root zone of a simulated Kolekole fairway soil at the Galbraith Trust Estate for (A) 1950-1964 and (B) 1965-1979.

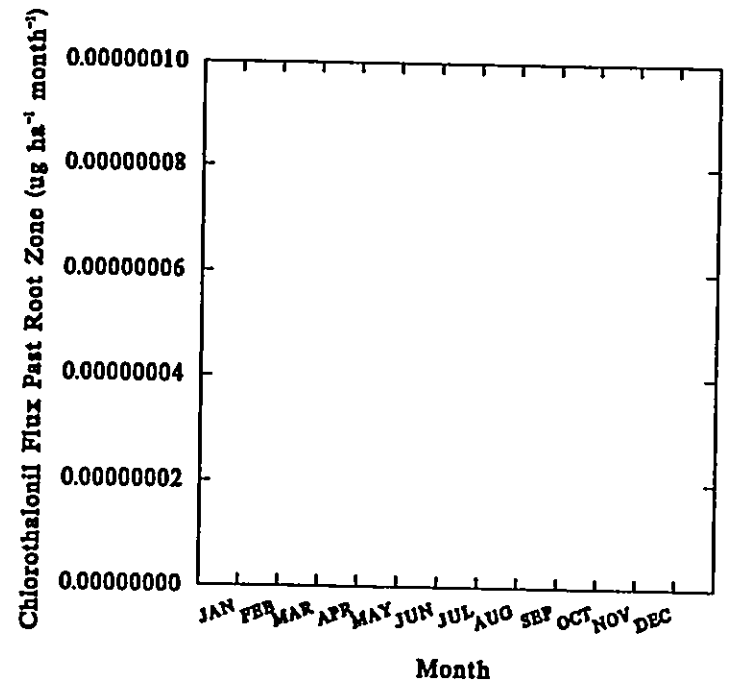


Figure B-82. Mean monthly subsurface movement of chlorothalonil beneath the root zone of a simulated USGA Green at the Galbraith Trust Estate. Error bars represent one standard error.

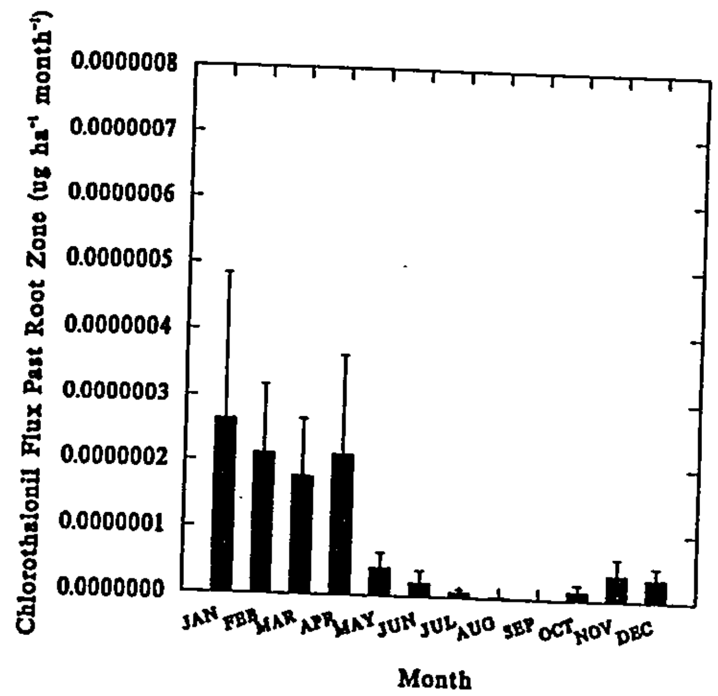


Figure B-83. Mean monthly subsurface movement of chlorothalonil beneath the root zone of a simulated Wahiawa fairway soil at the Galbraith Trust Estate. Error bars represent one standard error.

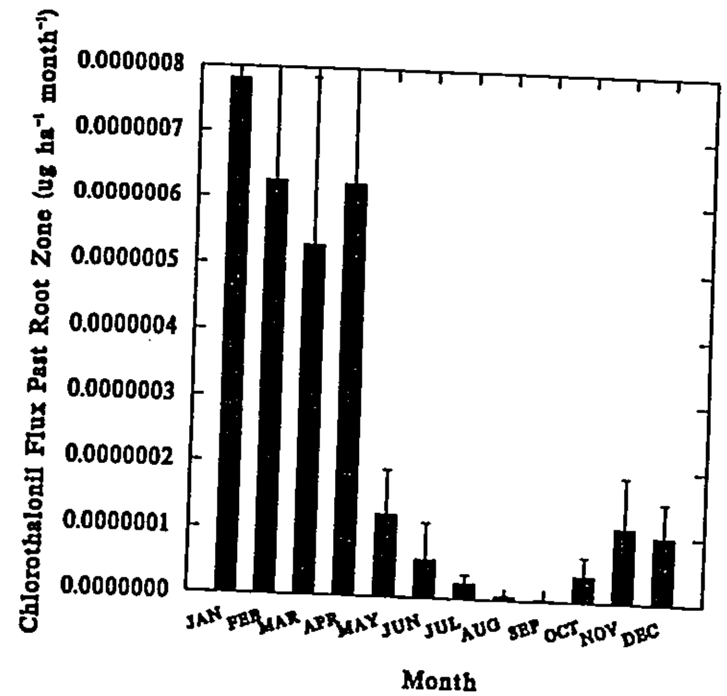


Figure B-84. Mean monthly subsurface movement of chlorothalonil beneath the root zone of a simulated Kolekole fairway soil at the Galbraith Trust Estate. Error bars represent one standard error.

Table 3.7-65. Monthly Concentration of Chlorothalinol (ng L[-1])[1] Beneath the Root Zone from a 30 Year Simulation of an Established USGA Green on the Proposed Galbraith Trust.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	0.00	0.00
Mean	0.00	0.00	0.00	0.00
SD	0.00	0.00	0.00	0.00
Median	0.00	0.00	0.00	0.00
	May	**June**	**July**	**August**
Minimum	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	0.00	0.00
Mean	0.00	0.00	0.00	0.00
SD	0.00	0.00	0.00	0.00
Median	0.00	0.00	0.00	0.00
	September	**October**	**November**	**December**
Minimum	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	0.00	0.00
Mean	0.00	0.00	0.00	0.00
SD	0.00	0.00	0.00	0.00
Median	0.00	0.00	0.00	0.00

Table 3.7-66. Monthly Concentration of Chlorothalinol (ng L[-1]) Beneath the Root Zone from a 30 Year Simulation of an Established Wahiawa Fairway Soil on the Proposed Galbraith Trust Estate.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	1.27E-10	1.66E-10	8.58E-11	1.20E-10
Mean	1.66E-12	5.81E-12	4.38E-12	4.62E-12
SD	9.03E-12	2.20E-11	1.26E-11	1.32E-11
Median	3.87E-14	4.97E-14	1.10E-13	1.38E-13
	May	**June**	**July**	**August**
Minimum	8.48E-18	3.60E-18	1.48E-18	0.00
Maximum	1.01E-10	4.45E-11	2.70E-11	1.11E-11
Mean	4.07E-12	2.06E-12	1.05E-12	4.94E-13
SD	1.28E-11	6.43E-12	3.40E-12	1.42E-12
Median	1.35E-13	5.67E-14	3.64E-14	4.45E-14
	September	**October**	**November**	**December**
Minimum	9.04E-18	7.76E-18	3.59E-18	2.03E-18
Maximum	4.58E-12	6.49E-12	1.19E-11	1.12E-11
Mean	2.16E-13	1.99E-13	5.61E-13	6.58E-13
SD	5.93E-13	7.20E-13	1.85E-12	1.83E-12
Median	2.31E-14	1.20E-14	7.05E-13	3.31E-14

Table 3.7-67. Monthly Concentration of Chlorothalinol (ng L[-1]) Beneath the Root Zone from a 30 Year Simulation of an Established Kolekole Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	4.49E-10	5.88E-10	3.03E-10	4.21E-10
Mean	5.86E-12	2.05E-11	1.55E-11	1.63E-11
SD	3.20E-11	7.78E-11	4.47E-11	4.65E-11
Median	1.37E-13	1.76E-13	3.87E-13	4.87E-13
	May	**June**	**July**	**August**
Minimum	3.09E-17	1.31E-17	5.40E-18	3.62E-18
Maximum	3.55E-10	1.56E-10	9.46E-11	3.90E-11
Mean	1.43E-11	7.26E-12	3.70E-12	1.74E-12
SD	4.49E-11	2.26E-11	1.19E-11	5.00E-12
Median	4.80E-13	2.01E-13	1.29E-13	1.57E-13
	September	**October**	**November**	**December**
Minimum	3.25E-17	2.80E-17	1.30E-17	7.31E-18
Maximum	1.61E-11	2.30E-11	4.22E-11	3.94E-11
Mean	7.62E-13	7.02E-13	1.99E-12	2.33E-12
SD	2.08E-12	2.55E-12	6.55E-12	6.45E-12
Median	8.10E-14	4.28E-14	2.50E-14	1.18E-13

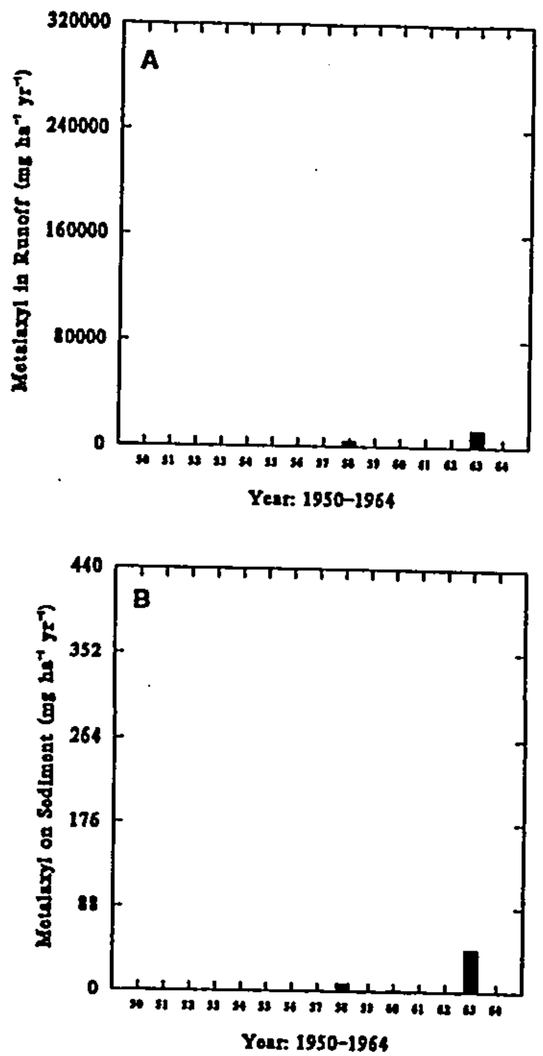


Figure B-85a. Annual surface loss of metalaxyl in runoff (A) water and (B) sediment from a simulated USGA Green at the Galbraith Trust Estate: 1950-1964.

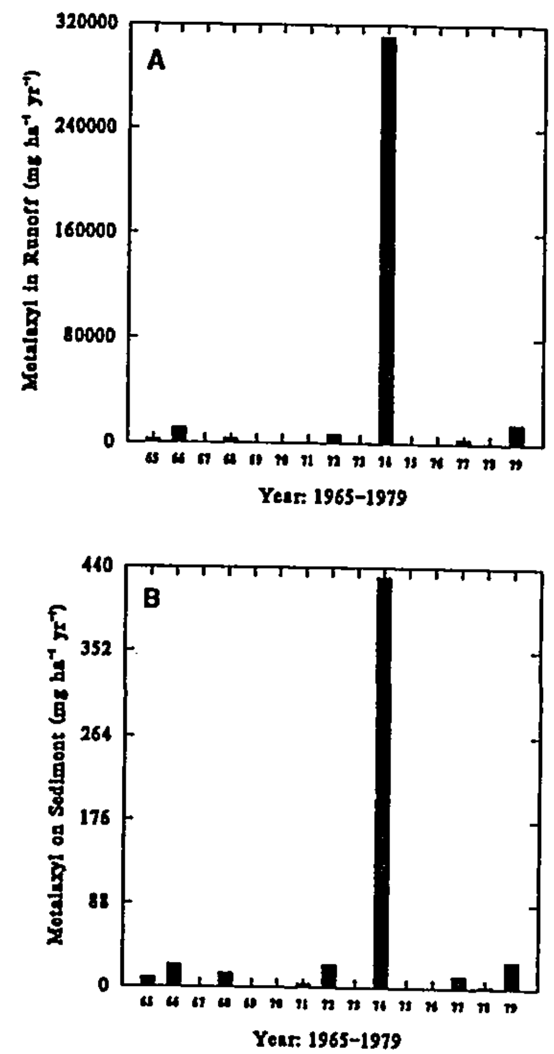


Figure B-85b. Annual surface loss of metalaxyl in runoff (A) water and (B) sediment from a simulated USGA Green at the Galbraith Trust Estate: 1965-1979.

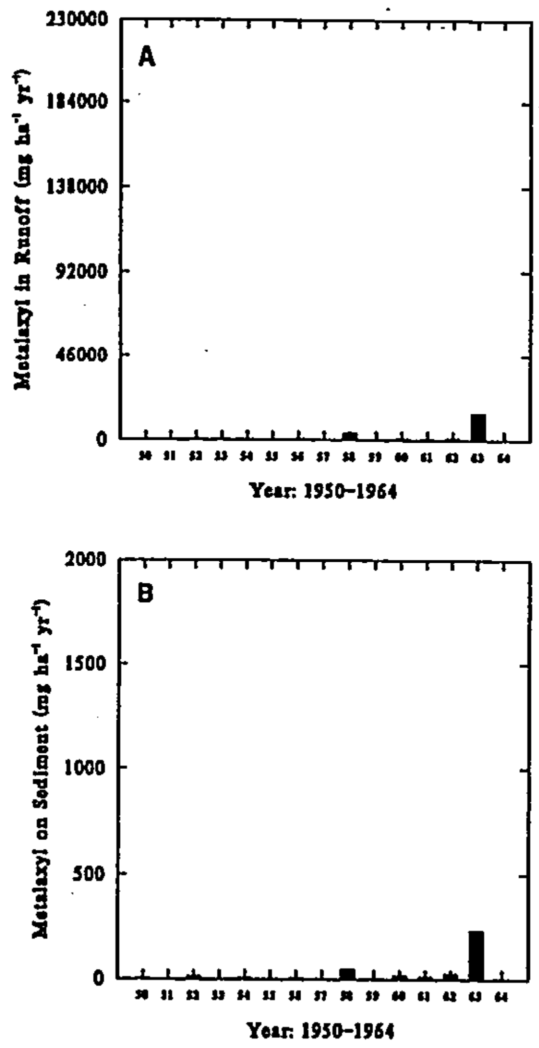


Figure B-86a. Annual surface loss of metalaxyl in runoff (A) water and (B) sediment from a simulated Wahiawa fairway soil at the Galbraith Trust Estate: 1950-1964.

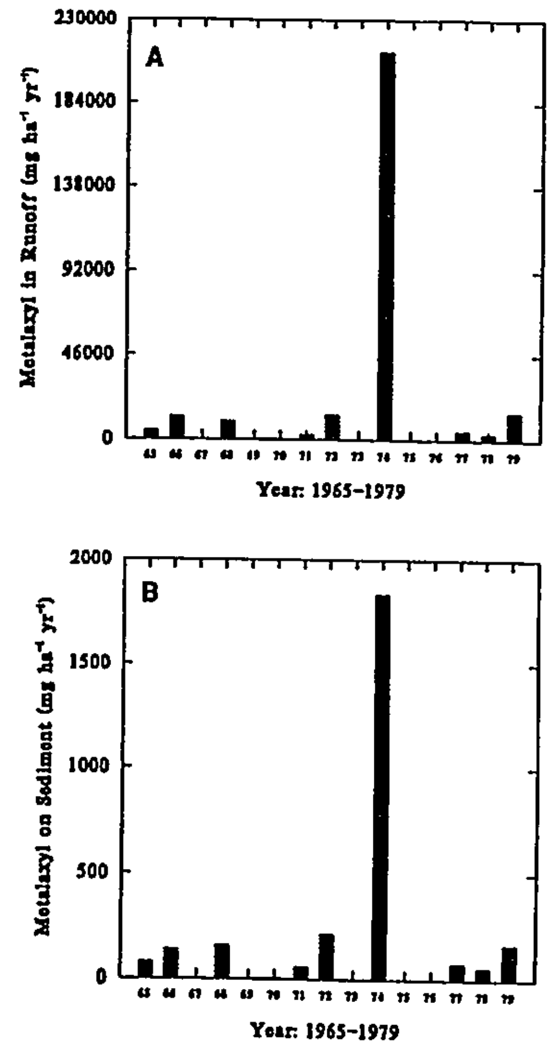


Figure B-86b. Annual surface loss of metalaxyl in runoff (A) water and (B) sediment from a simulated Wahiawa fairway soil at the Galbraith Trust Estate: 1965-1979.

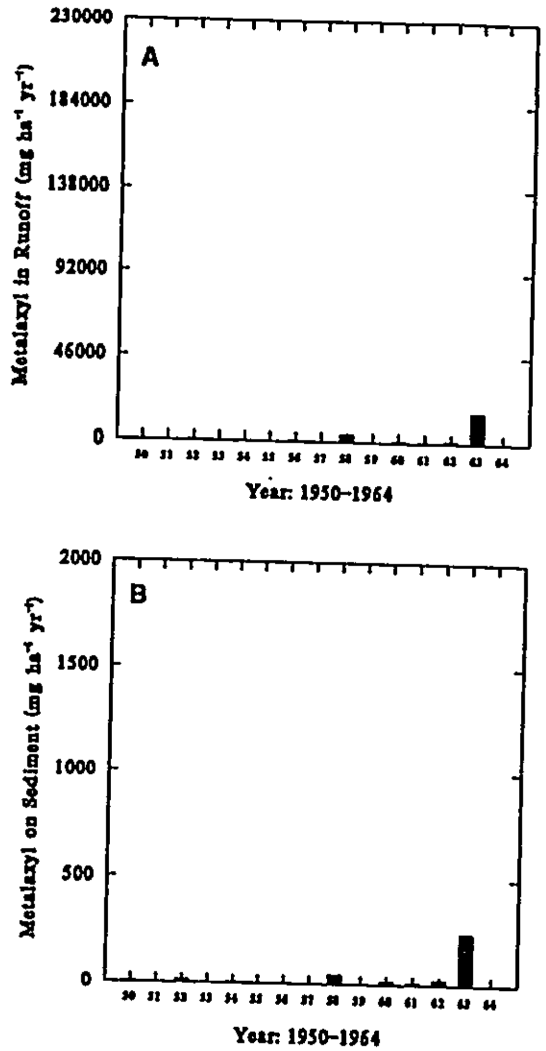


Figure B-87a. Annual surface loss of metalaxyl in runoff (A) water and (B) sediment from a simulated Kolekole fairway soil at the Galbraith Trust Estate: 1950-1964.

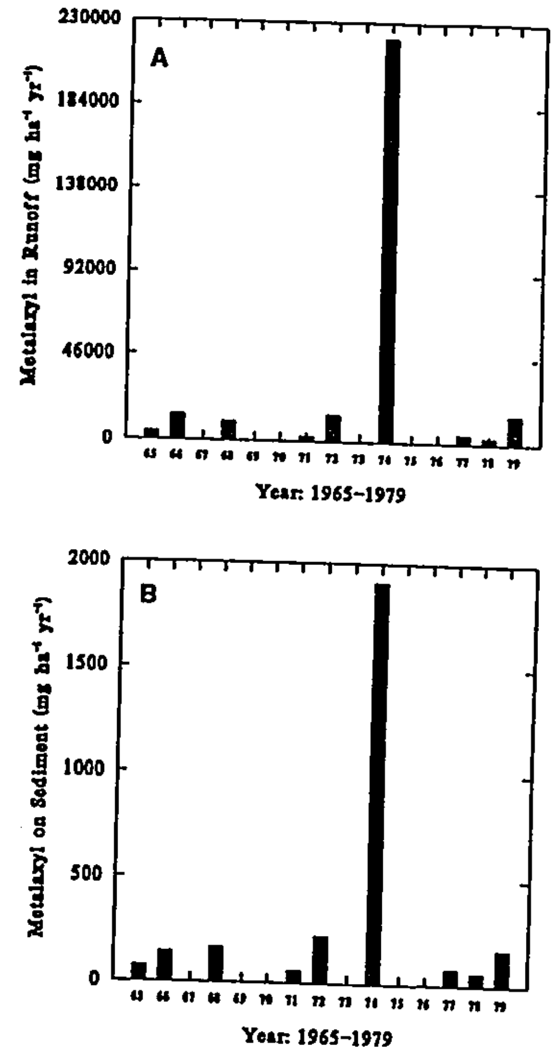


Figure B-87b. Annual surface loss of metalaxyl in runoff (A) water and (B) sediment from a simulated Kolekole fairway soil at the Galbraith Trust Estate: 1965-1979.

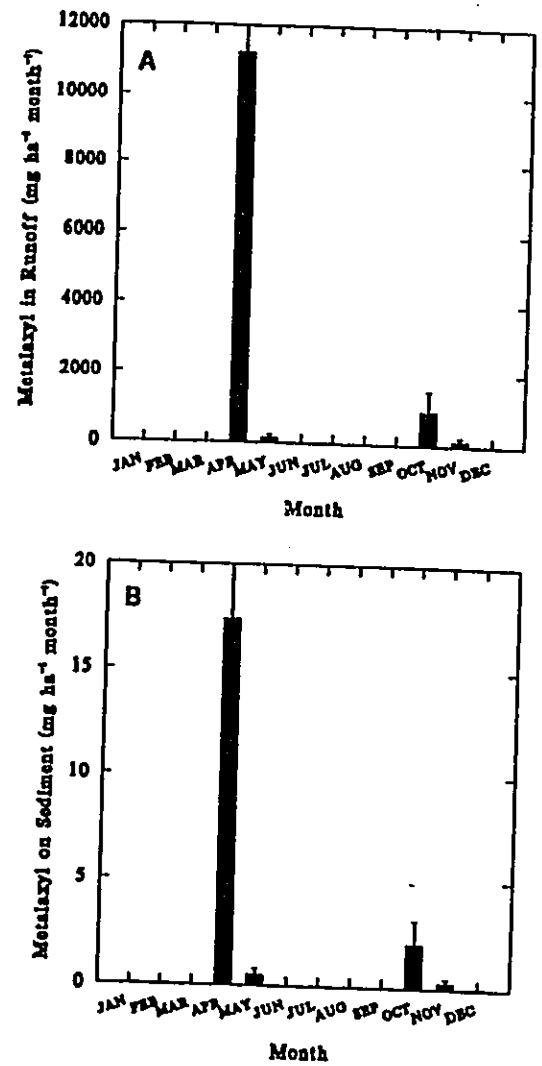


Figure B-88. Mean monthly loss of metalaxyl in runoff (A) water and (B) sediment from a simulated USGA Green at the Galbraith Trust Estate. Error bars represent one standard error.

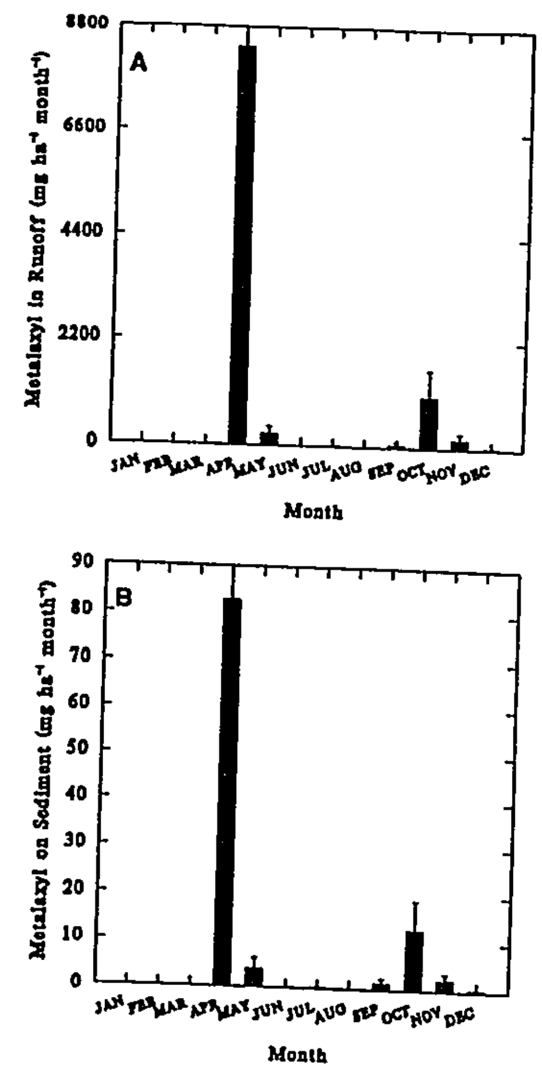


Figure B-89. Mean monthly loss of metalaxyl in runoff (A) water and (B) sediment from a simulated Wahiawa fairway soil at the Galbraith Trust Estate. Error bars represent one standard error.

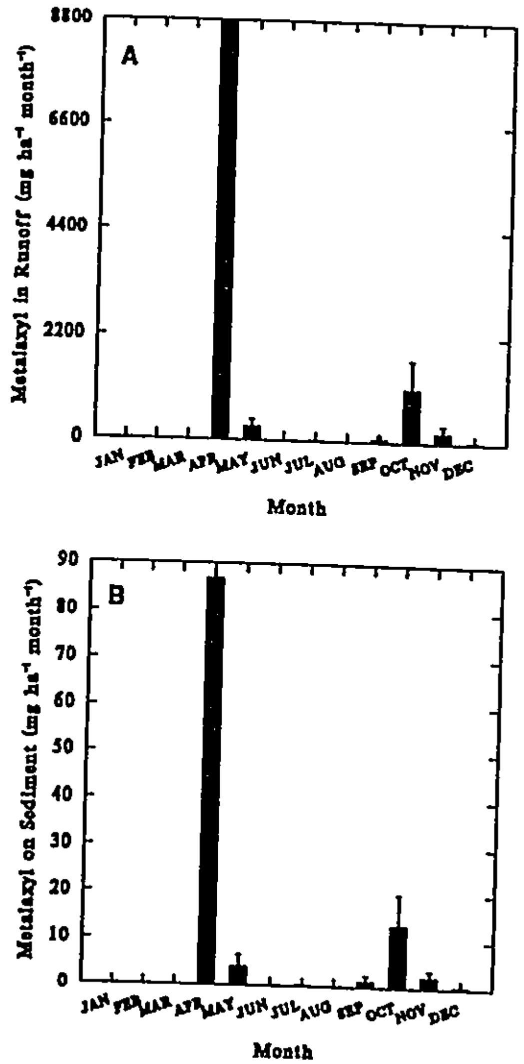


Figure B-90. Mean monthly loss of metalaxyl in runoff (A) water and (B) sediment from a simulated Kolekole fairway soil at the Galbraith Trust Estate. Error bars represent one standard error.

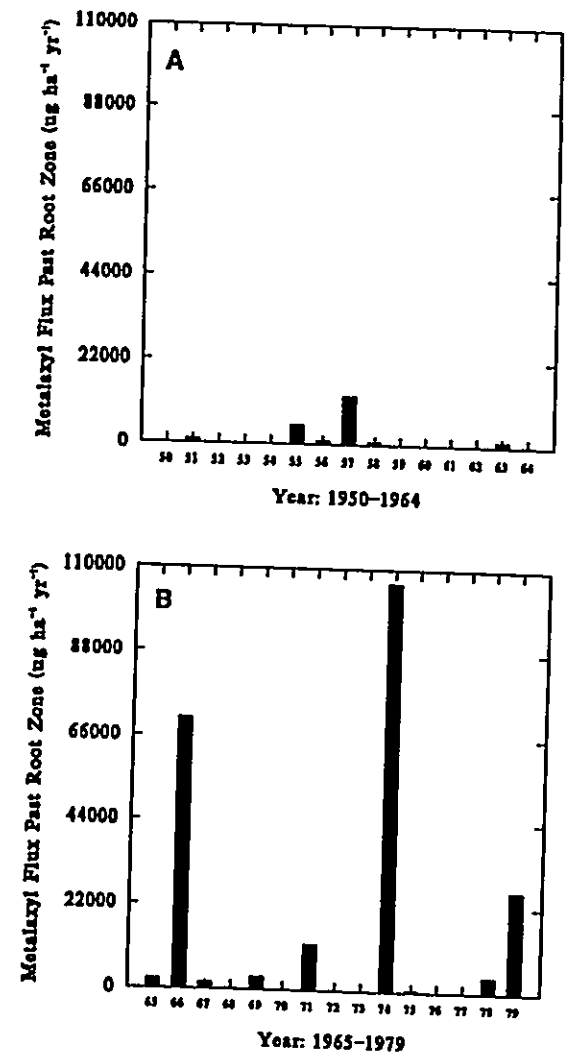


Figure B-91. Annual subsurface leaching of metalaxyl beneath the root zone of a simulated USGA Green at the Galbraith Trust Estate for (A) 1950-1964 and (B) 1965-1979.

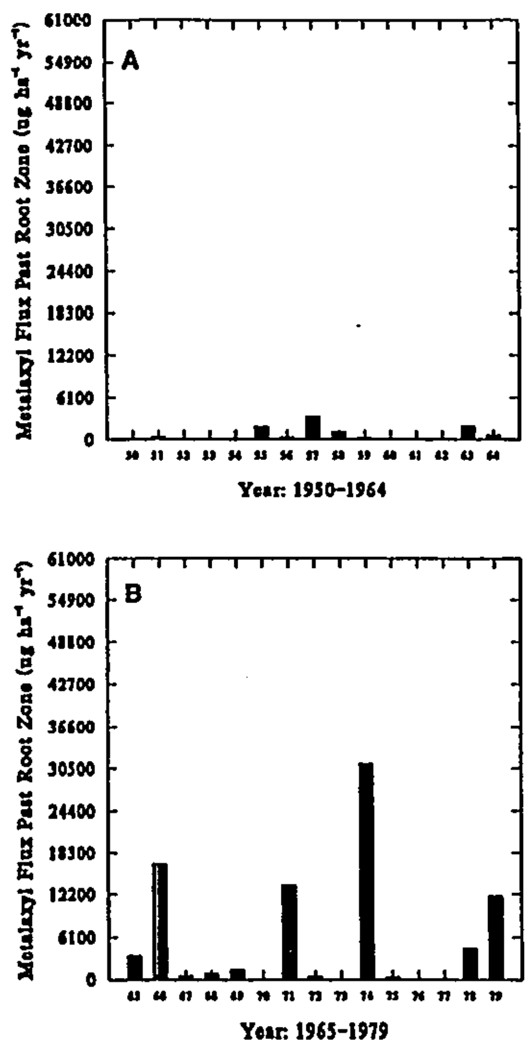


Figure B-92. Annual subsurface leaching of metalaxyl beneath the root zone of a simulated Wahiawa fairway soil at the Galbraith Trust Estate for (A) 1950-1964 and (B) 1965-1979.

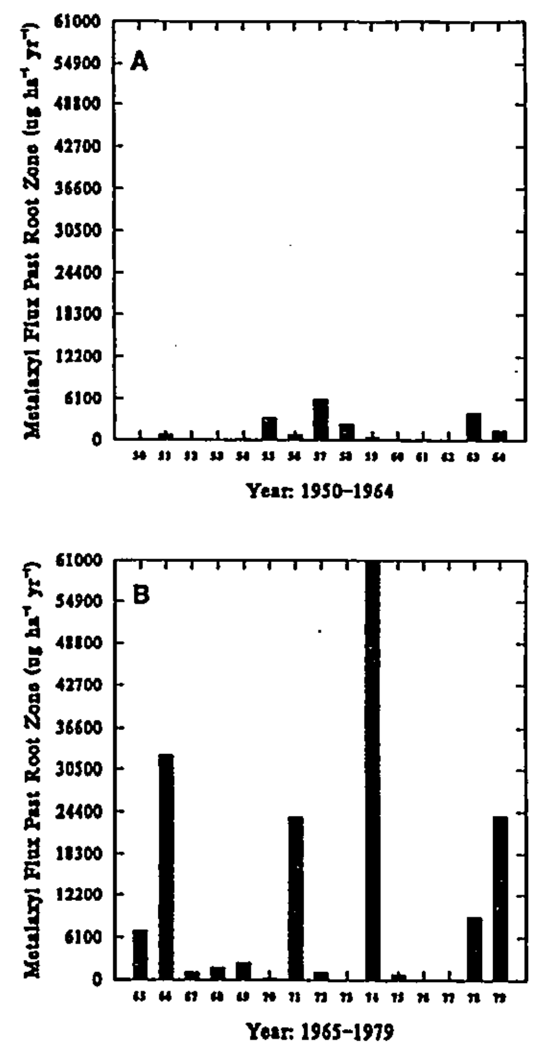


Figure B-93. Annual subsurface leaching of metalaxyl beneath the root zone of a simulated Kolekole fairway soil at the Galbraith Trust Estate for (A) 1950-1964 and (B) 1965-1979.

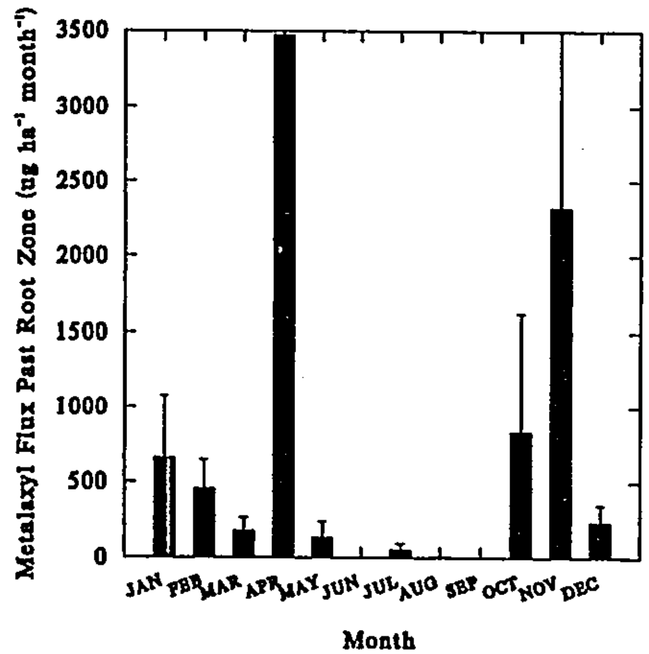


Figure B-94. Mean monthly subsurface movement of metalaxyl beneath the root zone of a simulated USGA Green at the Galbraith Trust Estate. Error bars represent one standard error.

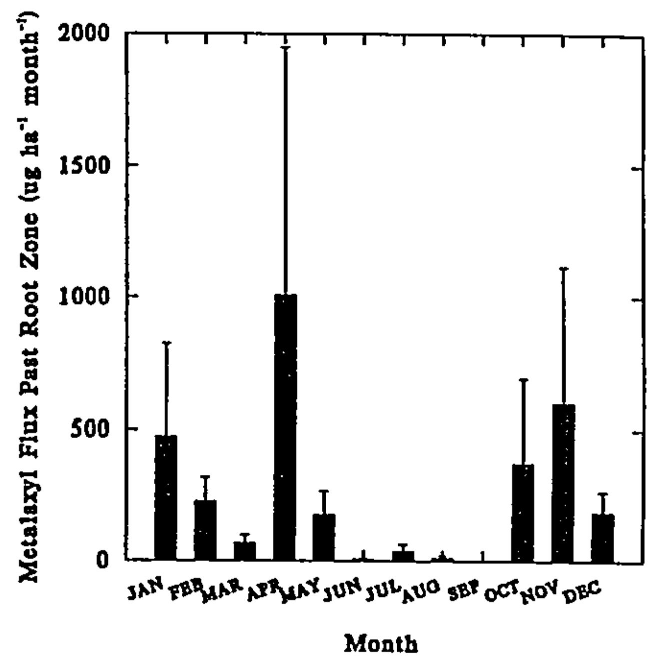


Figure B-95. Mean monthly subsurface movement of metalaxyl beneath the root zone of a simulated Wahiawa fairway soil at the Galbraith Trust Estate. Error bars represent one standard error.

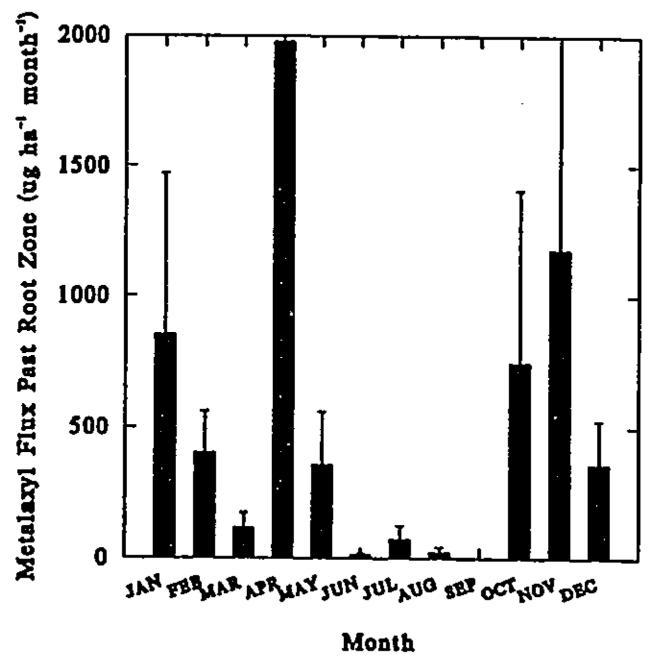


Figure B-96. Mean monthly subsurface movement of metalaxyl beneath the root zone of a simulated Kolekole fairway soil at the Galbraith Trust Estate. Error bars represent one standard error.

Table B-19. Monthly Concentration of Metalaxyl (ng L^{-1})[1] Beneath the Root Zone from a 30 Year Simulation of an Established USGA Green on the Proposed Galbraith Trust.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	5.42	6.21	1.61	70.51
Mean	0.22	0.32	0.14	0.85
SD	0.78	0.85	0.29	6.81
Median	2.64E-04	2.50E-04	3.42E-04	2.31E-04
	May	**June**	**July**	**August**
Minimum	7.02E-09	2.28E-09	4.75E-10	9.88E-11
Maximum	45.02	10.50	2.30	1.04
Mean	0.85	0.20	0.06	0.02
SD	4.69	1.08	0.29	0.11
Median	8.28E-04	1.81E-04	1.02E-04	1.38E-04
	September	**October**	**November**	**December**
Minimum	3.59E-11	1.26E-10	8.42E-11	8.01E-11
Maximum	0.22	19.02	38.22	14.49
Mean	5.44E-03	0.24	0.88	0.37
SD	0.02	1.76	4.33	1.51
Median	4.92E-05	2.09E-05	1.89E-05	2.12E-04

Table B-20. Monthly Concentration of Metalaxyl (ng L^{-1}) Beneath the Root Zone from a 30 Year Simulation of an Established Wahiawa Fairway Soil on the Proposed Galbraith Trust Estate.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	2.22	2.40	0.64	7.85
Mean	0.06	0.08	0.03	0.10
SD	0.21	0.26	0.07	0.72
Median	1.38E-04	1.33E-04	1.18E-04	1.10E-04
	May	**June**	**July**	**August**
Minimum	5.55E-08	2.00E-08	5.64E-09	2.82E-09
Maximum	4.98	1.31	0.41	0.20
Mean	0.12	0.03	0.01	6.25E-03
SD	0.53	0.14	0.05	0.02
Median	9.66E-04	2.50E-04	1.61E-04	1.01E-04
	September	**October**	**November**	**December**
Minimum	6.17E-10	4.45E-09	1.36E-09	4.94E-10
Maximum	0.04	3.05	3.71	1.50
Mean	1.60E-03	0.04	0.10	0.06
SD	5.28E-03	0.28	0.44	0.18
Median	3.83E-05	2.75E-05	7.80E-05	3.31E-04

Table B-21. Monthly Concentration of Metalaxyl (ng L⁻¹) Beneath the Root Zone from a 30 Year Simulation of an Established Kolekole Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	4.21	4.48	1.18	17.17
Mean	0.12	0.15	0.06	0.22
SD	0.41	0.49	0.14	1.58
Median	3.16E-04	2.68E-04	2.56E-04	2.55E-04
	May	June	July	August
Minimum	0.00	4.56E-08	1.28E-08	5.90E-09
Maximum	10.88	2.87	0.89	0.44
Mean	0.26	0.07	0.03	0.01
SD	1.17	0.31	0.10	0.05
Median	2.33E-03	5.87E-04	3.78E-04	2.29E-04
	September	October	November	December
Minimum	1.29E-09	0.00	3.47E-08	1.26E-09
Maximum	0.09	6.86	8.00	3.23
Mean	3.69E-03	0.09	0.23	0.13
SD	0.01	0.64	0.96	0.39
Median	9.17E-05	7.18E-05	1.90E-04	7.96E-04

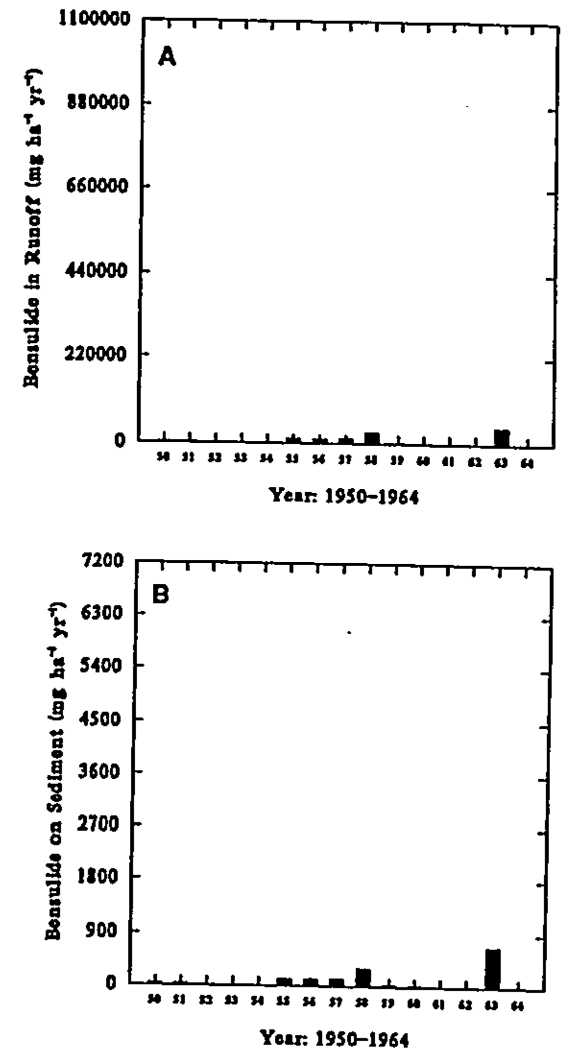


Figure B-97a. Annual surface loss of bensulide in runoff (A) water and (B) sediment from a simulated USGA Green at the Galbraith Trust Estate: 1950-1964.

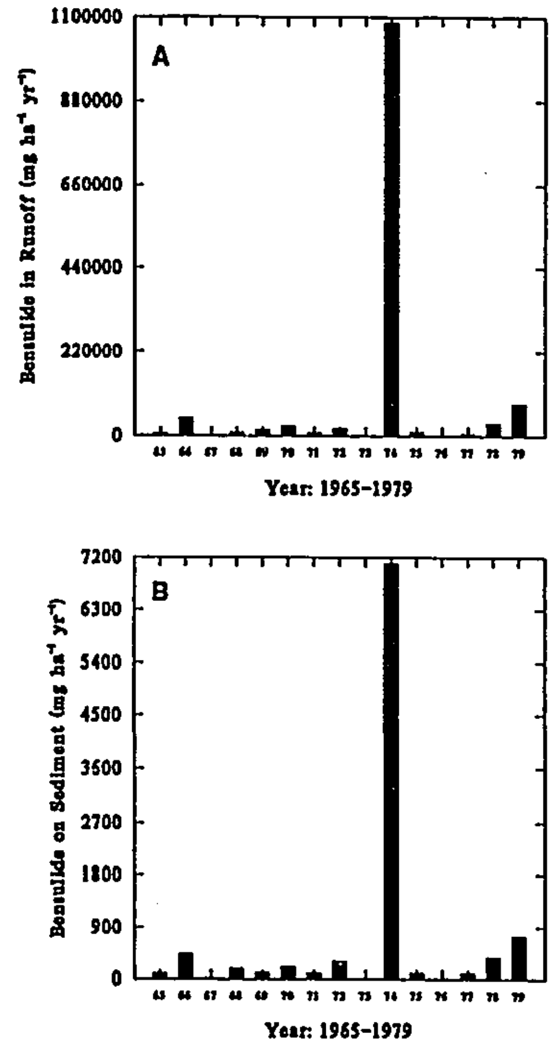


Figure B-97b. Annual surface loss of bensulide in runoff (A) water and (B) sediment from a simulated USGA Green at the Galbraith Trust Estate: 1965-1979.

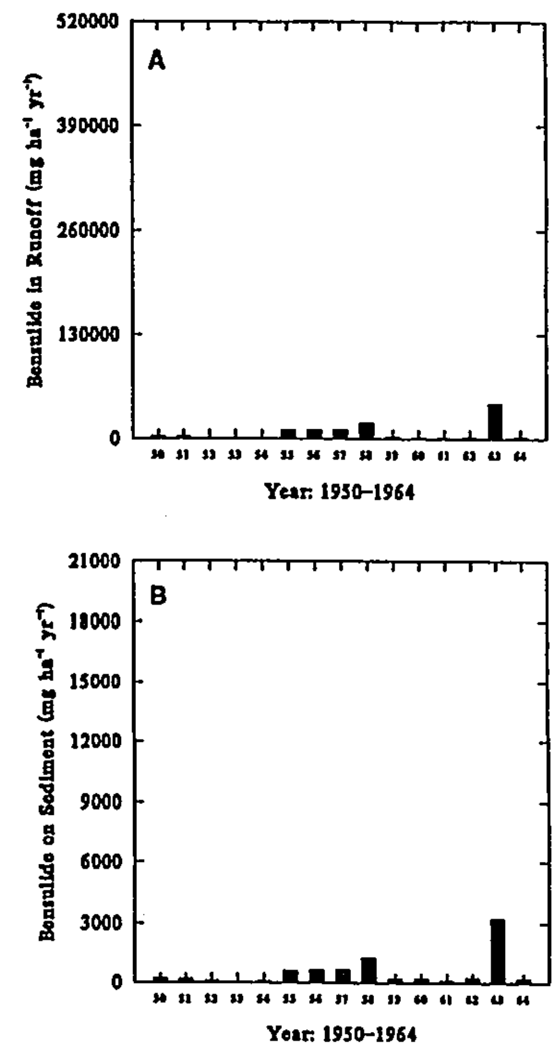


Figure B-98a. Annual surface loss of bensulide in runoff (A) water and (B) sediment from a simulated Wahiawa fairway soil at the Galbraith Trust Estate: 1950-1964.

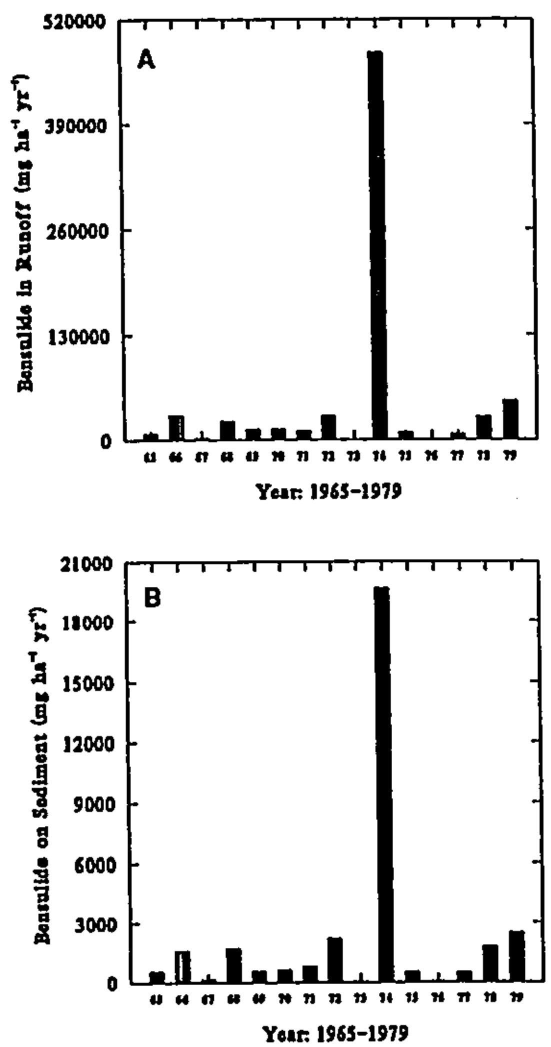


Figure B-98b. Annual surface loss of bensulide in runoff (A) water and (B) sediment from a simulated Wahiawa fairway soil at the Galbraith Trust Estate: 1965-1979.

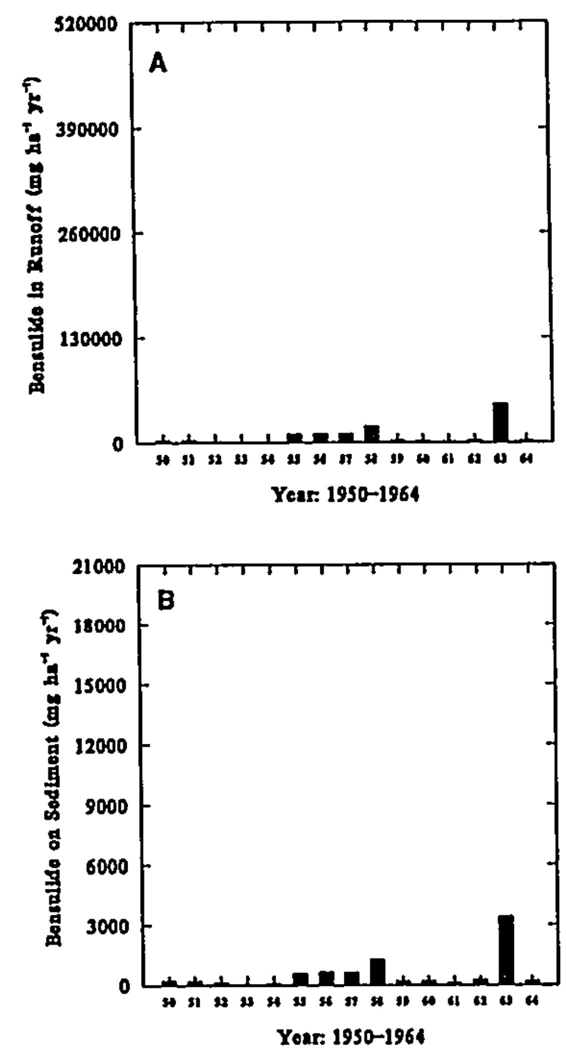


Figure B-99a. Annual surface loss of bensulide in runoff (A) water and (B) sediment from a simulated Kolekole fairway soil at the Galbraith Trust Estate: 1950-1964.

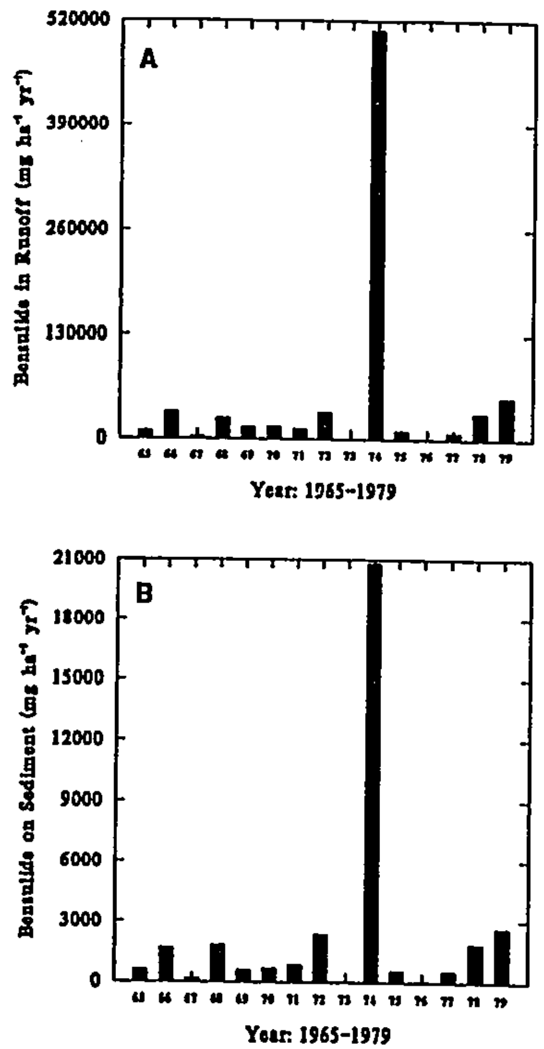


Figure B-99b. Annual surface loss of bensulide in runoff (A) water and (B) sediment from a simulated Kolekole fairway soil at the Galbraith Trust Estate: 1965-1979.

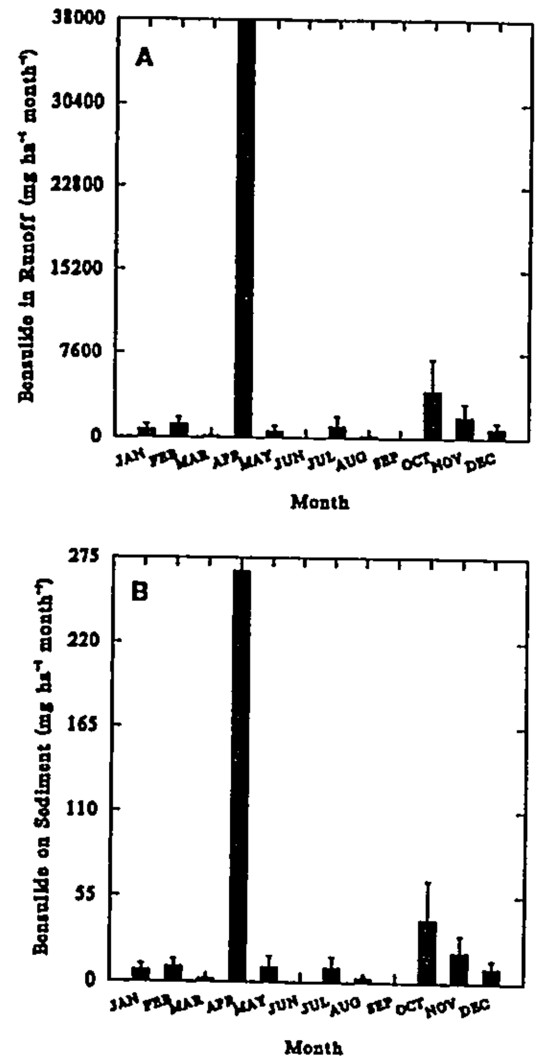


Figure B-100. Mean monthly loss of bensulide in runoff (A) water and (B) sediment from a simulated USGA Green at the Galbraith Trust Estate. Error bars represent one standard error.

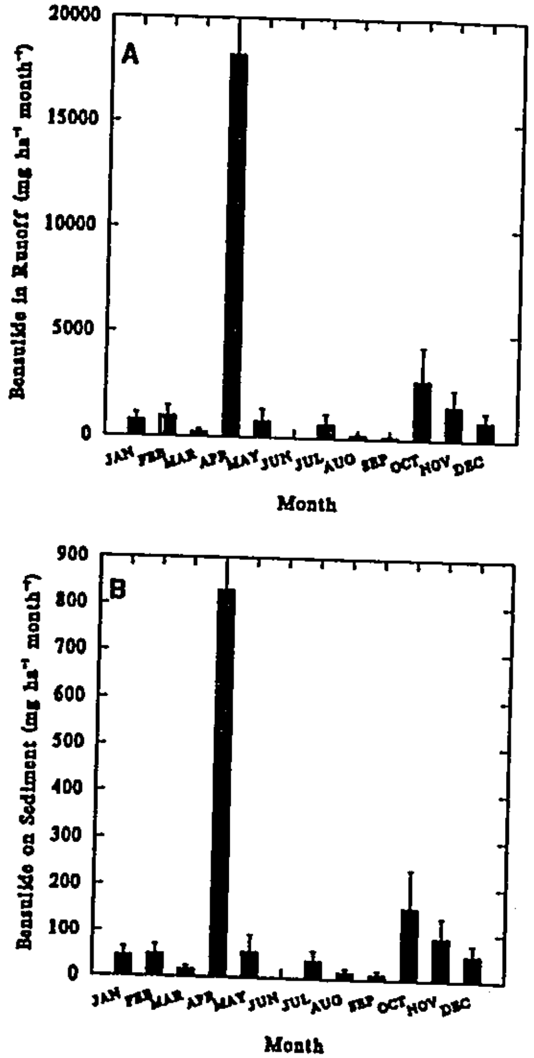


Figure B-101. Mean monthly loss of bensulide in runoff (A) water and (B) sediment from a simulated Wahiawa fairway soil at the Galbraith Trust Estate. Error bars represent one standard error.

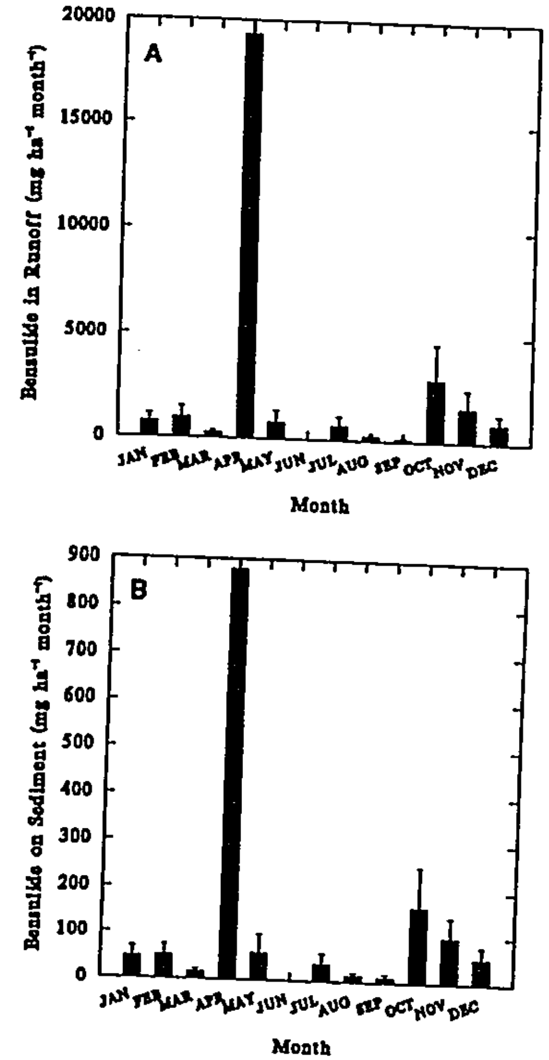


Figure B-102. Mean monthly loss of bensulide in runoff (A) water and (B) sediment from a simulated Kolekole fairway soil at the Galbraith Trust Estate. Error bars represent one standard error.

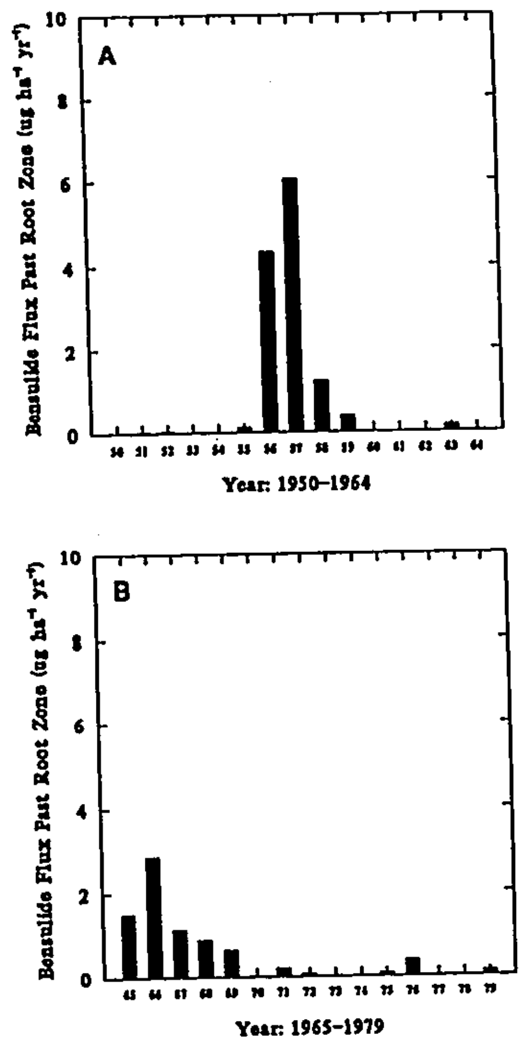


Figure B-103. Annual subsurface leaching of bensulide beneath the root zone of a simulated USGA Green at the Galbraith Trust Estate for (A) 1950-1964 and (B) 1965-1979.

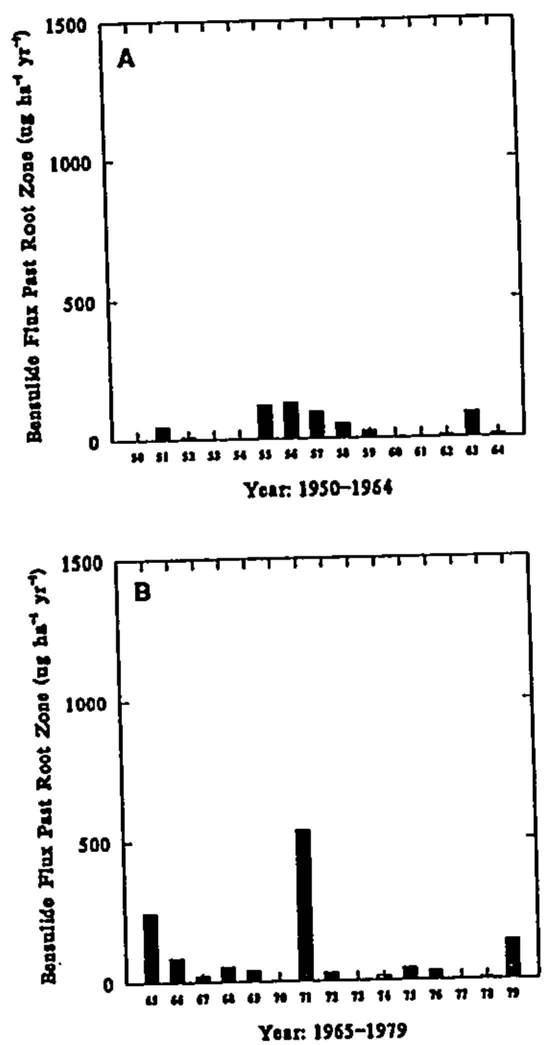


Figure B-104. Annual subsurface leaching of bensulide beneath the root zone of a simulated Wahiawa fairway soil at the Galbraith Trust Estate for (A) 1950-1964 and (B) 1965-1979.

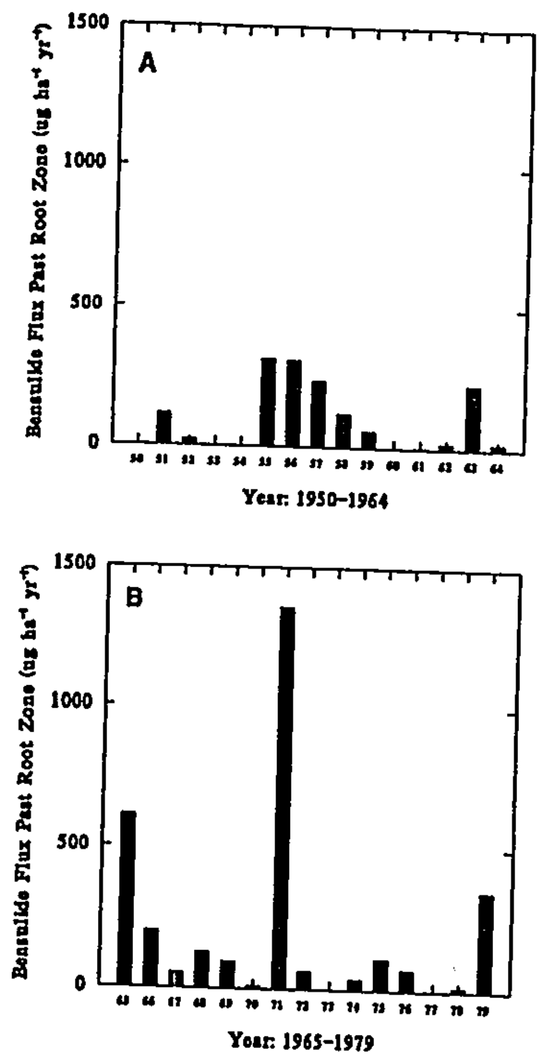


Figure B-105. Annual subsurface leaching of bensulide beneath the root zone of a simulated Kolekole fairway soil at the Galbraith Trust Estate for (A) 1950-1964 and (B) 1965-1979.

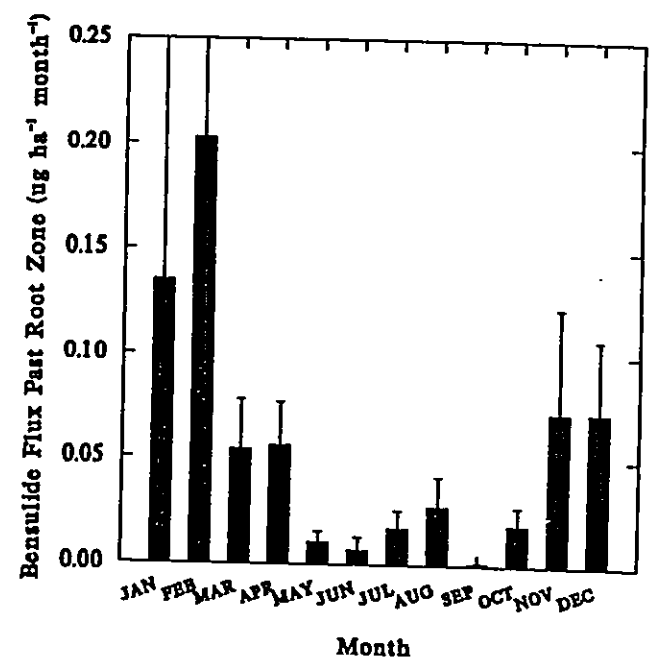


Figure B-106. Mean monthly subsurface movement of bensulide beneath the root zone of a simulated USGA Green at the Galbraith Trust Estate. Error bars represent one standard error.

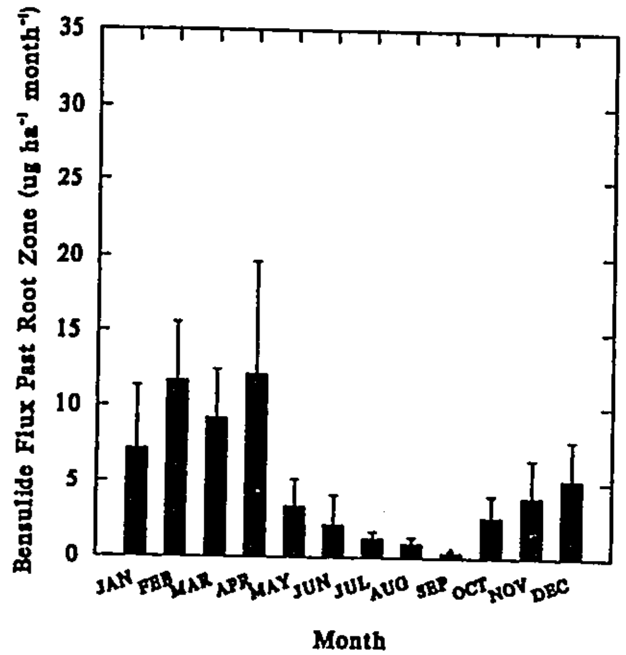


Figure B-107. Mean monthly subsurface movement of bensulide beneath the root zone of a simulated Wahiawa fairway soil at the Galbraith Trust Estate. Error bars represent one standard error.

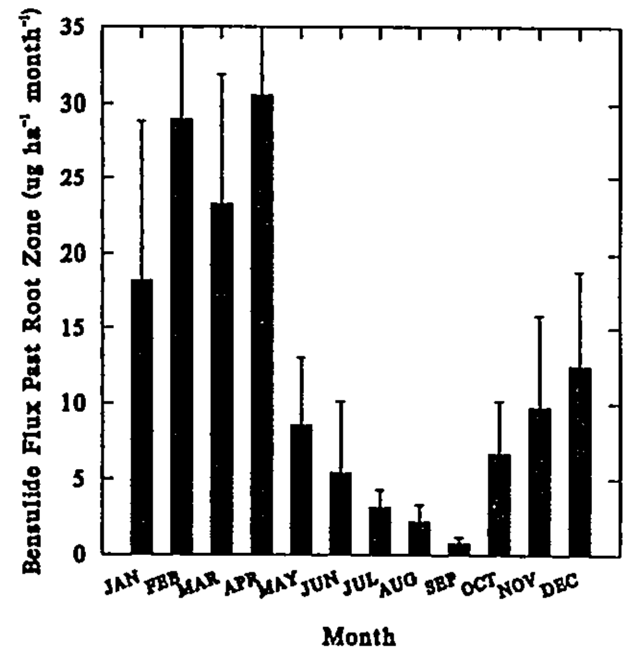


Figure B-108. Mean monthly subsurface movement of bensulide beneath the root zone of a simulated Kolekole fairway soil at the Galbraith Trust Estate. Error bars represent one standard error.

Table 3.7-22. Monthly Concentration of Bensulide (ng L^{-1})[1] Beneath the Root Zone from a 30 Year Simulation of an Established USGA Green on the Proposed Galbraith Trust.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	1.69E-03	1.80E-03	1.49E-03	1.02E-03
Mean	6.72E-05	1.19E-04	1.39E-04	1.10E-04
SD	1.95E-04	3.27E-04	3.12E-04	2.21E-04
Median	3.50E-06	6.50E-06	6.24E-06	9.99E-06
	May	**June**	**July**	**August**
Minimum	0.00	0.00	0.00	0.00
Maximum	8.30E-04	5.47E-04	4.35E-04	4.17E-04
Mean	8.77E-05	6.03E-05	4.53E-05	4.00E-05
SD	1.66E-04	1.13E-04	8.80E-05	7.95E-05
Median	7.24E-06	4.92E-06	3.44E-06	2.85E-06
	September	**October**	**November**	**December**
Minimum	1.66E-16	1.08E-16	8.52E-17	6.87E-16
Maximum	3.32E-04	2.19E-04	6.89E-04	7.27E-04
Mean	2.97E-05	2.40E-05	4.10E-05	5.82E-05
SD	6.07E-05	4.52E-05	1.12E-04	1.35E-04
Median	1.86E-06	1.76E-06	4.28E-06	4.36E-06

Table 3.7-23. Monthly Concentration of Bensulide (ng L^{-1}) Beneath the Root Zone from a 30 Year Simulation of an Established Wahiawa Fairway Soil on the Proposed Galbraith Trust Estate.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	0.01	0.01	0.01	0.03
Mean	7.35E-04	1.39E-03	1.56E-03	1.80E-03
SD	1.61E-03	2.63E-03	2.43E-03	3.14E-03
Median	2.17E-04	3.76E-04	5.76E-04	9.76E-04
	May	**June**	**July**	**August**
Minimum	6.29E-10	4.15E-10	2.70E-10	2.22E-10
Maximum	0.03	0.02	0.02	0.01
Mean	1.88E-03	1.41E-03	1.05E-03	7.69E-04
SD	3.89E-03	3.07E-03	2.39E-03	1.57E-03
Median	7.64E-04	5.12E-04	3.72E-04	3.21E-04
	September	**October**	**November**	**December**
Minimum	2.96E-08	1.93E-08	1.52E-08	1.92E-06
Maximum	6.77E-03	4.46E-03	7.38E-03	0.01
Mean	5.35E-04	4.61E-04	5.75E-04	7.30E-04
SD	1.03E-03	8.44E-04	1.15E-03	1.69E-03
Median	2.20E-04	1.51E-04	1.13E-04	1.31E-04

Table 3.7-24. Monthly Concentration of Bensulide (ng L^{-1}) Beneath the Root Zone from a 30 Year Simulation of an Established Kolekole Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	0.03	0.04	0.03	0.08
Mean	2.09E-03	4.03E-03	4.51E-03	5.24E-03
SD	4.55E-03	7.70E-03	7.08E-03	9.24E-03
Median	6.49E-04	1.09E-03	1.68E-03	2.80E-03
	May	**June**	**July**	**August**
Minimum	2.19E-09	1.45E-09	9.40E-10	7.73E-10
Maximum	0.08	0.06	0.05	0.03
Mean	5.47E-03	4.09E-03	3.06E-03	2.23E-03
SD	0.01	8.98E-03	6.96E-03	4.56E-03
Median	2.19E-03	1.48E-03	1.08E-03	9.08E-04
	September	**October**	**November**	**December**
Minimum	1.01E-07	6.54E-08	5.16E-08	6.52E-07
Maximum	0.02	0.01	0.02	0.03
Mean	1.55E-03	1.33E-03	1.64E-03	2.06E-03
SD	3.00E-03	2.45E-03	3.25E-03	4.70E-03
Median	6.32E-04	4.33E-04	3.27E-04	3.82E-04

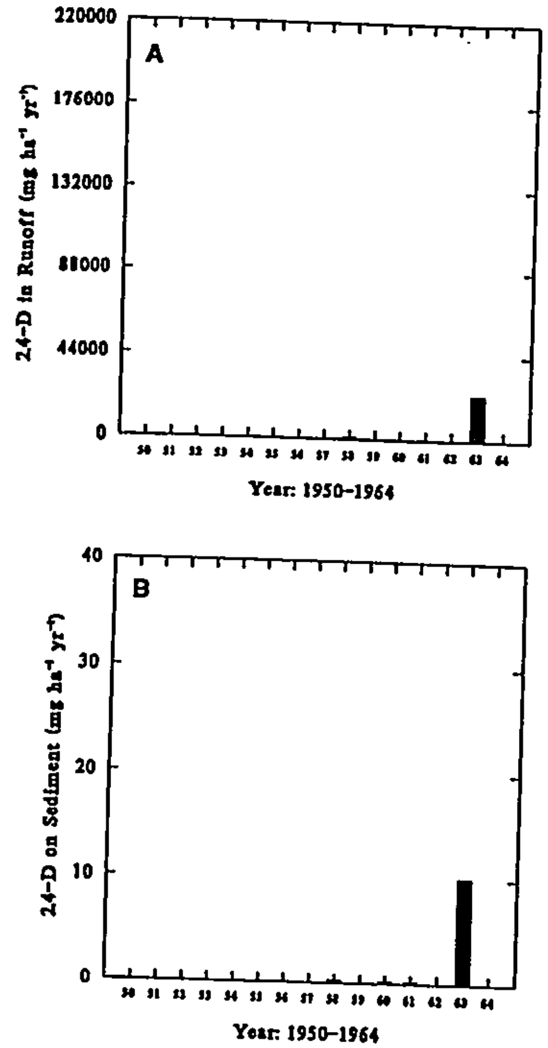


Figure B-109a. Annual surface loss of 2,4-D in runoff (A) water and (B) sediment from a simulated USGA Green at the Galbraith Trust Estate: 1950-1964.

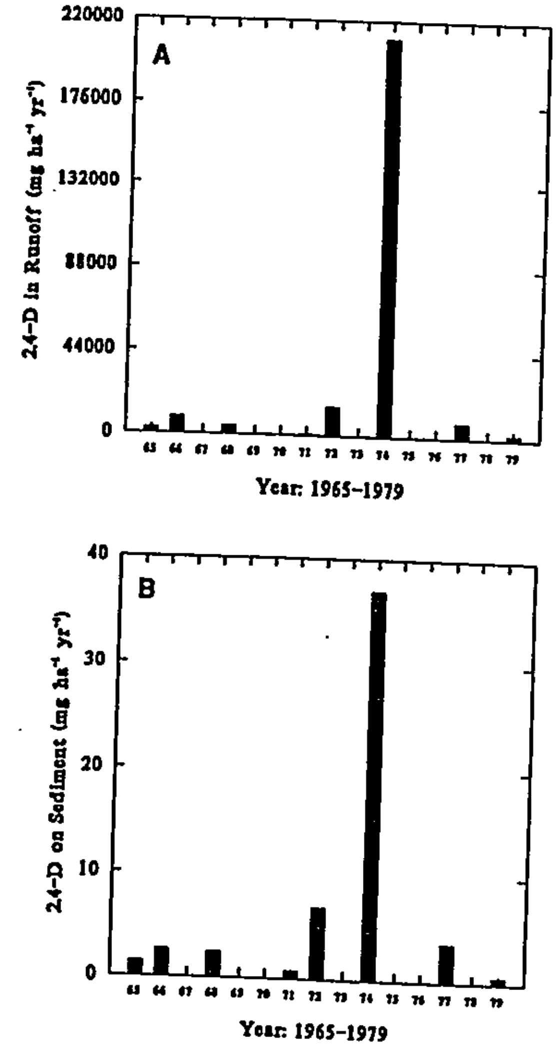


Figure B-109b. Annual surface loss of 2,4-D in runoff (A) water and (B) sediment from a simulated USGA Green at the Galbraith Trust Estate: 1965-1979.

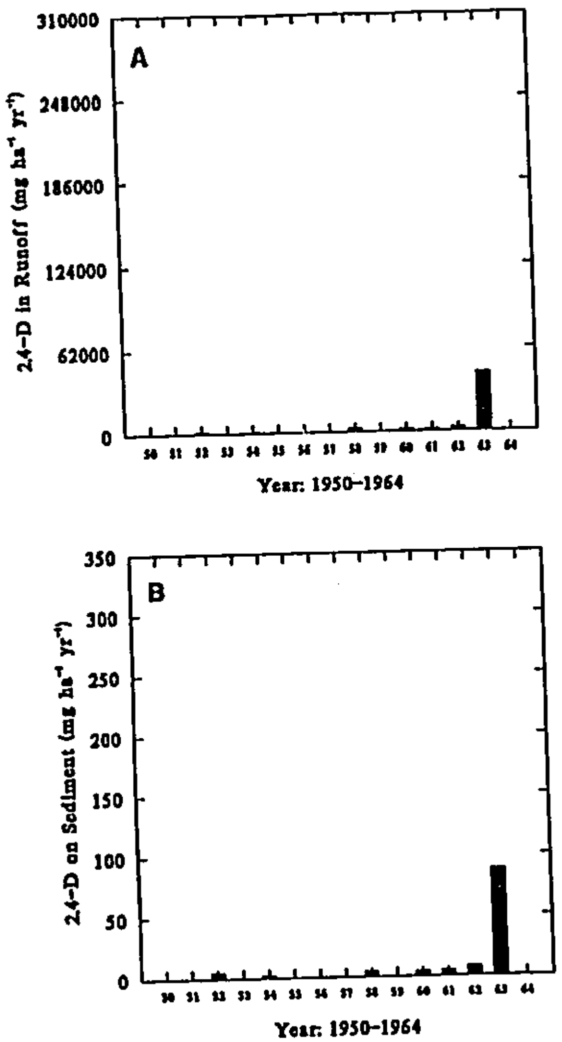


Figure B-110a. Annual surface loss of 2,4-D in runoff (A) water and (B) sediment from a simulated Wahiawa fairway soil at the Galbraith Trust Estate: 1950-1964.

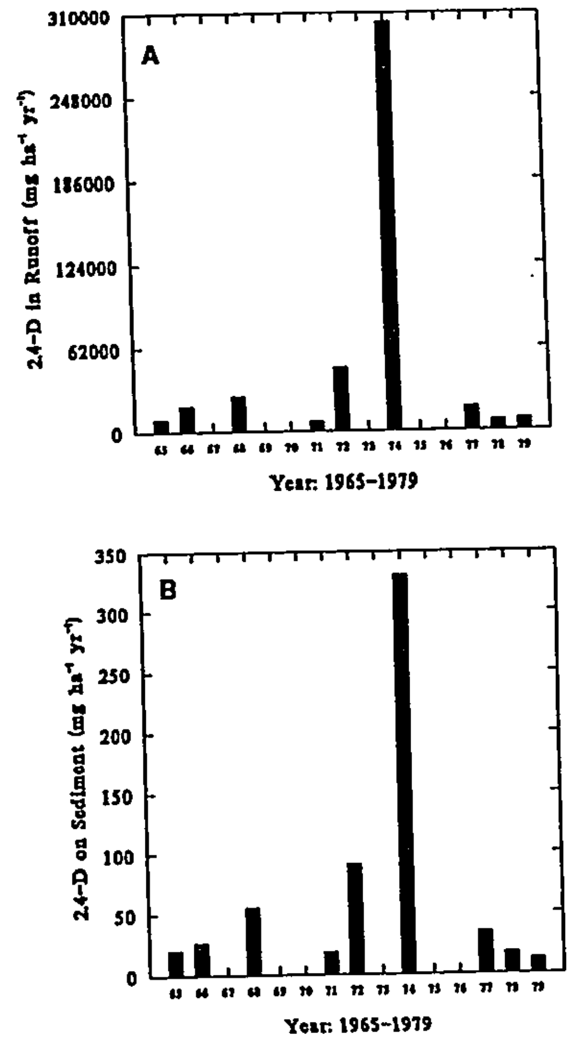


Figure B-110b. Annual surface loss of 2,4-D in runoff (A) water and (B) sediment from a simulated Wahiawa fairway soil at the Galbraith Trust Estate: 1965-1979.

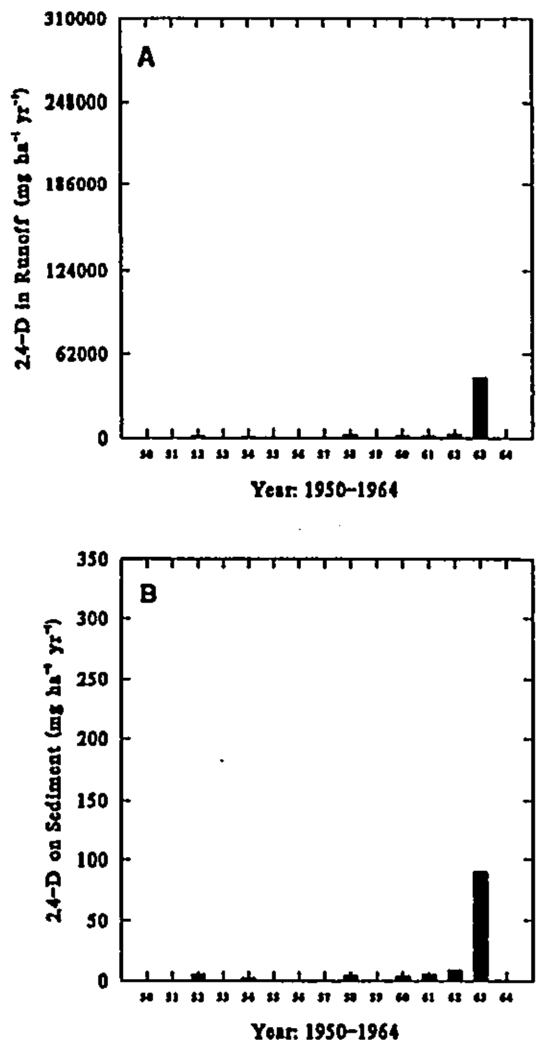


Figure B-111a. Annual surface loss of 2,4-D in runoff (A) water and (B) sediment from a simulated Kolekole fairway soil at the Galbraith Trust Estate: 1950-1964.

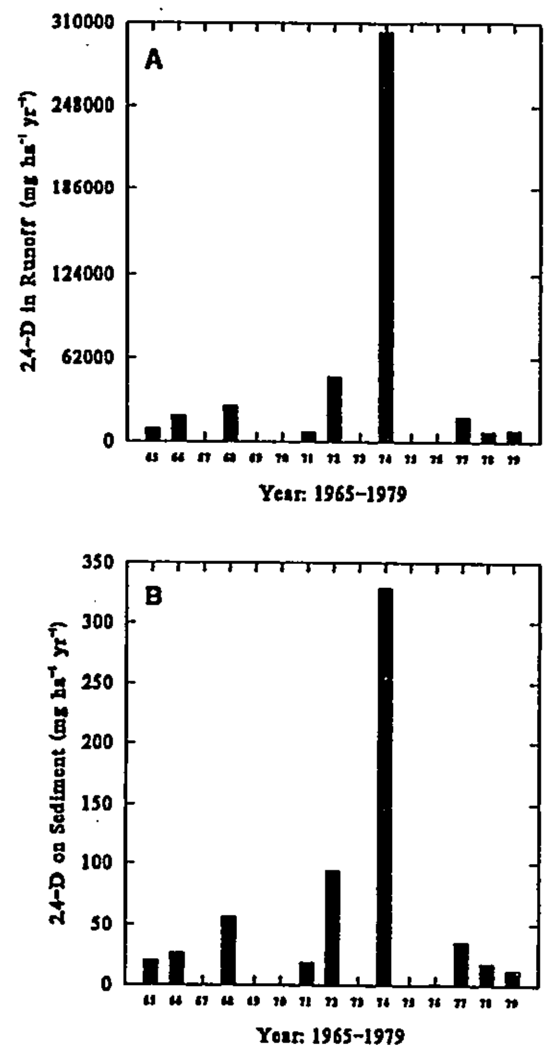


Figure B-111b. Annual surface loss of 2,4-D in runoff (A) water and (B) sediment from a simulated Kolekole fairway soil at the Galbraith Trust Estate: 1965-1979.

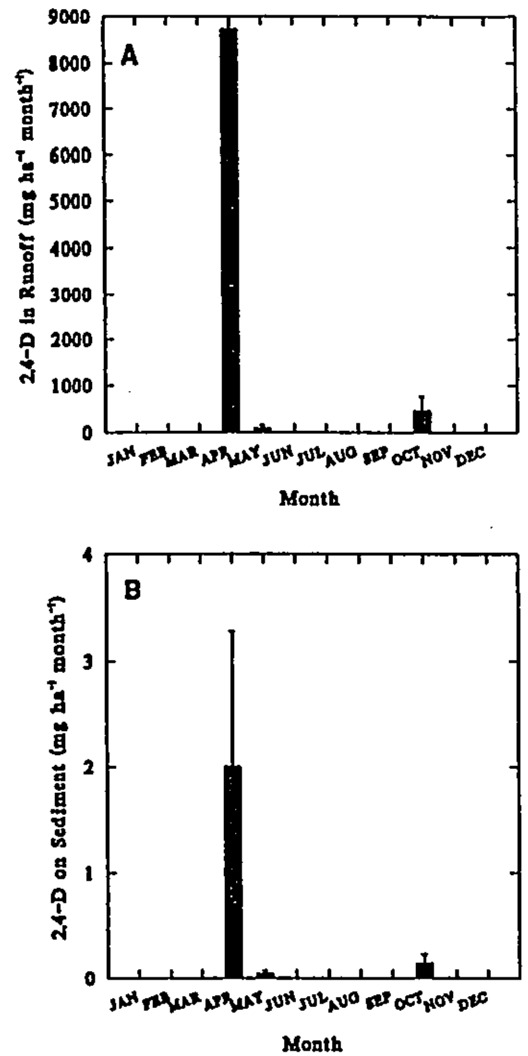


Figure B-112. Mean monthly loss of 2,4-D in runoff (A) water and (B) sediment from a simulated USGA Green at the Galbraith Trust Estate. Error bars represent one standard error.

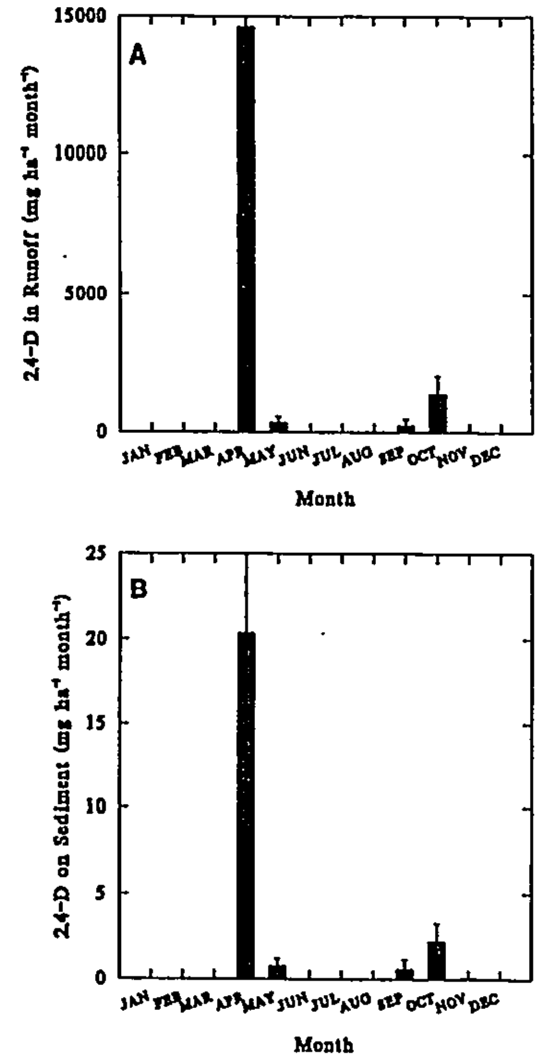


Figure B-113. Mean monthly loss of 2,4-D in runoff (A) water and (B) sediment from a simulated Wahiawa fairway soil at the Galbraith Trust Estate. Error bars represent one standard error.

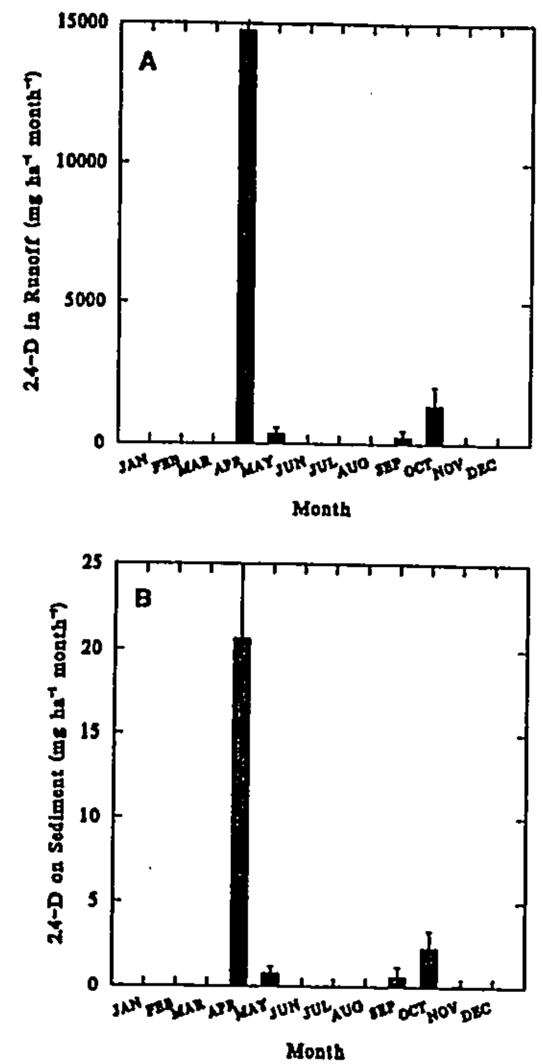


Figure B-114. Mean monthly loss of 2,4-D in runoff (A) water and (B) sediment from a simulated Kolekole fairway soil at the Galbraith Trust Estate. Error bars represent one standard error.

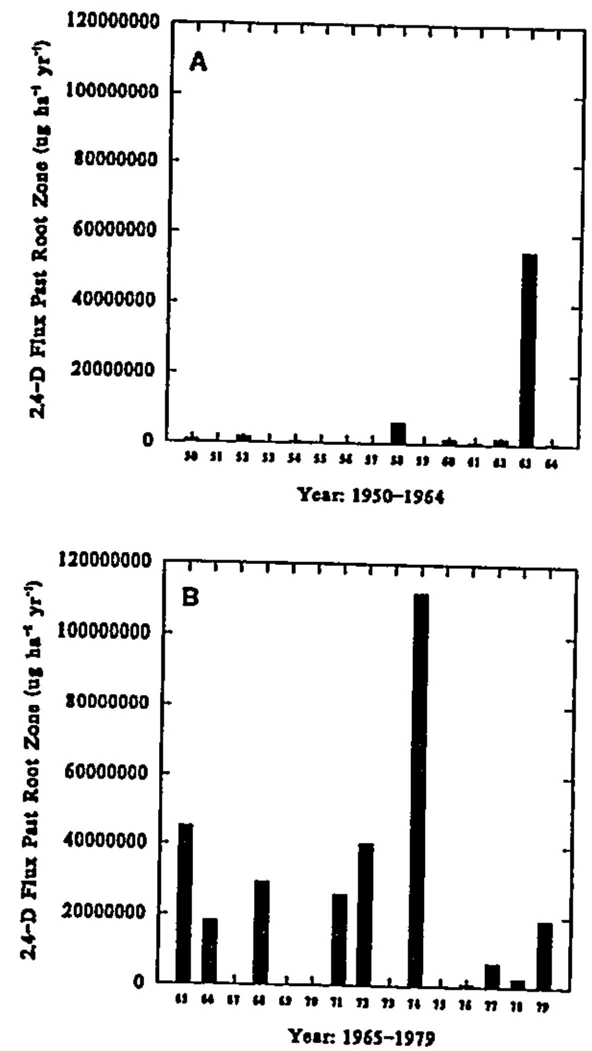


Figure B-115. Annual subsurface leaching of 2,4-D beneath the root zone of a simulated USGA Green at the Galbraith Trust Estate for (A) 1950-1964 and (B) 1965-1979.

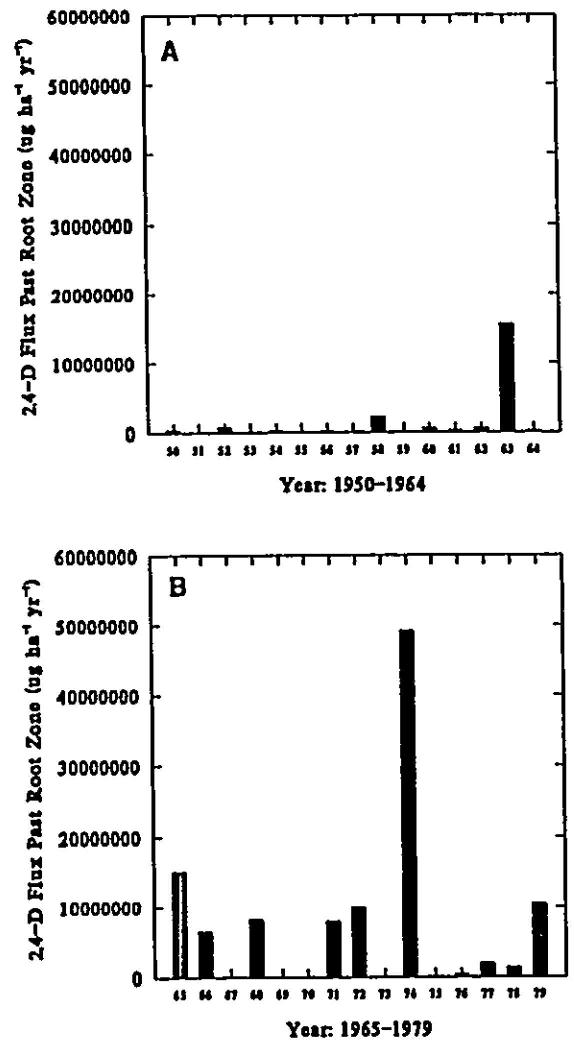


Figure B-116. Annual subsurface leaching of 2,4-D beneath the root zone of a simulated Wahiawa fairway soil at the Galbraith Trust Estate for (A) 1950-1964 and (B) 1965-1979.

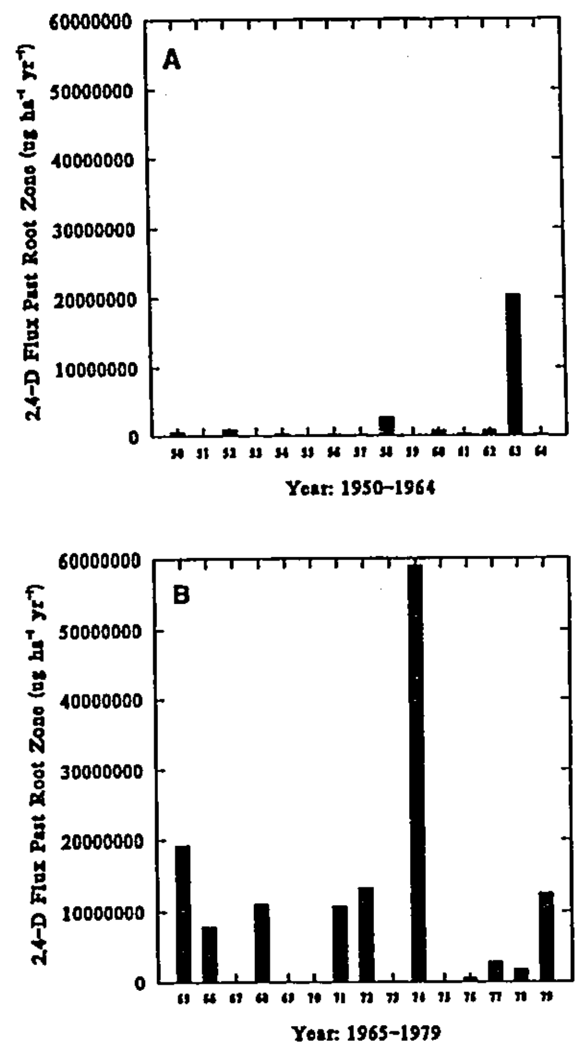


Figure B-117. Annual subsurface leaching of 2,4-D beneath the root zone of a simulated Kolekole fairway soil at the Galbraith Trust Estate for (A) 1950-1964 and (B) 1965-1979.

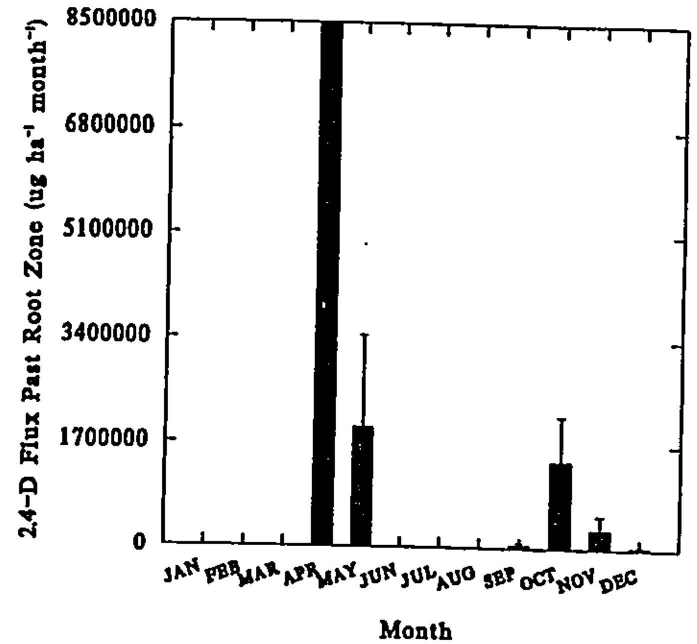


Figure B-118. Mean monthly subsurface movement of 2,4-D beneath the root zone of a simulated USGA Green at the Galbraith Trust Estate. Error bars represent one standard error.

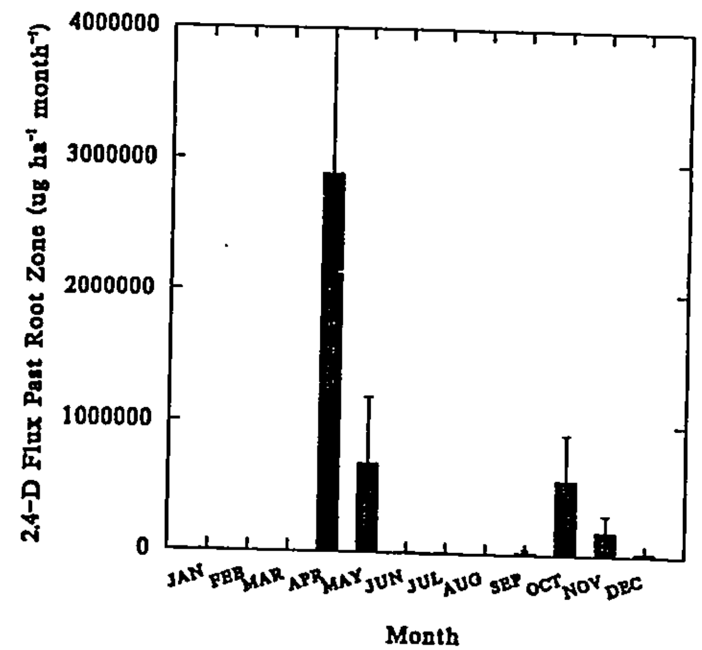


Figure B-119. Mean monthly subsurface movement of 2,4-D beneath the root zone of a simulated Wahiawa fairway soil at the Galbraith Trust Estate. Error bars represent one standard error.

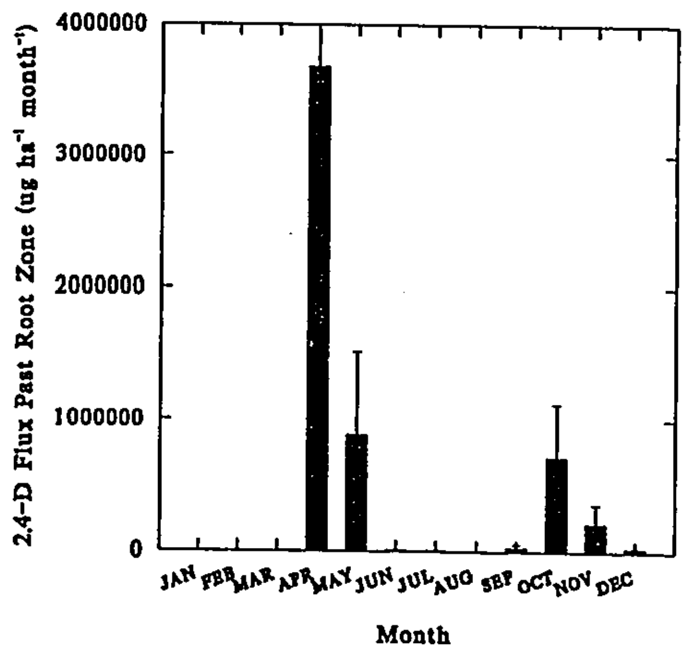


Figure B-120. Mean monthly subsurface movement of 2,4-D beneath the root zone of a simulated Kolekole fairway soil at the Galbraith Trust Estate. Error bars represent one standard error.

Table B-23. Monthly Concentration of 2,4-D (ng L^{-1})[1] Beneath the Root Zone from a 30 Year Simulation of an Established USGA Green on the Proposed Galbraith Trust.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	25.86	1.79	0.13	70560.00
Mean	2.42	0.12	6.47E-03	2412.41
SD	4.30	0.26	0.02	9164.51
Median	9.63E-06	6.50E-07	9.10E-07	3.09E-05
	May	**June**	**July**	**August**
Minimum	2.65E-16	1.85E-17	2.19E-18	2.69E-16
Maximum	33060.00	4975.00	347.50	24.03
Mean	1985.21	190.04	17.47	1.72
SD	4633.22	510.20	38.68	3.13
Median	11.28	6.36	1.34	0.52
	September	**October**	**November**	**December**
Minimum	1.87E-17	3.51E-13	2.94E-12	4.97E-13
Maximum	4116.00	11790.00	3154.00	240.40
Mean	36.72	450.12	175.61	30.53
SD	312.76	1491.97	443.74	47.20
Median	0.06	9.96E-03	1.99E-03	1.13E-03

Table B-24. Monthly Concentration of 2,4-D (ng L^{-1}) Beneath the Root Zone from a 30 Year Simulation of an Established Wahiawa Fairway Soil on the Proposed Galbraith Trust Estate.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	18.66	1.19	0.10	26850.00
Mean	1.56	0.13	0.01	567.02
SD	2.72	0.21	0.02	2581.39
Median	4.03E-05	1.21E-06	2.74E-06	6.13E-04
	May	**June**	**July**	**August**
Minimum	6.33E-13	4.40E-14	5.20E-15	5.96E-15
Maximum	12060.00	1656.00	115.00	11.56
Mean	496.73	55.44	5.58	0.74
SD	1305.72	167.11	13.23	1.54
Median	5.16	2.16	0.48	0.13
	September	**October**	**November**	**December**
Minimum	4.14E-16	1.76E-11	2.13E-12	3.59E-13
Maximum	665.30	6169.00	1625.00	204.20
Mean	6.27	122.85	68.81	14.63
SD	51.07	526.20	203.97	27.73
Median	0.02	5.17E-03	1.93E-03	0.01

Table B-25. Monthly Concentration of 2,4-D (ng L^{-1}) Beneath the Root Zone from a 30 Year Simulation of an Established Kolekole Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	19.88	1.26	0.11	33130.00
Mean	1.80	0.14	0.01	752.76
SD	3.07	0.23	0.02	3281.21
Median	6.50E-05	1.23E-06	5.12E-06	5.76E-04
	May	**June**	**July**	**August**
Minimum	3.46E-13	2.40E-14	2.85E-15	4.99E-15
Maximum	14880.00	2070.00	143.70	13.80
Mean	659.44	72.10	7.32	0.93
SD	1667.93	209.61	16.66	1.83
Median	9.21	3.66	0.80	0.20
	September	**October**	**November**	**December**
Minimum	3.46E-16	1.31E-11	2.48E-12	4.18E-13
Maximum	1026.00	7413.00	1953.00	220.30
Mean	9.79	160.59	85.26	17.91
SD	79.11	647.59	240.80	32.07
Median	0.03	6.69E-03	2.23E-03	0.02

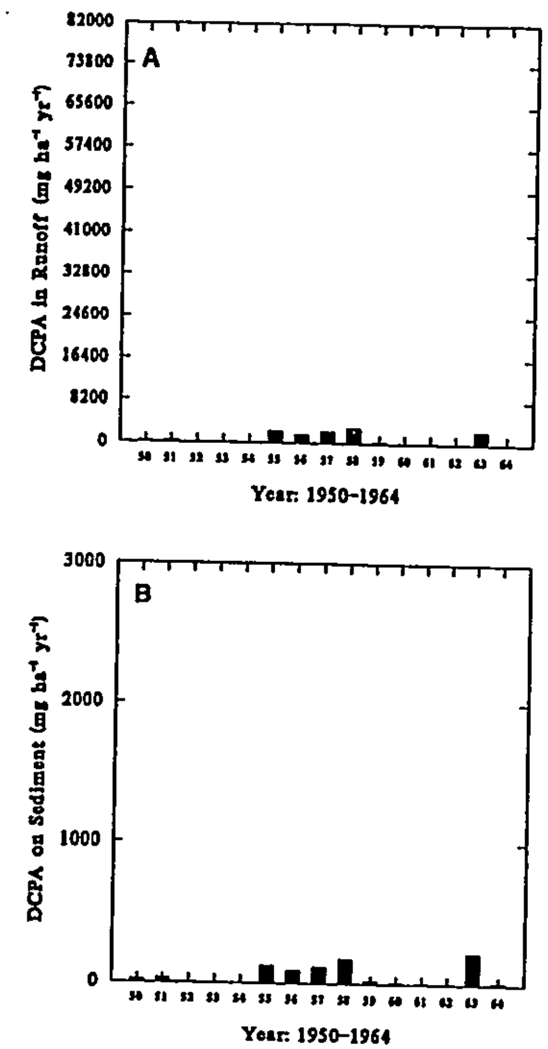


Figure B-121a. Annual surface loss of DCPA in runoff (A) water and (B) sediment from a simulated USGA Green at the Galbraith Trust Estate: 1950-1964.

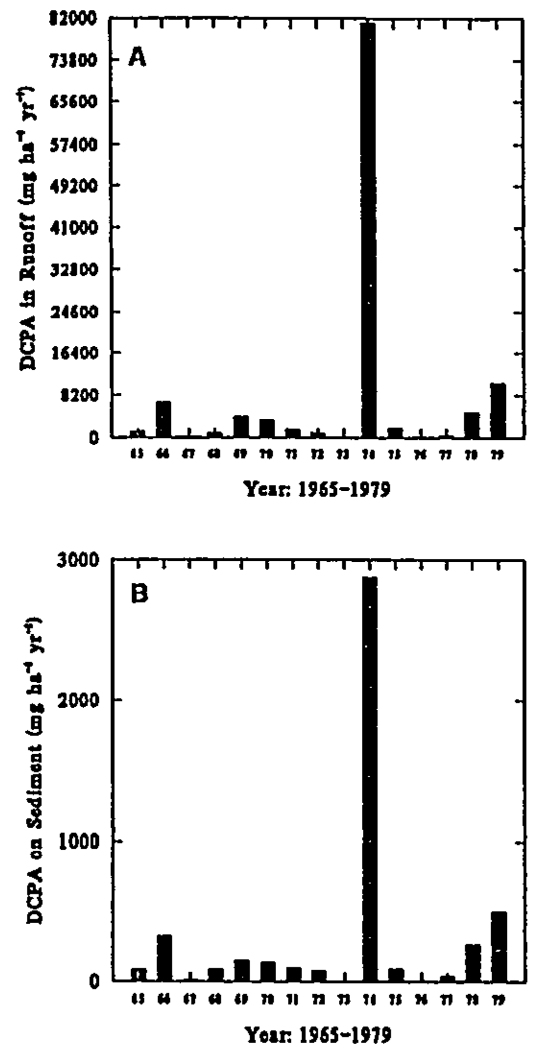


Figure B-121b. Annual surface loss of DCPA in runoff (A) water and (B) sediment from a simulated USGA Green at the Galbraith Trust Estate: 1965-1979.

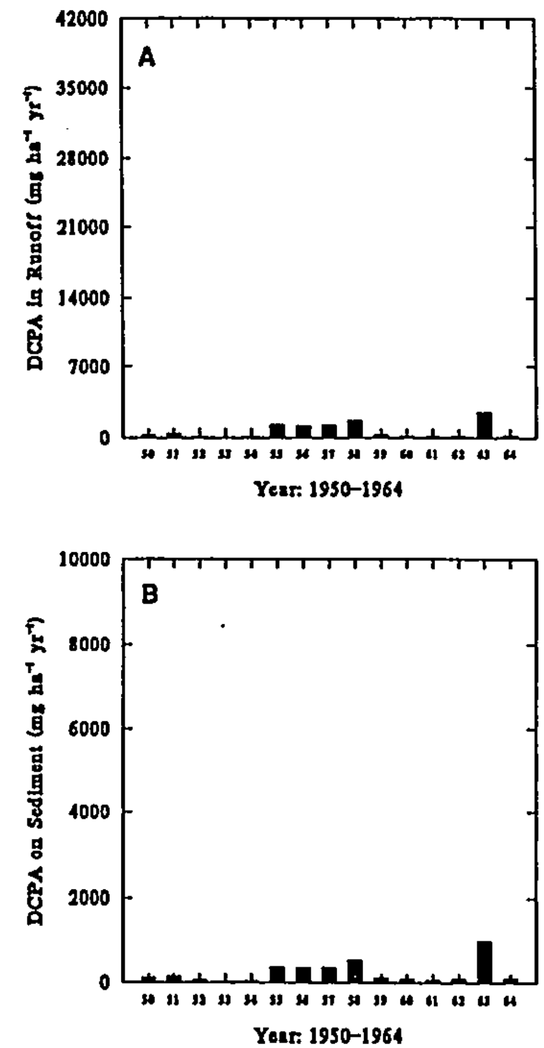


Figure B-122a. Annual surface loss of DCPA in runoff (A) water and (B) sediment from a simulated Wahiawa fairway soil at the Galbraith Trust Estate: 1950-1964.

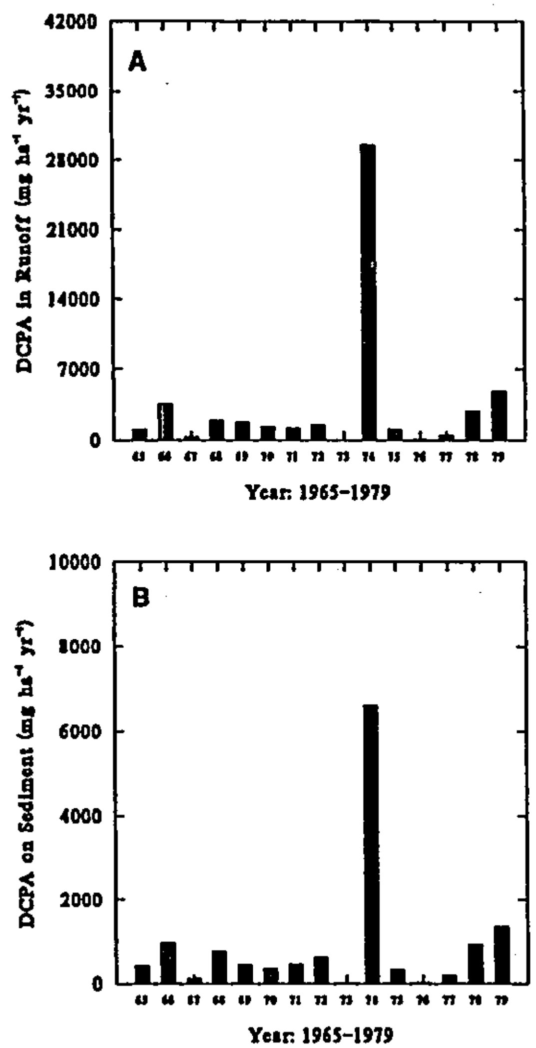


Figure B-122b. Annual surface loss of DCPA in runoff (A) water and (B) sediment from a simulated Wahiawa fairway soil at the Galbraith Trust Estate: 1965-1979.

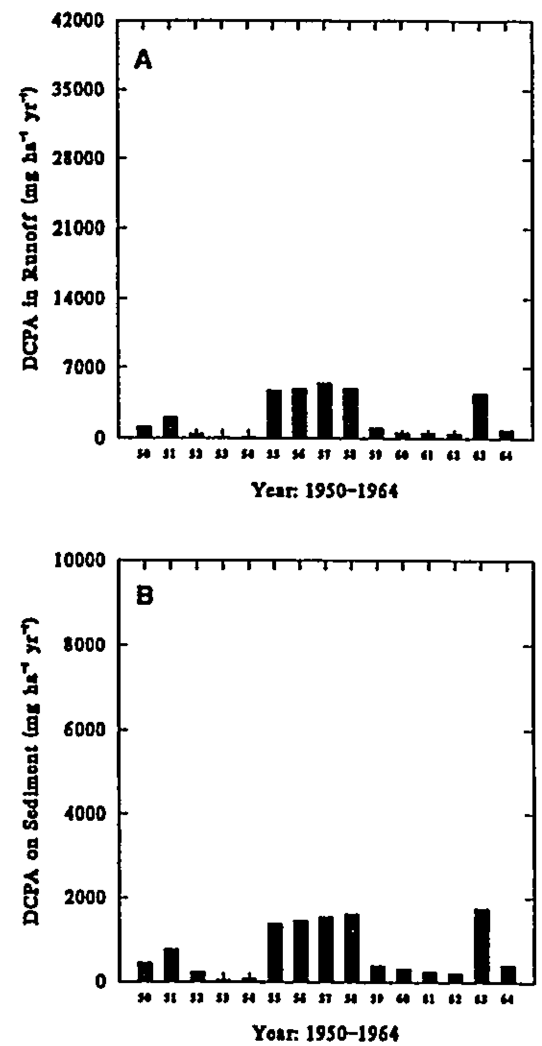


Figure B-123a. Annual surface loss of DCPA in runoff (A) water and (B) sediment from a simulated Kolekole fairway soil at the Galbraith Trust Estate: 1950-1964.

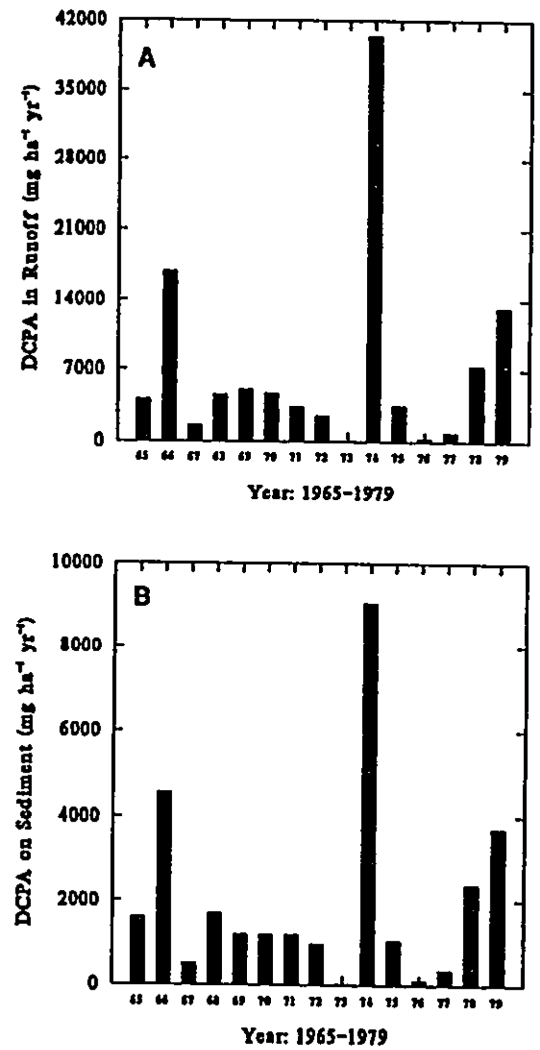


Figure B-123b. Annual surface loss of DCPA in runoff (A) water and (B) sediment from a simulated Kolekole fairway soil at the Galbraith Trust Estate: 1965-1979.

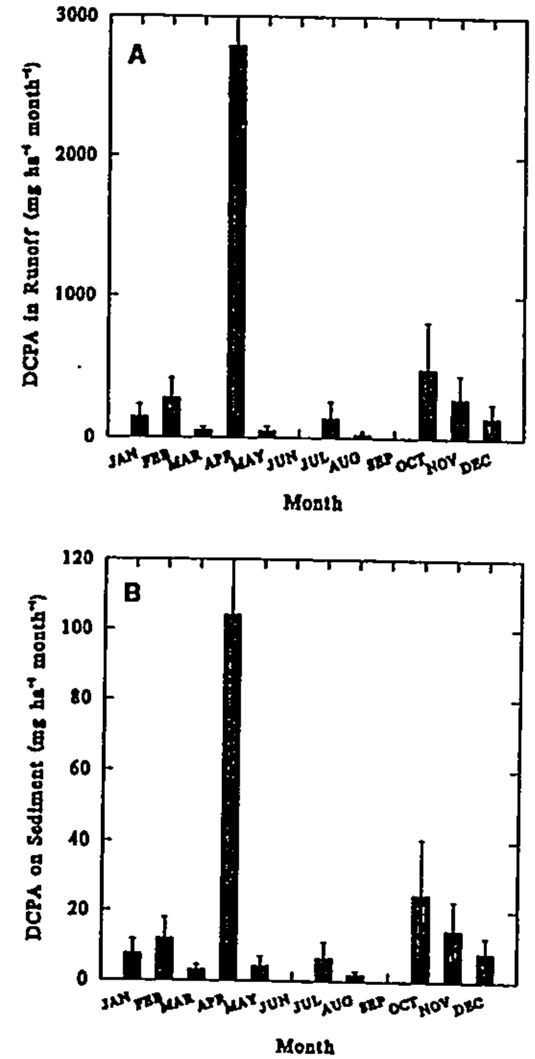


Figure B-124. Mean monthly loss of DCPA in runoff (A) water and (B) sediment from a simulated USGA Green at the Galbraith Trust Estate. Error bars represent one standard error.

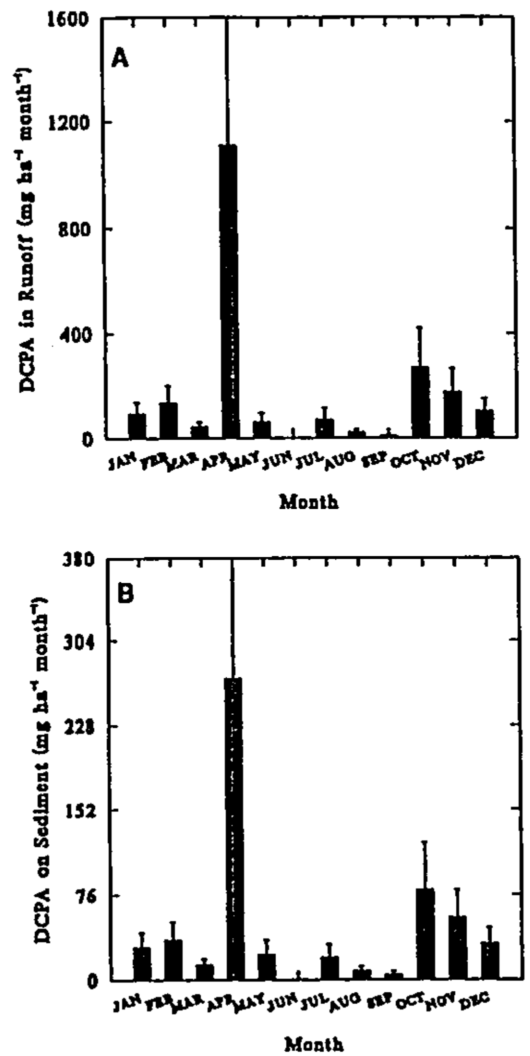


Figure B-125. Mean monthly loss of DCPA in runoff (A) water and (B) sediment from a simulated Wahiawa fairway soil at the Galbraith Trust Estate. Error bars represent one standard error.

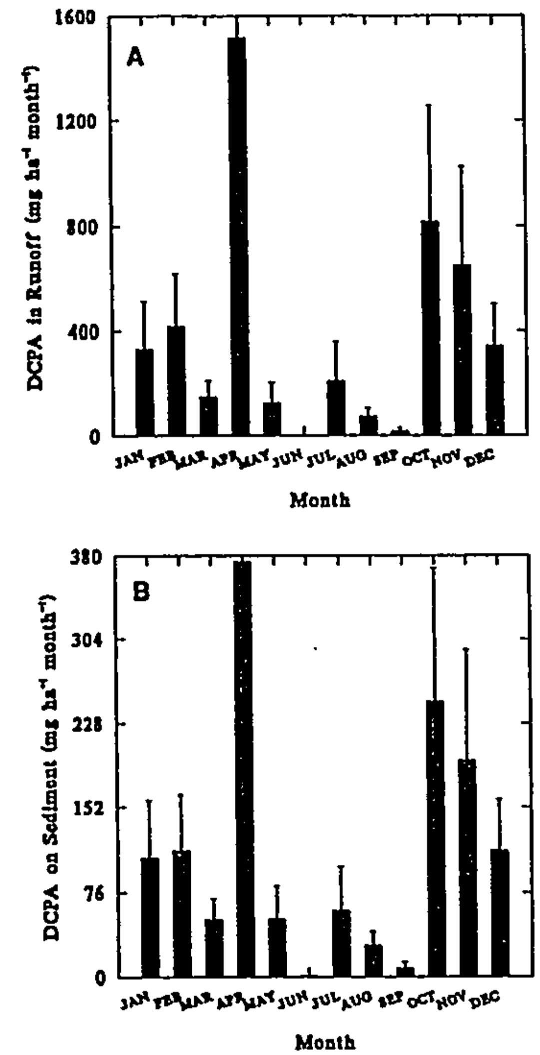


Figure B-126. Mean monthly loss of DCPA in runoff (A) water and (B) sediment from a simulated Kolekole fairway soil at the Galbraith Trust Estate. Error bars represent one standard error.

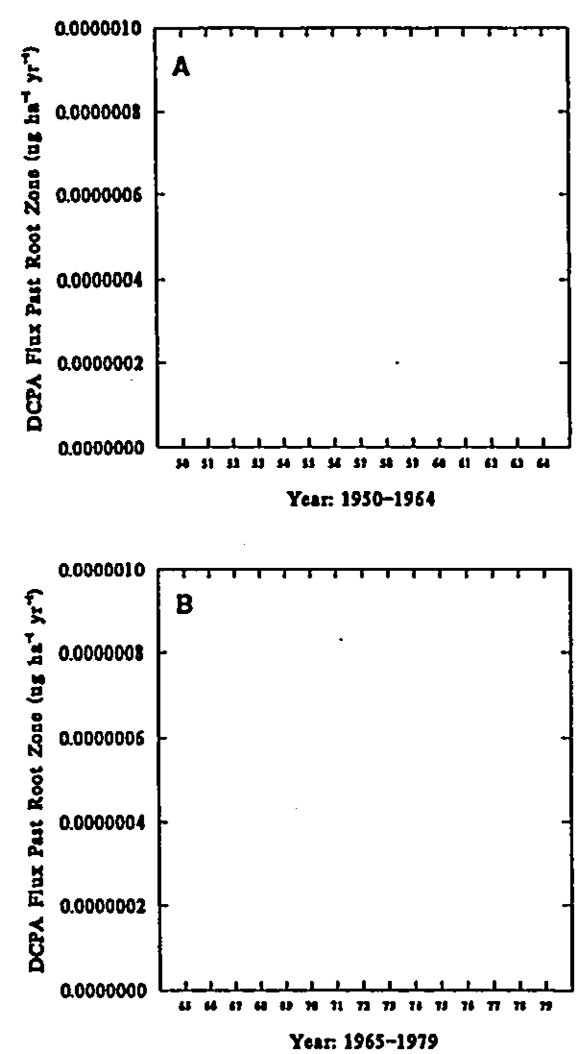


Figure B-127. Annual subsurface leaching of DCPA beneath the root zone of a simulated USGA Green at the Galbraith Trust Estate for (A) 1950-1964 and (B) 1965-1979.

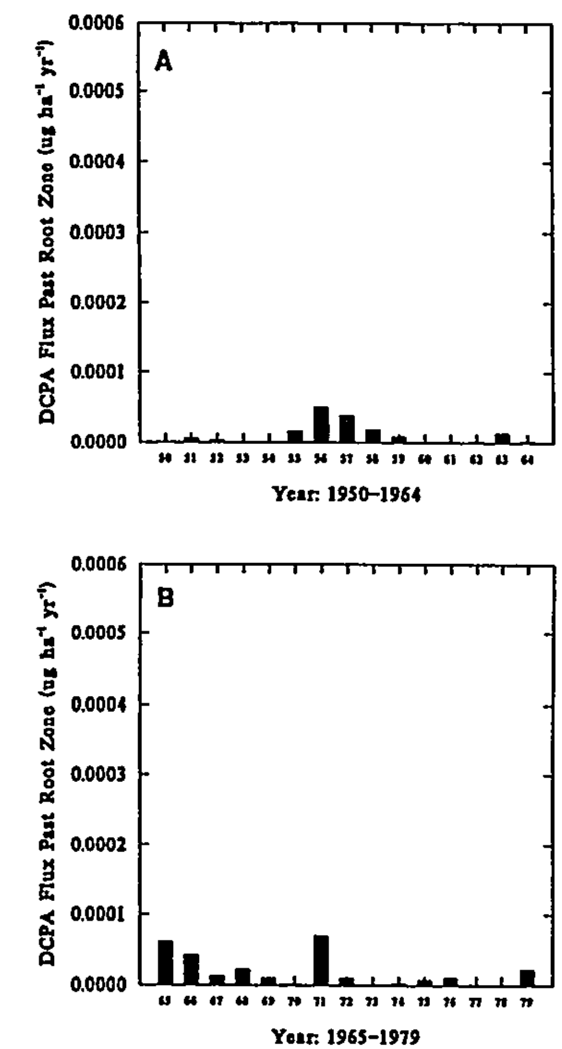


Figure B-128. Annual subsurface leaching of DCPA beneath the root zone of a simulated Wahiawa fairway soil at the Galbraith Trust Estate for (A) 1950-1964 and (B) 1965-1979.

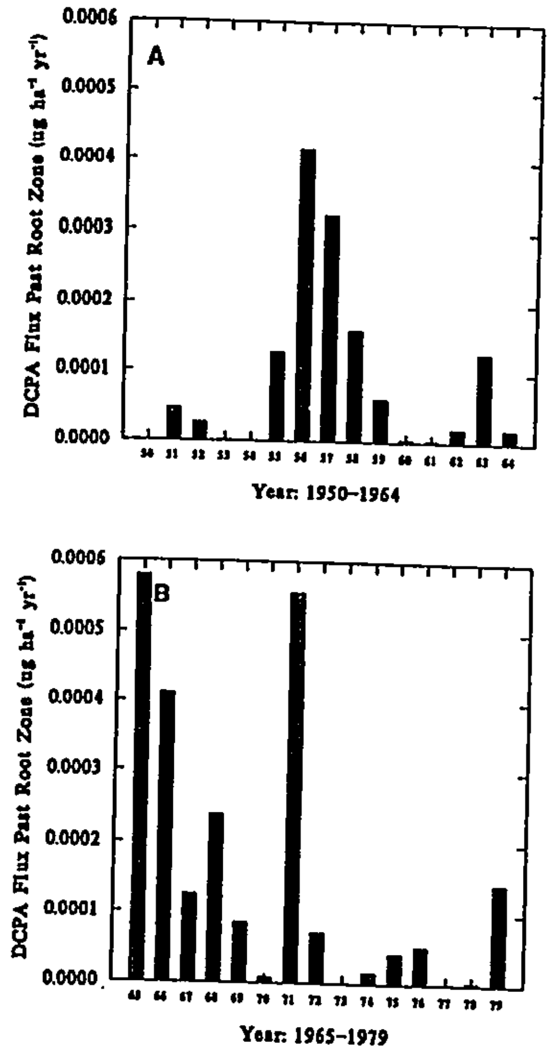


Figure B-129. Annual subsurface leaching of DCPA beneath the root zone of a simulated Kolekole fairway soil at the Galbraith Trust Estate for (A) 1950-1964 and (B) 1965-1979.

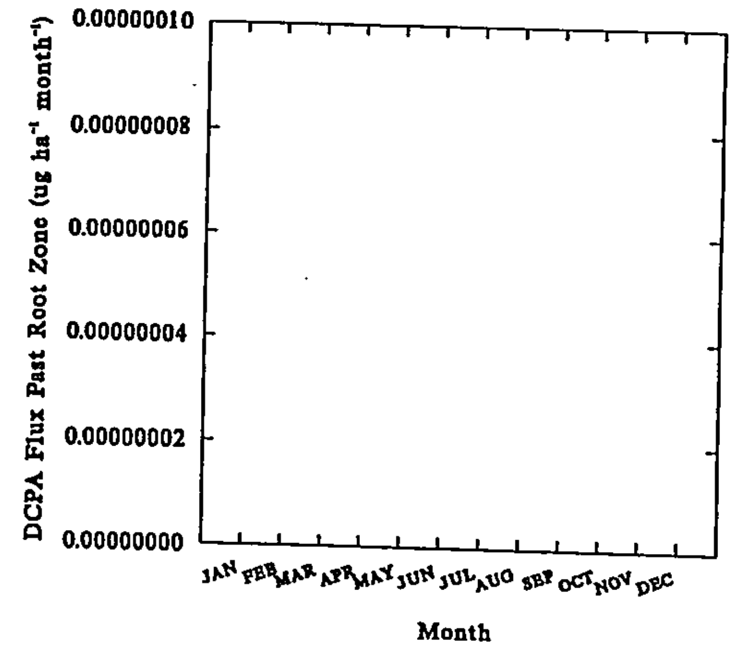


Figure B-130. Mean monthly subsurface movement of DCPA beneath the root zone of a simulated USGA Green at the Galbraith Trust Estate. Error bars represent one standard error.

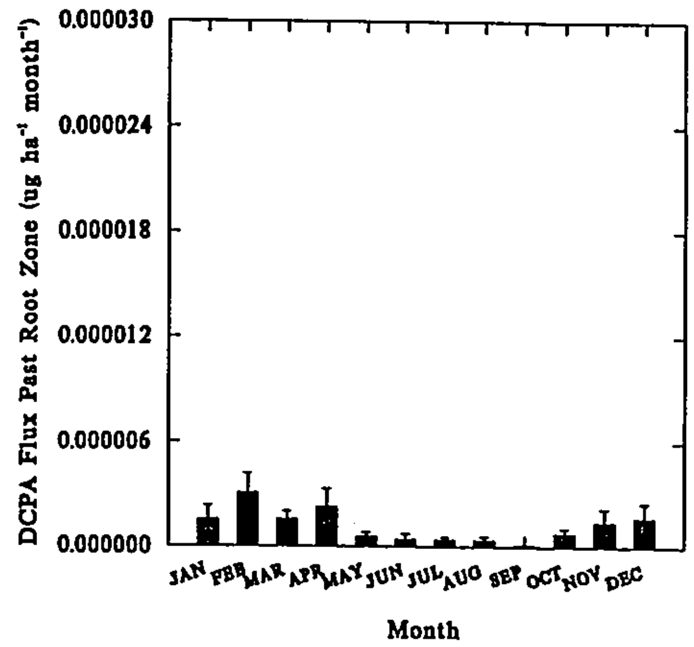


Figure B-131. Mean monthly subsurface movement of DCPA beneath the root zone of a simulated Wahiawa fairway soil at the Galbraith Trust Estate. Error bars represent one standard error.

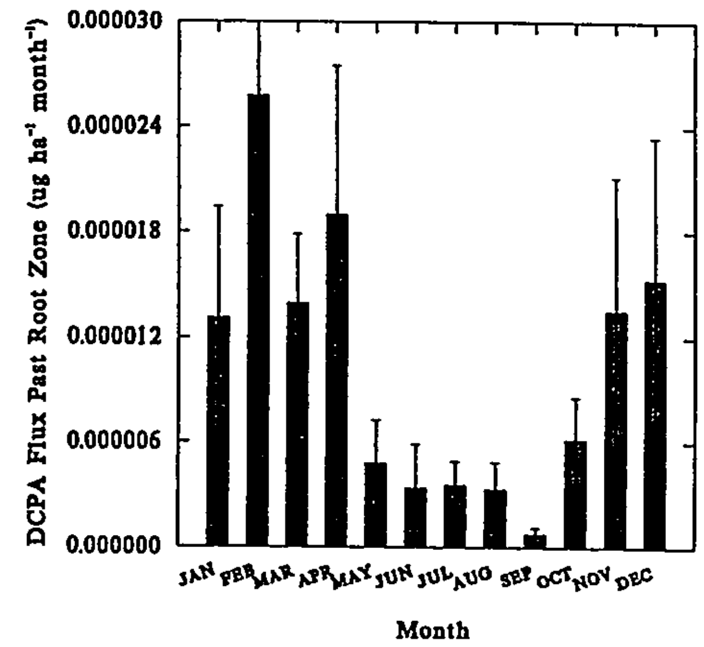


Figure B-132. Mean monthly subsurface movement of DCPA beneath the root zone of a simulated Kolekole fairway soil at the Galbraith Trust Estate. Error bars represent one standard error.

Table B-26. Monthly Concentration of DCPA (ng L^{-1}) Beneath the Root Zone from a 30 Year Simulation of an Established USGA Green on the Proposed Galbraith Trust Estate.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	0.00	0.00
Mean	0.00	0.00	0.00	0.00
SD	0.00	0.00	0.00	0.00
Median	0.00	0.00	0.00	0.00
	May	June	July	August
Minimum	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	0.00	0.00
Mean	0.00	0.00	0.00	0.00
SD	0.00	0.00	0.00	0.00
Median	0.00	0.00	0.00	0.00
	September	October	November	December
Minimum	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	0.00	0.00
Mean	0.00	0.00	0.00	0.00
SD	0.00	0.00	0.00	0.00
Median	0.00	0.00	0.00	0.00

Table B-27. Monthly Concentration of DCPA (ng L^{-1}) Beneath the Root Zone from a 30 Year Simulation of an Established Wahiawa Fairway Soil on the Proposed Galbraith Trust Estate.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	6.43E-11	6.65E-10	6.33E-10	7.93E-10
Mean	5.39E-11	8.14E-11	9.13E-11	9.25E-11
SD	1.10E-10	1.39E-10	1.39E-10	1.21E-10
Median	1.29E-11	2.00E-11	2.56E-11	4.19E-11
	May	June	July	August
Minimum	1.99E-18	1.99E-18	0.00	0.00
Maximum	7.38E-10	7.38E-10	5.36E-10	3.70E-10
Mean	9.08E-11	9.08E-11	5.53E-11	4.52E-11
SD	1.29E-10	1.29E-10	8.81E-11	6.66E-11
Median	4.08E-11	4.08E-11	2.28E-11	1.79E-11
	September	October	November	December
Minimum	1.78E-16	1.23E-16	1.00E-16	1.38E-15
Maximum	2.56E-10	1.85E-10	4.32E-10	7.51E-10
Mean	3.39E-11	3.01E-11	4.07E-11	5.43E-11
SD	4.83E-11	4.19E-11	7.41E-11	1.14E-10
Median	1.25E-11	1.12E-11	1.04E-11	9.30E-12

Table B-28. Monthly Concentration of DCPA (ng L^{-1}) Beneath the Root Zone from a 30 Year Simulation of an Established Kolekole Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	7.45E-09	7.77E-09	7.42E-09	7.47E-09
Mean	5.89E-10	8.51E-10	9.56E-10	9.61E-10
SD	1.25E-09	1.53E-09	1.52E-09	1.28E-09
Median	1.24E-10	1.96E-10	2.92E-10	3.93E-10
	May	June	July	August
Minimum	9.54E-18	6.67E-18	4.61E-18	3.90E-18
Maximum	6.95E-09	5.96E-09	5.04E-09	3.48E-09
Mean	9.36E-10	7.18E-10	5.67E-10	4.68E-10
SD	1.29E-09	1.05E-09	8.64E-10	6.68E-10
Median	3.90E-10	3.04E-10	2.16E-10	1.63E-10
	September	October	November	December
Minimum	8.73E-16	6.03E-16	4.92E-16	7.20E-15
Maximum	2.41E-09	1.68E-09	4.91E-09	8.70E-09
Mean	3.52E-10	3.10E-10	4.34E-10	5.88E-10
SD	4.89E-10	4.18E-10	8.37E-10	1.31E-09
Median	1.13E-10	9.31E-11	9.83E-11	8.96E-11

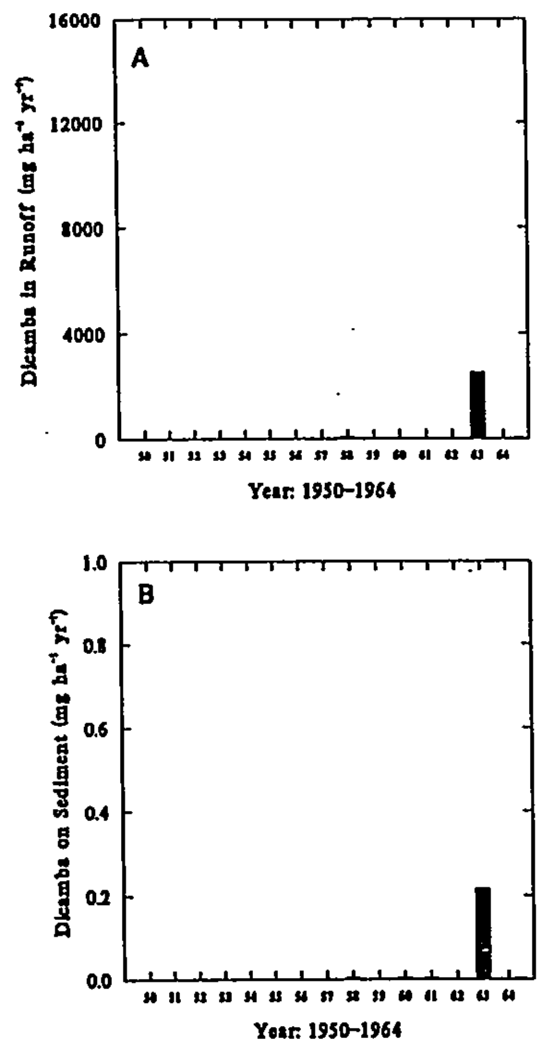


Figure B-133a. Annual surface loss of dicamba in runoff (A) water and (B) sediment from a simulated USGA Green at the Galbraith Trust Estate: 1950-1964.

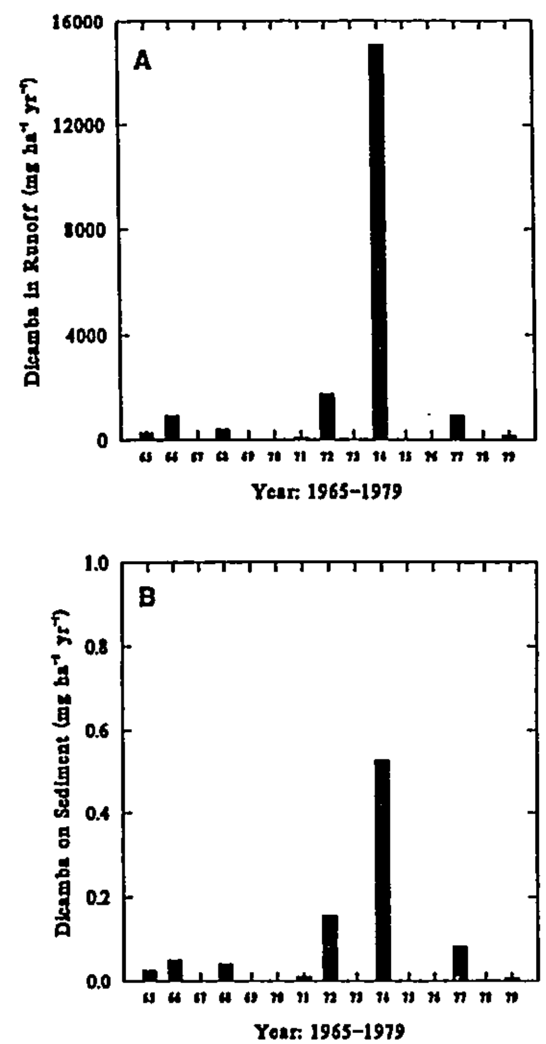


Figure B-133b. Annual surface loss of dicamba in runoff (A) water and (B) sediment from a simulated USGA Green at the Galbraith Trust Estate: 1965-1979.

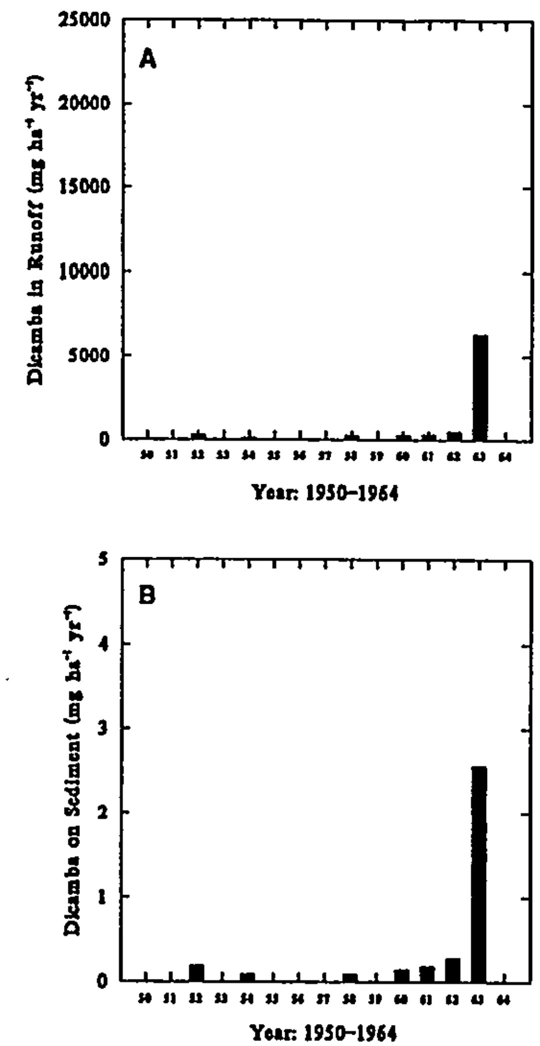


Figure B-134a. Annual surface loss of dicamba in runoff (A) water and (B) sediment from a simulated Wahiawa fairway soil at the Galbraith Trust Estate: 1950-1964.

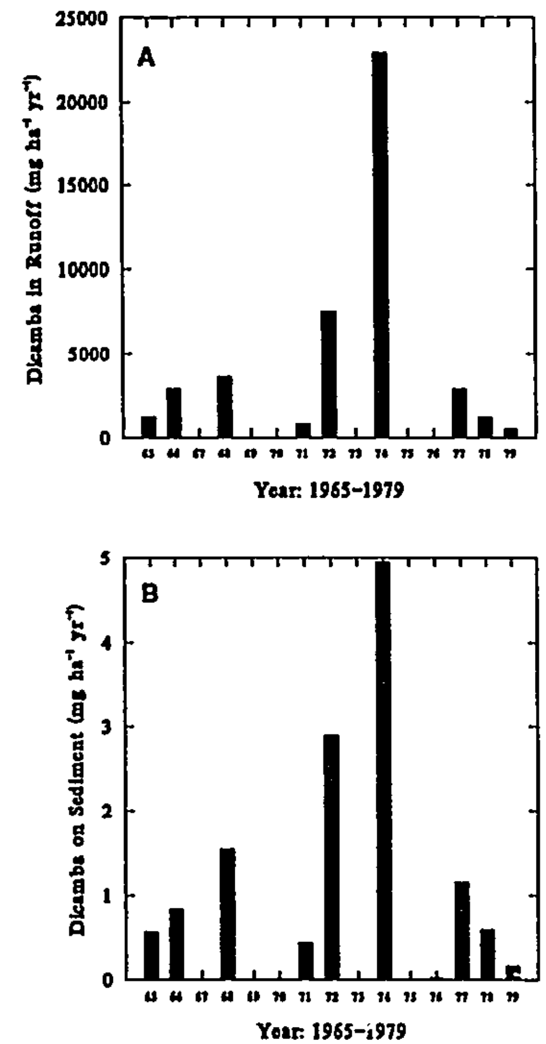


Figure B-134b. Annual surface loss of dicamba in runoff (A) water and (B) sediment from a simulated Wahiawa fairway soil at the Galbraith Trust Estate: 1965-1979.

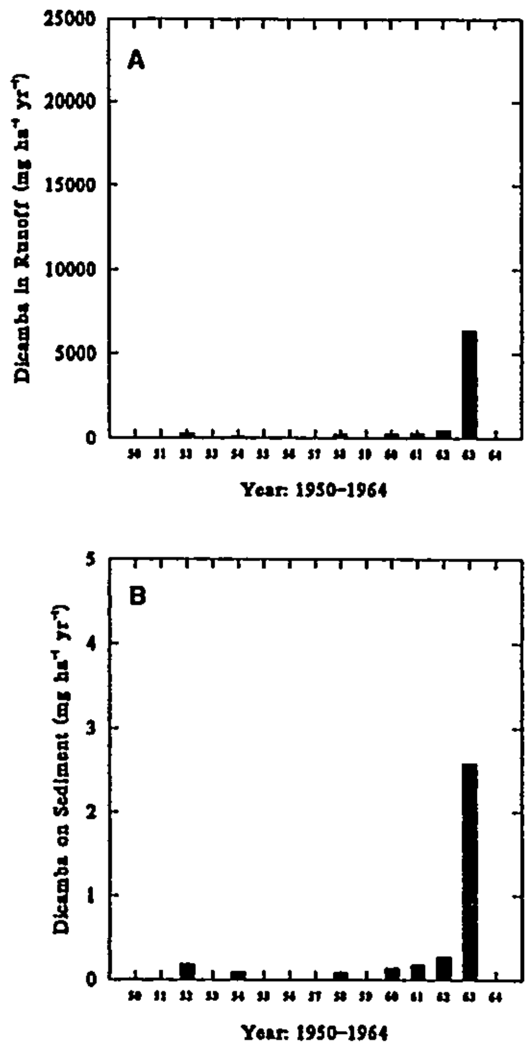


Figure B-135a. Annual surface loss of dicamba in runoff (A) water and (B) sediment from a simulated Kolekole fairway soil at the Galbraith Trust Estate: 1950-1964.

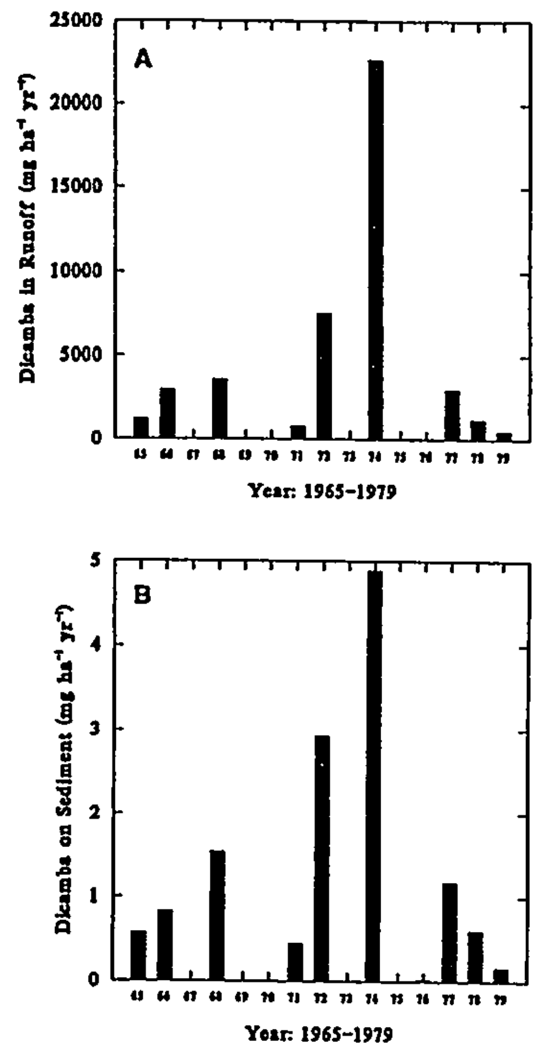


Figure B-135b. Annual surface loss of dicamba in runoff (A) water and (B) sediment from a simulated Kolekole fairway soil at the Galbraith Trust Estate: 1965-1979.

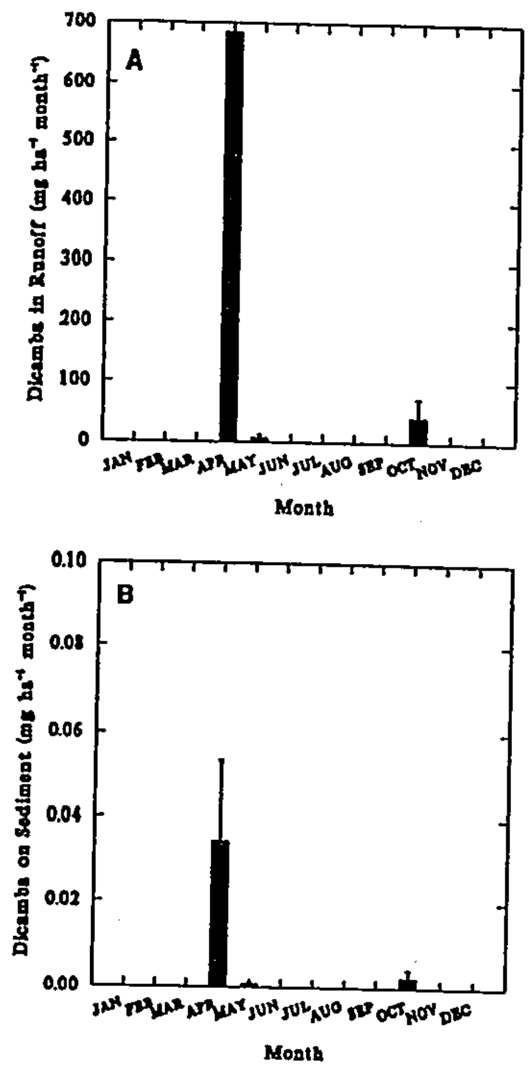


Figure B-136. Mean monthly loss of dicamba in runoff (A) water and (B) sediment from a simulated USGA Green at the Galbraith Trust Estate. Error bars represent one standard error.

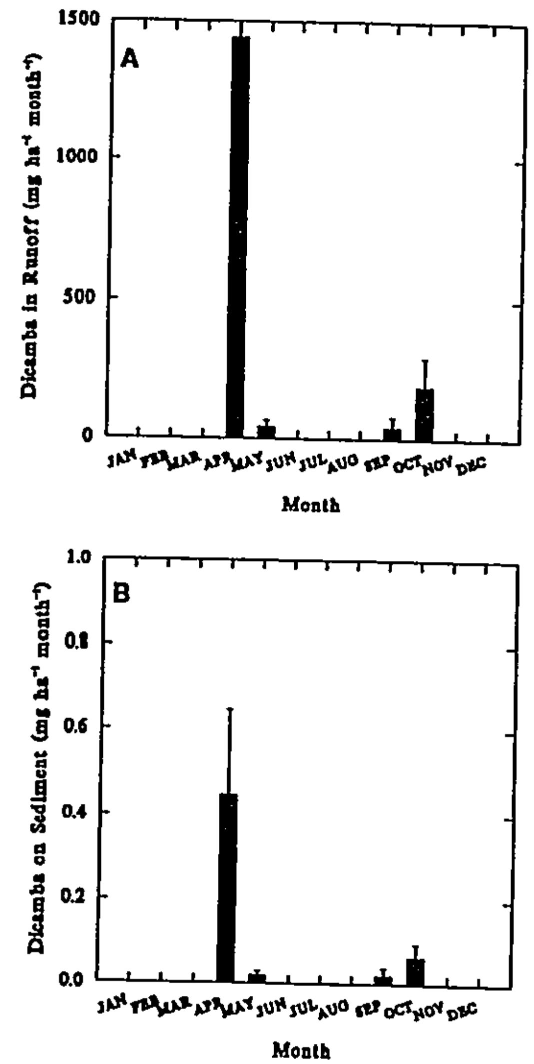


Figure B-137. Mean monthly loss of dicamba in runoff (A) water and (B) sediment from a simulated Wahiawa fairway soil at the Galbraith Trust Estate. Error bars represent one standard error.

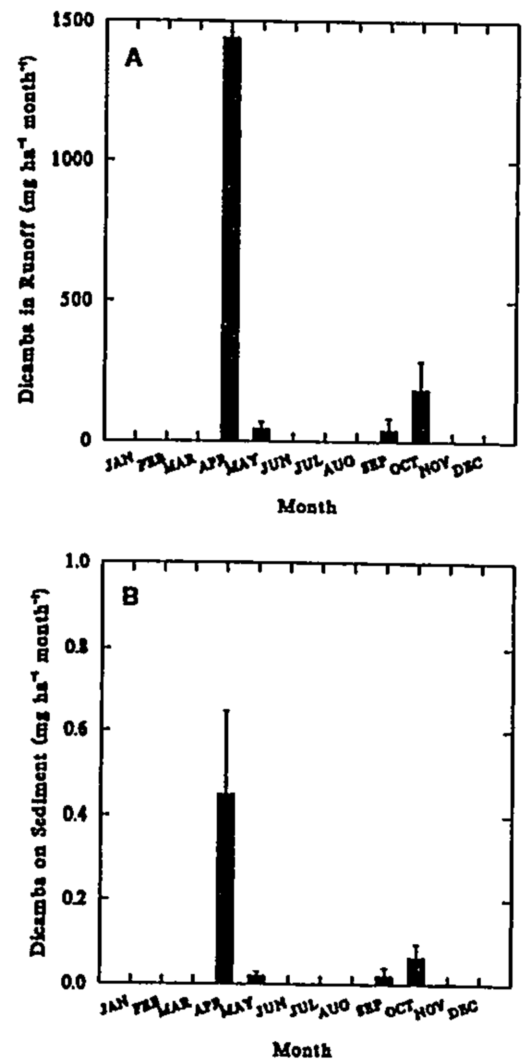


Figure B-138. Mean monthly loss of dicamba in runoff (A) water and (B) sediment from a simulated Kolekole fairway soil at the Galbraith Trust Estate. Error bars represent one standard error.

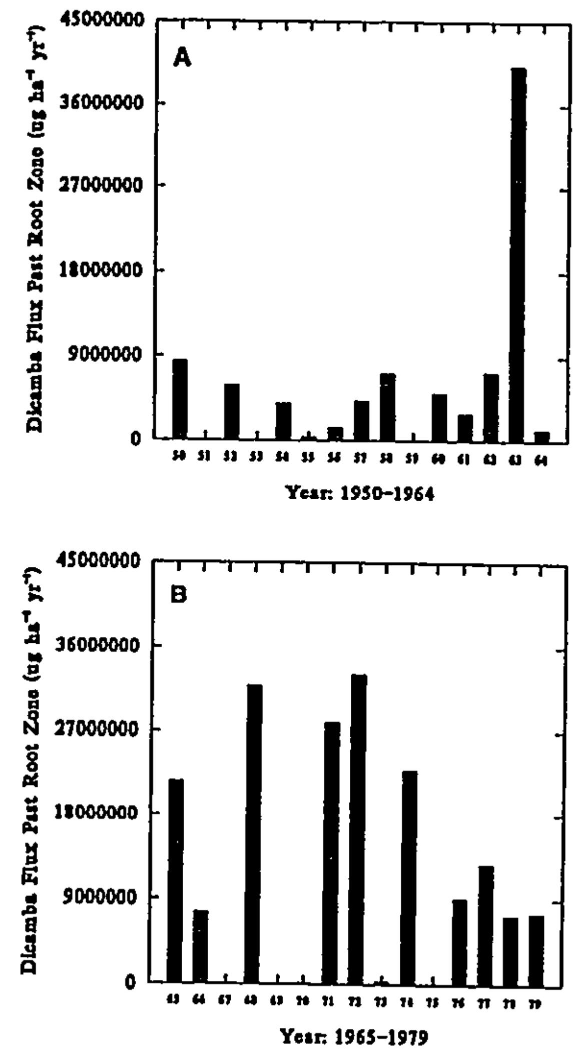


Figure B-139. Annual subsurface leaching of dicamba beneath the root zone of a simulated USGA Green at the Galbraith Trust Estate for (A) 1950-1964 and (B) 1965-1979.

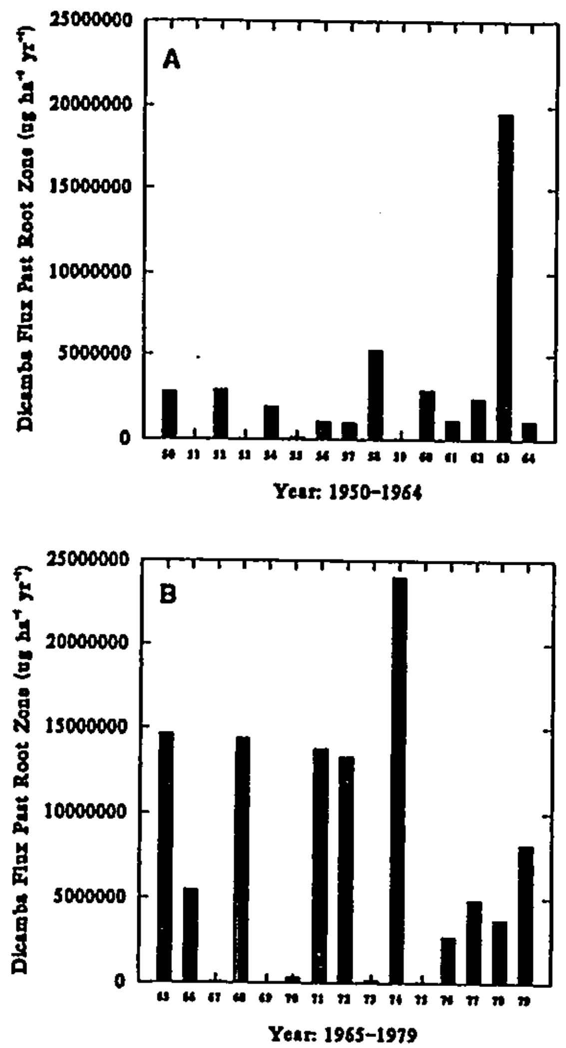


Figure B-140. Annual subsurface leaching of dicamba beneath the root zone of a simulated Wahiawa fairway soil at the Galbraith Trust Estate for (A) 1950-1964 and (B) 1965-1979.

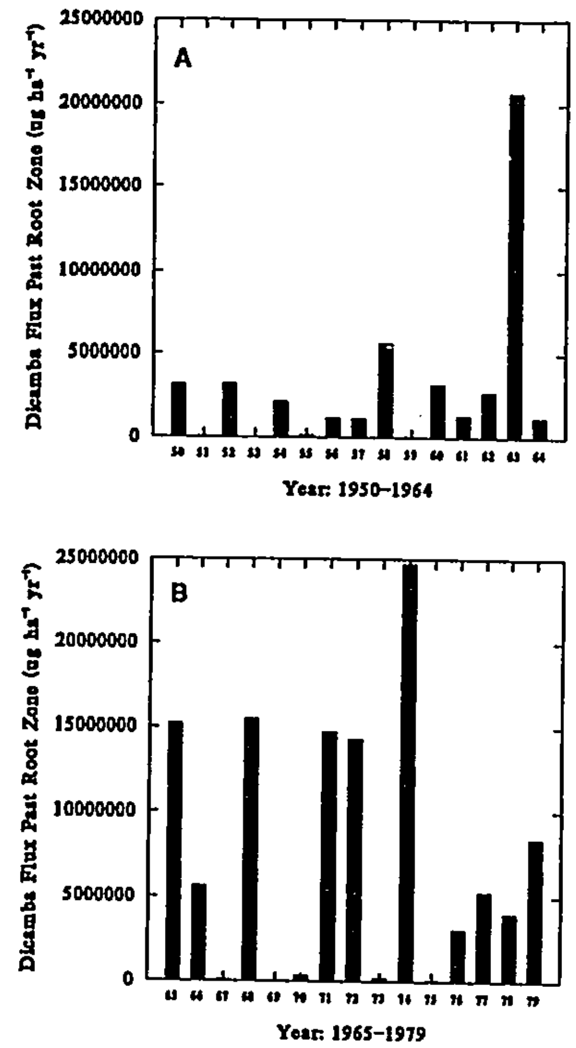
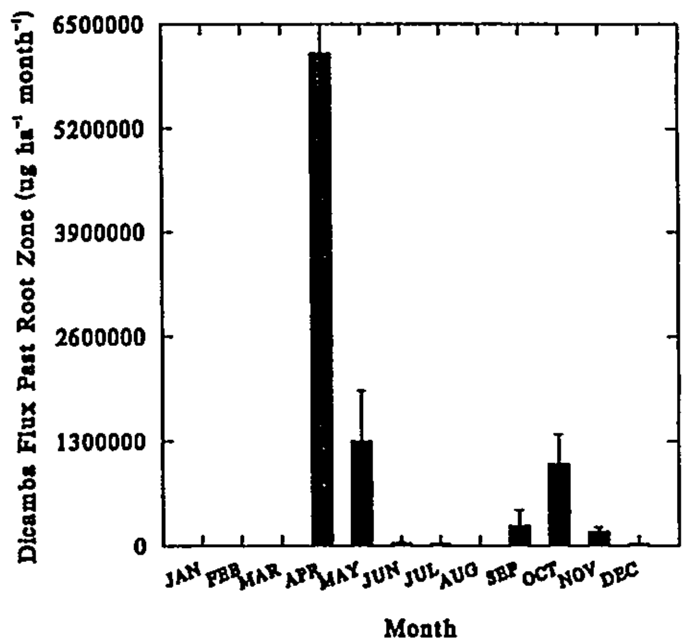


Figure B-141. Annual subsurface leaching of dicamba beneath the root zone of a simulated Kolekole fairway soil at the Galbraith Trust Estate for (A) 1950-1964 and (B) 1965-1979.



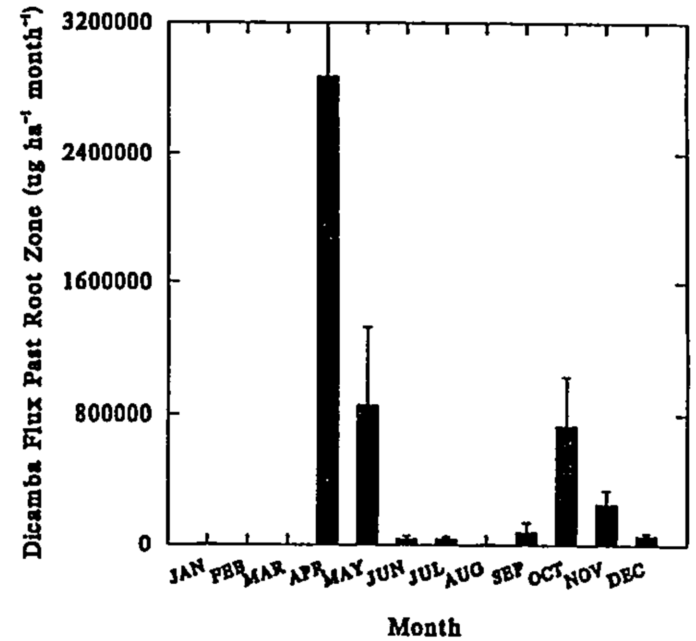


Figure B-142. Mean monthly subsurface movement of dicamba beneath the root zone of a simulated USGA Green at the Galbraith Trust Estate. Error bars represent one standard error.

Figure B-143. Mean monthly subsurface movement of dicamba beneath the root zone of a simulated Wahiawa fairway soil at the Galbraith Trust Estate. Error bars represent one standard error.

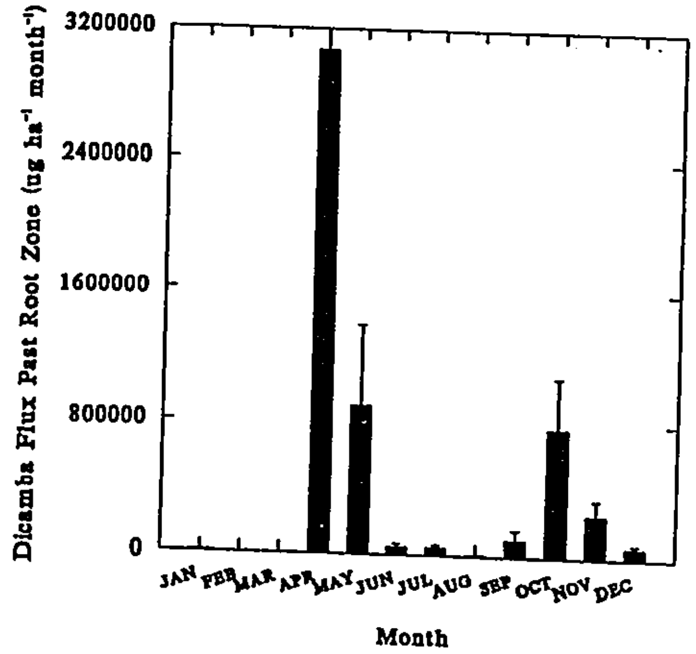


Figure B-144. Mean monthly subsurface movement of dicamba beneath the root zone of a simulated Kolekole fairway soil at the Galbraith Trust Estate. Error bars represent one standard error.

Table B-29. Monthly Concentration of Dicamba (ng L^{-1})[1] Beneath the Root Zone from a 30 Year Simulation of an Established USGA Green on the Proposed Galbraith Trust.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	73.04	14.09	1.12	32340.00
Mean	3.28	0.34	0.03	2240.97
SD	9.24	1.56	0.14	5965.67
Median	2.29E-03	1.04E-04	9.41E-07	9.86E-07
	May	**June**	**July**	**August**
Minimum	1.97E-16	3.99E-17	1.11E-17	3.17E-15
Maximum	16870.00	3392.00	690.60	133.40
Mean	3179.84	731.46	144.26	25.83
SD	3901.81	793.42	162.33	29.22
Median	1329.50	550.85	91.55	15.54
	September	**October**	**November**	**December**
Minimum	6.43E-16	4.04E-12	4.26E-09	2.53E-11
Maximum	15770.00	10370.00	2810.00	468.60
Mean	227.92	915.03	309.98	37.42
SD	1595.87	1878.39	511.71	74.84
Median	2.79	1.06	0.45	0.17

Table B-30. Monthly Concentration of Dicamba (ng L^{-1}) Beneath the Root Zone from a 30 Year Simulation of an Established Wahiawa Fairway Soil on the Proposed Galbraith Trust Estate.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	84.76	16.12	3.12	13980.00
Mean	9.26	0.95	0.11	843.03
SD	16.36	2.44	0.34	2596.61
Median	0.02	1.39E-03	9.85E-05	3.15E-04
	May	**June**	**July**	**August**
Minimum	7.76E-13	1.56E-13	4.31E-14	3.32E-11
Maximum	9342.00	2260.00	513.00	99.55
Mean	1253.56	312.84	86.16	19.59
SD	1816.41	403.35	96.45	18.55
Median	339.75	179.00	53.71	15.38
	September	**October**	**November**	**December**
Minimum	6.66E-12	7.53E-10	3.70E-07	1.27E-07
Maximum	3053.00	4062.00	1930.00	409.50
Mean	45.98	318.52	218.94	70.52
SD	295.94	706.43	352.88	99.80
Median	3.73	1.30	0.47	4.19

Table B-31. Monthly Concentration of Dicamba (ng L^{-1}) Beneath the Root Zone from a 30 Year Simulation of an Established Kolekole Fairway Soil on the Proposed Galbraith Trust Estate, Wahiawa, Hawaii.

	January	February	March	April
Minimum	0.00	0.00	0.00	0.00
Maximum	88.70	16.87	3.09	14340.00
Mean	9.11	0.92	0.10	909.72
SD	16.48	12.46	0.33	2766.33
Median	0.02	1.26E-03	7.77E-05	2.28E-04
	May	**June**	**July**	**August**
Minimum	4.11E-13	8.24E-14	2.28E-14	2.29E-11
Maximum	9929.00	2326.00	523.80	103.00
Mean	1351.47	336.35	91.67	20.61
SD	1917.79	419.65	100.45	19.15
Median	404.50	203.50	58.88	16.56
	September	**October**	**November**	**December**
Minimum	4.60E-12	5.08E-10	3.24E-07	7.72E-08
Maximum	3434.00	4274.00	1996.00	423.30
Mean	51.95	346.63	231.27	71.56
SD	335.46	753.59	368.87	102.84
Median	3.96	1.33	0.48	5.06

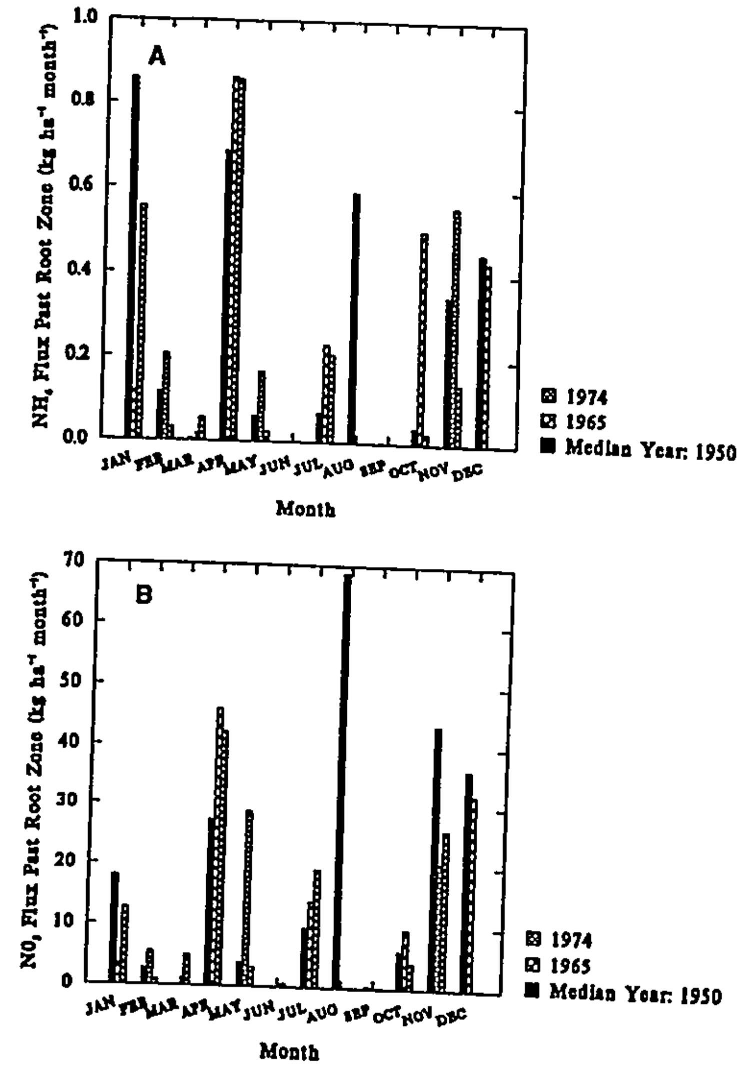


Figure B-189. Monthly subsurface loss of (A) NH_4^+ and (B) NO_3^- from a simulated USGA Green at the Galbraith Trust Estate for 1950, 1965, 1974.

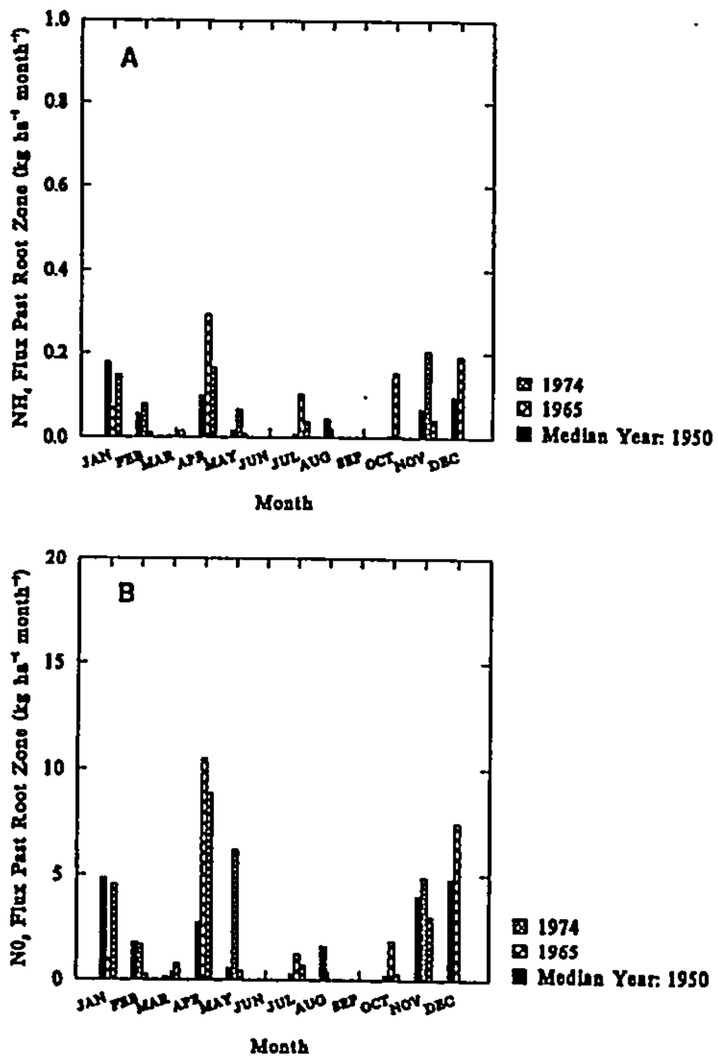


Figure B-190. Monthly subsurface loss of (A) NH_4^+ and (B) NO_3^- from a simulated Wahiawa fairway soil at the Galbraith Trust Estate for 1950, 1965, 1974.

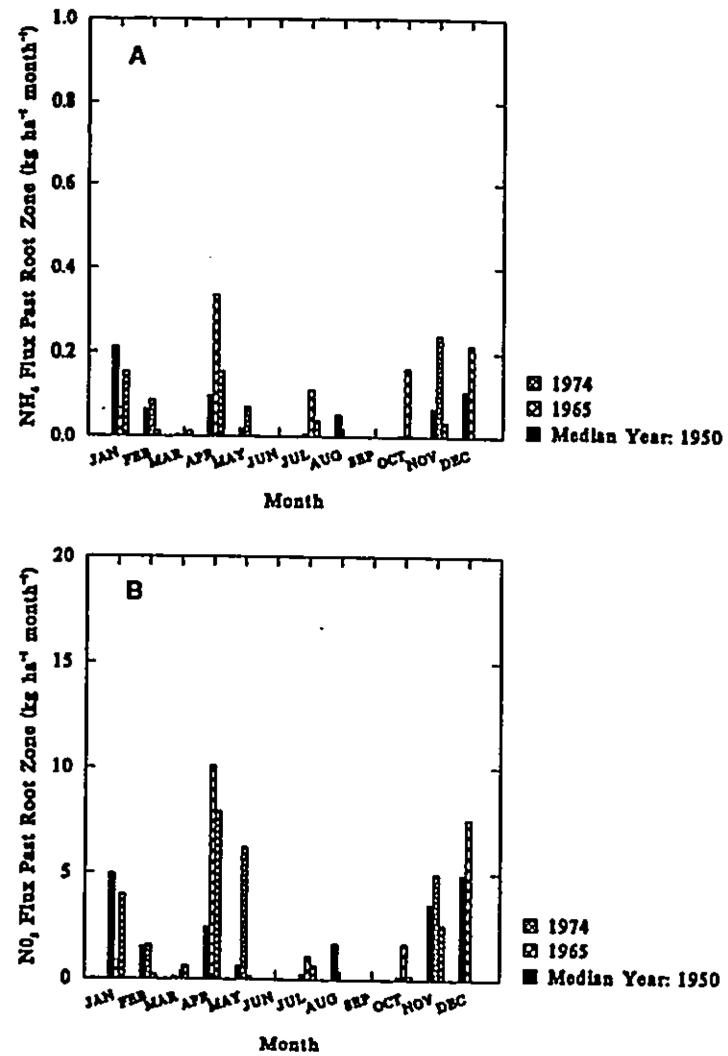


Figure B-191. Monthly subsurface loss of (A) NH_4^+ and (B) NO_3^- from a simulated Kolekole fairway soil at the Galbraith Trust Estate for 1950, 1965, 1974.

APPENDIX B

Groundwater Resources and Supply
Water Resource Associates

GROUNDWATER RESOURCES AND SUPPLY
for
GALBRAITH TRUST LANDS
Wahiawa, Oahu

Prepared for

Helber Hastert & Fee

Water Resource Associates

Honolulu, Hawaii
December 1992

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FIGURE

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MAP

GROUNDWATER RESOURCES AND SUPPLY
for
GALBRAITH TRUST LANDS AT WAHIAWA, OAHU

INTRODUCTION

Proposed Project

The Galbraith Trust Estate is proposing a residential and mixed use development on 900 acres of its lands located north of Wahiawa and west of Whitmore Village (see Figure 1). Approximately 3,000 housing units, a 40-acre business center, a light industrial site, public parks, and a public golf course. The development is expected to have a build-out period of 20 years.

Scope of the Report

This report presents a discussion of the groundwater resources and supply related to the proposed project and evaluates the availability of ground water for the project. Also discussed are the potential impacts on ground water and the mitigative measures which can be undertaken to reduce or eliminate the potential for contamination of the underlying aquifer.

REGIONAL HYDROGEOLOGIC SETTING

Geology

The project site is situated on gently sloping, thin-bedded basalt lava flows which erupted from the Koolau Range. During the shield-building period of Koolau Volcano, innumerable lava flows originated in the Koolau Range and flowed 10 miles westward toward the Waianae Range. Eventually, these lava flows (Koolau) accumulated and banked up against the older, steeply dipping, eroded Waianae lava flows, forming the Wahiawa-Schofield plateau and the gentle slopes of north-central and south-central Oahu. The accumulation of these thin-bedded, permeable Koolau lavas set the stage for the occurrence of three major aquifers--the Wahiawa High-Level Aquifer, the Waialua

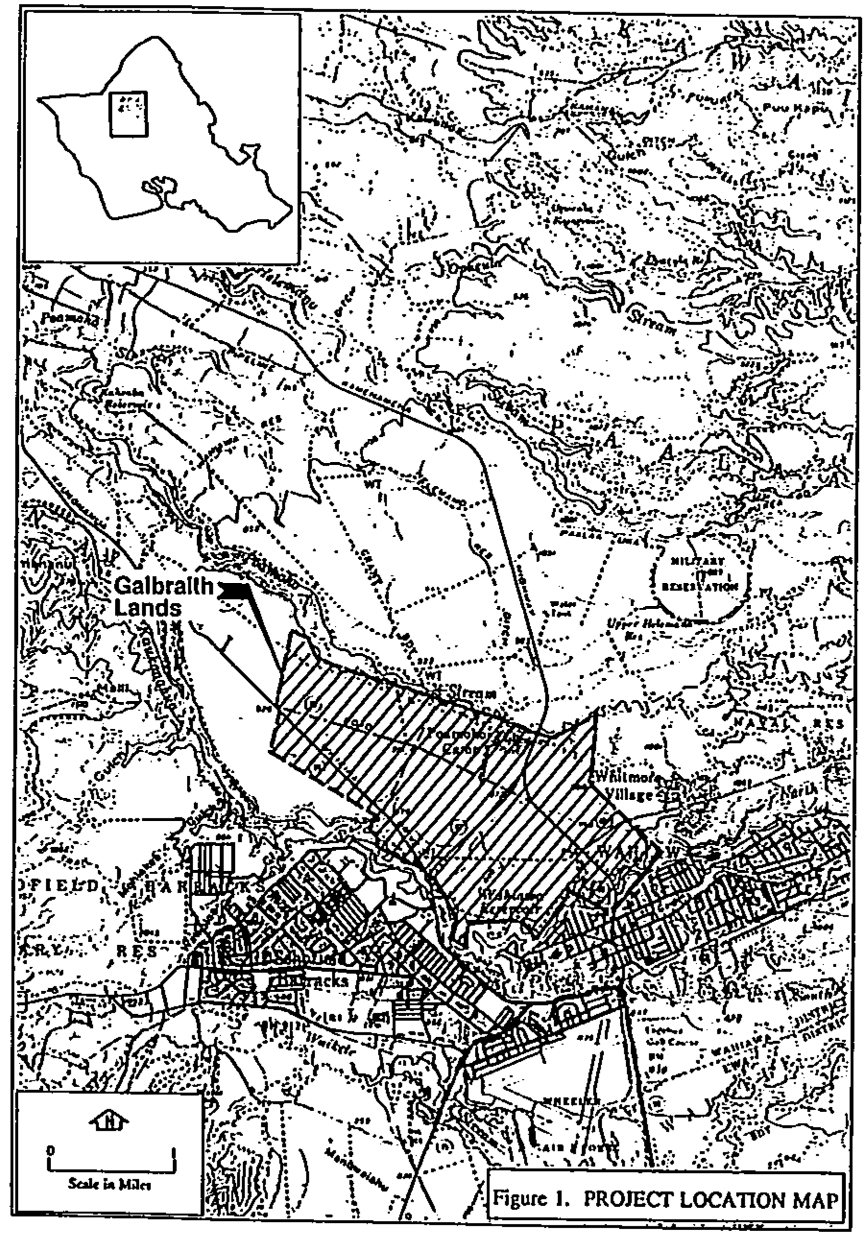

Figure 1. PROJECT LOCATION MAP

Basal Aquifer on the north, and the Koolau (Pearl Harbor) Basal Aquifer on the south. The Koolau lava flows in the Wahiawa area are deeply weathered with a typical horizon consisting of about 20 ft. of residually weathered soils/subsoils, 120 ft. of saprolite, and unweathered basalt below the saprolite. The project site is located in the western portion of the Wahiawa-Schofield plateau.

Groundwater Occurrence

The rugged mountains of the Koolau Range, where rainfall averages between 200 and 250 inches a year, are the primary source of groundwater recharge to the great groundwater bodies of central Oahu (see Figure 2a and Map 1). Rainfall on the Koolau range percolates easily into the ground and sustains ground water at high levels in dike-intruded lavas associated with the Koolau rift zone. Beneath the Koolau Range, east of the Wahiawa plateau, dike-confined groundwater bodies occur at levels approaching 880 feet above sea level and continue to occur northward in the dike-intruded lavas of the rift zone, at gradually declining levels which fall to about 20 feet above sea level at Kawela Bay.

Beneath the Wahiawa plateau, high-level groundwater (referred to as the Schofield high-level body in Figure 2a, but now called the Wahiawa High-Level Aquifer) occurs at a somewhat lower level of about 280 feet above sea level. The Wahiawa High-Level Aquifer covers a 69-square mile trapezoidal area and is bounded on the north and south by groundwater dams consisting of ridges of low permeability formations which are inferred entirely from hydrologic evidence of differential water levels in several wells (see Figure 2a). The cross-sectional width of the southern dam is about a mile across based upon two closely spaced wells, but the width of the northern dam is less well known due to the lack of sufficient well data.

Along the northern boundary and hydraulically downgradient of the Wahiawa High-Level Aquifer occurs the Waialua Basal Aquifer which discharges northward to the coast. This coastal aquifer comprises a 17 square-mile trapezoidally shaped area with Kaukonahua Gulch marking its western boundary and Anahulu River its eastern boundary.

Along the southern boundary of the Wahiawa High-Level Aquifer and hydraulically downgradient, occurs the Pearl Harbor basal water body which embraces an area of 120 square miles and discharges southward to the broad coastal stretch of Pearl Harbor.

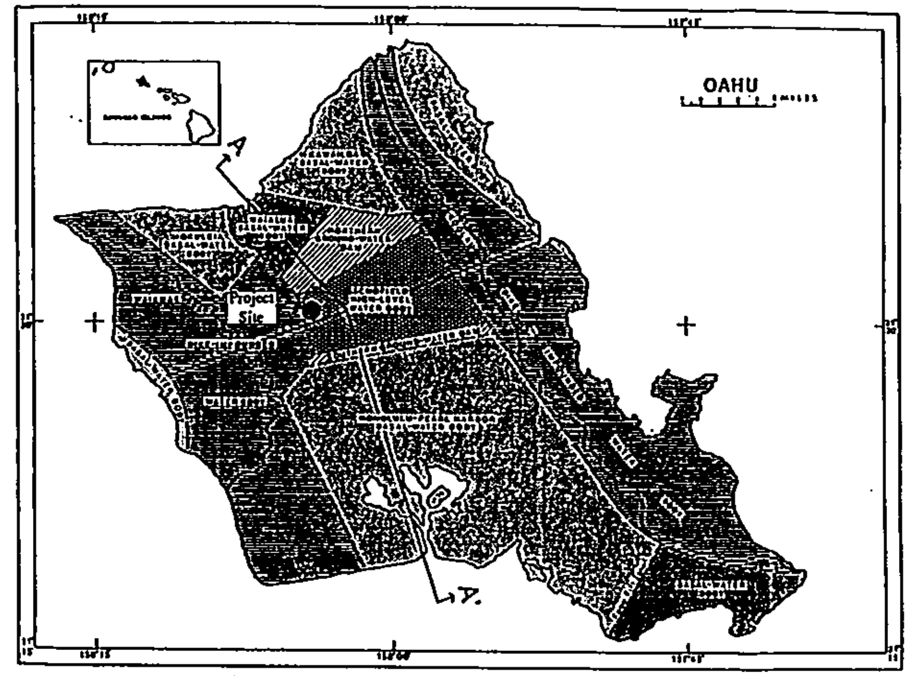

Figure 2a. HYDROLOGIC MAP OF OAHU SHOWING PROJECT SITE
(Modified after Dale & Takasaki, 1976)

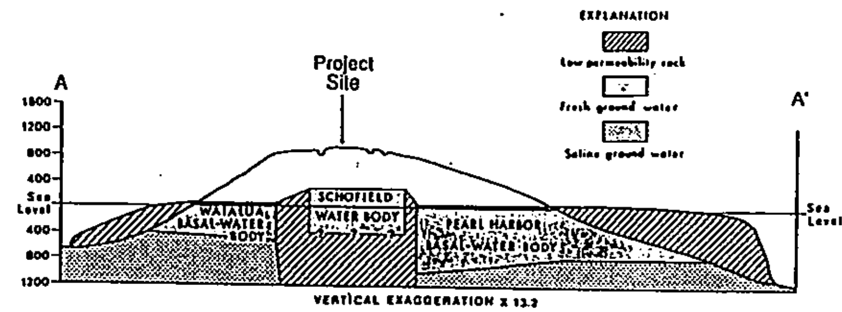

Figure 2b. HYDROLOGIC SECTION A - A'
(Modified after Dale & Takasaki, 1976)

Groundwater Movement

Principal groundwater movement is from the water-rich areas of the Koolau Range, westward toward the Waianae Range. Deep below the surface of the Koolau Range, ground water spills and leaks westward from 880 ft. high, dike-intruded water bodies into the 280 ft. high dike-free Wahiawa aquifer (see Figure 3 and Map 2). Ground water spills and leaks from the Wahiawa aquifer southward into the Pearl Harbor basal aquifer northward into the Waialua basal aquifer (see Map 2). According to Dale and Takasaki (1976), most of the Wahiawa high-level water moves southward into Pearl Harbor basal aquifers.

Hydrologic Sectors and Aquifer Systems

The State Commission on Water Resource Management (CWRM) has divided the island of Oahu into six major hydrologic sectors containing one or more aquifer systems (see Figure 3). Except for the Waianae Sector, the CWRM has designated all hydrologic sectors on Oahu as Water Management Areas (WMA) for the protection and regulation of groundwater resources. Consequently, all wells and groundwater use in these designated areas are now regulated by the CWRM by means of well construction, pump installation, and water use permits.

Of principal interest and direct relationship to the proposed project is the Wahiawa High-Level Aquifer which occurs below the project site. Indirectly related are the downgradient basal aquifers of Waialua, Ewa-Kunia, Waipahu, and Waiawa.

WAHIAWA HIGH-LEVEL AQUIFER

Boundaries

The Wahiawa High-Level Aquifer extends across central Oahu from the Koolau Range on the east to the Waianae Range on the west. As delineated by the CWRM (1990), the aquifer system comprises a trapezoidally shaped area 14 miles long and 4 to 7 miles wide with an area of 68.9 square miles (see Figure 3 and Map 2). The southern boundary strikes easterly through Wheeler Airfield and the northern boundary strikes northeasterly just north of the junction between Wilikini Drive and Kaukonahua Road. Although the Wahiawa Aquifer plays a key role in the occurrence of groundwater resources of north and south central Oahu, its hydrologic boundaries and

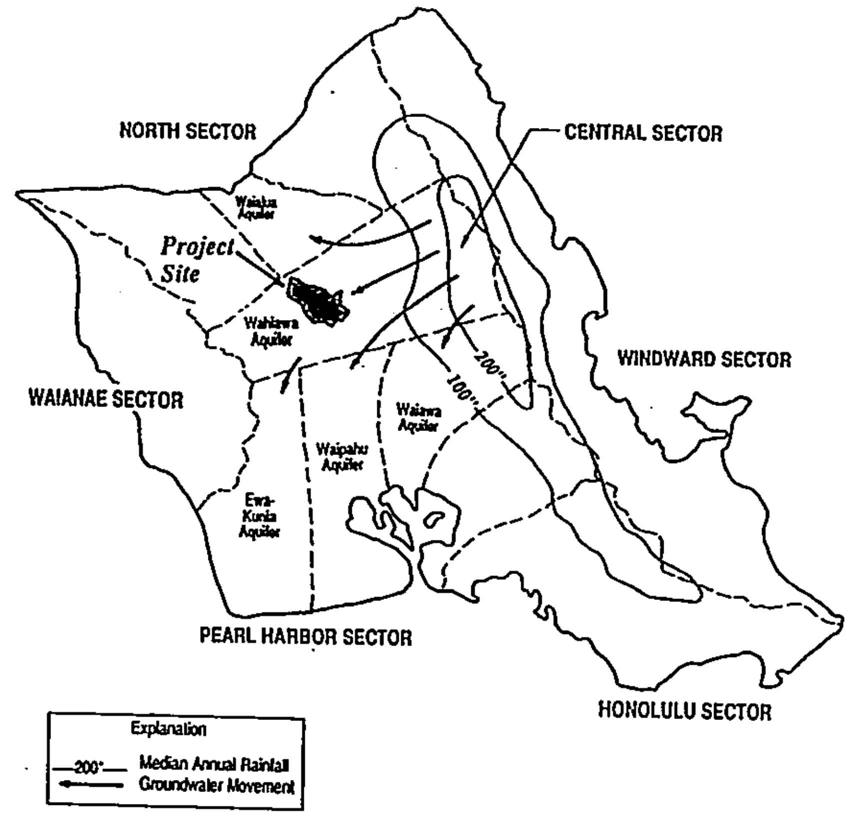

Figure 3. **HYDROLOGIC SECTORS OF OAHU.** Aquifer systems identified in the North, Central, and Pearl Harbor Sectors are related to the proposed project.

features are poorly known due to its complexity and the lack of sufficient well data. The only detailed study of the hydrology of the Wahiawa Aquifer was made by Dale and Takasaki (1976).

The Wahiawa high-level aquifer was discovered in 1936, during the construction of the Schofield Shaft by the U.S. Army (see Map 2, Well ID No. 11). Instead of encountering a basal aquifer with a head of about 30 feet, the Shaft unexpectedly encountered water standing 284 feet above sea level. At first, the ground water was believed to be perched on an ash or soil bed, but later a test boring drilled to a depth of 30 feet below sea level proved the absence of any perching formations.

The location of the northern boundary was first delineated by Swartz (1940) using the electrical resistivity method of geophysical exploration and subsequently confirmed by Waialua Sugar Co.'s Pumps 25 and 26 (3203-01 and 3203-02) as shown in Map 2. The location of the southern boundary is based upon the midpoint between the Army's Schofield Shaft (reported initial head of 284 feet) and an old, now abandoned well (reported head of 24 feet) located about a mile south of the Shaft. The southern boundary passes about 500 feet south of the Navy's Kunia Well 2803-02 (reported head of about 200 feet) located two miles west of the Schofield Shaft.

Water Levels and Groundwater Movement

The Wahiawa Aquifer System is comprised of three distinct water bodies. In the extreme eastern part of the aquifer system, beneath the Koolau Range, high-level groundwater bodies occur in dike-intruded lava flows associated with the Koolau Rift Zone (see Map 2). These rift zone basalts have moderate yields and water levels occurring approximately 880 feet above sea level, based upon water development tunnels constructed beneath the Koolau Range. In the extreme western part of the aquifer system little hydrologic data is available, but groundwater bodies presumably occur at similar high levels in moderate to low yield, dike-intruded Waianae basalts. The bulk of the Wahiawa Aquifer System, however, is comprised of an extensive body of high-level water occurring approximately 280 feet above sea level in dike-free Koolau lava flows extending across the Wahiawa Plateau. Water levels in the Wahiawa Aquifer have been measured and reported at various times by various well owners and methods. Consequently, such data can only be used to give an approximation of the water table and direction of groundwater movement within the aquifer.

Based upon the occurrence of rainfall and the reported heads (water levels) of the various wells in the Wahiawa Aquifer, principal groundwater movement is westward

from the high recharge area of the Koolau Range toward the project site, northward toward the Waialua Basal Aquifer and southward toward the Ewa-Kunia, Waipahu, and Waiawa Basal Aquifers. Relatively minor groundwater movement probably occurs from the suspected higher-level water bodies beneath the Waianae Range toward the Schofield area.

Groundwater Recharge

Most of the groundwater recharge reaching the Wahiawa Aquifer originates as rainfall over the Koolau Range located approximately seven miles east of the project site. Dale and Takasaki (1976), estimated groundwater recharge to the Wahiawa aquifer at 126 mgd (million gallons per day), with 52 mgd coming from the dike-intruded basalts beneath the Koolau Range and 74 mgd coming from direct infiltration of rainfall over the aquifer. Of the 126 mgd, Dale and Takasaki roughly estimated that less than 20%, or 18 mgd, flows north into the Waialua Basal Aquifer, with the remainder flowing south into the Pearl Harbor Sector. However, a more reliable estimate of groundwater recharge is difficult because of uncertainties and lack of good data concerning the subsurface inflows and outflows of the system. Probably because of this difficulty, no other detailed hydrologic analysis of recharge has been made since Dale and Takasaki's 1976 study.

Sustainable Yield

Sustainable yield, as used in Hawaii and by the Commission on Water Resource Management, is by definition the amount of water that can be developed overall from an aquifer on a long-term basis without affecting the aquifer's utility or water quality relative to salt water intrusion. The term was originally developed for basal aquifers, but is also applied to high-level aquifers because they are often interrelated with the sustainable yield of downgradient basal aquifers.

The Wahiawa High-Level Aquifer affects the sustainable yield of the Waialua, Ewa-Kunia, Waipahu, and Waiawa basal aquifers. Consequently, the Commission on Water Resource Management in October 1991 arbitrarily set the sustainable yield of the Wahiawa Aquifer at 23 mgd, the equivalent of existing authorized water uses in the aquifer.

Water Quality

The Wahiawa Basal Aquifer is not subject to salt water intrusion because it is a groundwater system confined at high level by low permeability hydrogeologic structures or dikes. The aquifer produces potable water with a low chloride content of about 30 ppm (250 ppm is the arbitrary limit for potable drinking water).

Volatile organic chemicals (the pesticides DBCP, EDB, and Shell DD with TCP as an impurity) have been used for many years as soil fumigants in pineapple fields overlying the Wahiawa and other aquifers of central Oahu. The first survey of organic chemicals in potable water sources on Oahu was conducted in 1971, and during the 1980's various investigations concerning organic chemical contamination of ground water in the Pearl Harbor region were conducted, primarily by the University of Hawaii Water Resources Research Center (Orr and Lau, 1987; Lau, 1987; Miller, et al, 1988; and Orr and Lau, 1988). DBCP and TCP were found to be relatively widespread in wells located in and downgradient of pineapple fields. However, with the discontinued use of DBCP in pineapple fields, modeling studies predicted a decline in DBCP levels in the Mililani area to less than regulated contaminant levels by the year 2000 (Lau, 1987, p. 113).

DBCP and TCP were detected in the northern portion of the Wahiawa High-Level Aquifer in two wells (Well Nos. 7 and 8, Map 2), but not in its southern portion in a Board of Water Supply well located 2.7 miles south in Wahiawa town.

Most recently, based upon groundwater contamination maps prepared by the Department of Health in December 1991, DBCP and TCP were detected in several irrigation well sources in the Waialua and Wahiawa aquifers, but at levels well below existing standards.

HYDROLOGIC CHARACTERISTICS OF SUBSURFACE FORMATIONS

Existing Conditions

The project site, similar to all of central Oahu from Pearl Harbor to Waialua-Haleiwa, is underlain by thin-bedded Koolau basalt lava flows which have been weathered to an average depth of about 150 feet. In-place weathering of these basalts in a humid, sub-tropical to tropical environment during the geologic past has produced a distinctive reddish-brown lateritic soil-saprolite profile. Within the project site,

approximately 20 feet of reddish-brown soil and subsoil overlie about 120 feet of saprolite below which occurs unweathered basalts, based upon data from Del Monte Well 5 (State Well No. 3103-01) located in the project site. Saprolite is a geologic term used to describe basaltic rocks which have been thoroughly weathered and decomposed to clay material, but which retain (in the undisturbed state) recognizable textural features of the parent rock. Below the saprolite interval, which gradually becomes less weathered with depth, the unweathered basalts actually range from unweathered in dense rock to highly weathered in joints, clinkers, and interflow zones. Overall, the basalts are very permeable and yield ground water readily to wells.

Within the project site, the groundwater table lies approximately 580 to 700 ft. below the ground surface which ranges from approximately 860 to 980 ft. in elevation. The subsurface strata above the aquifer are unsaturated and consist of 20 ft. of soil/subsoil, 120 ft. of saprolite, and 440 to 560 ft. of unweathered basalt.

Current and past use of the project land has been for pineapple cultivation. Consequently, the soils may contain some residual DBCP, a soil fumigant that is no longer used in pineapple fields.

Leachability of Residual DBCP Pesticide in Soil-Saprolite

Because the geology and hydrologic characteristics of the subsurface strata in the project site are similar to that in the Pearl Harbor, the results of extensive investigations in the Pearl Harbor region concerning the potential of residual pesticides in soils and saprolites to contaminate underlying ground water are applicable to the project site. During 1985-1989, the University of Hawaii Water Resources Research Center conducted a number of studies relating to volatile organic chemical (VOC) contamination of ground water. Some of these studies assessed the potential release (leachability and desorption) of residual pesticides in soil-saprolite caused by percolation of rainfall or irrigation water.

Based upon laboratory analyses of soil samples contaminated with DBCP and obtained from eight fields on Oahu and Maui, Lau (1987) found that the residual pesticides in soils in the Mililani area do not constitute a significant source for future groundwater contamination, because the pesticide residues are held tightly in the sorbed state on the organic carbon content (2 to 4%). Using a water-balance model, Lau indicated that the amount of residual pesticide capable of contributing to groundwater contamination during any one rainfall event is on the order of one thousandth to one millionth of the amount of the residual pesticide retained in the soil (Lau, 1987, p. 36).

Furthermore, the leachate from such a rainfall event would likely be diluted by large quantities of uncontaminated water from other sources and, thus, reduces even further any impact of residual pesticides in soils on groundwater quality (Lau, 1987, p. 61). These conclusions for DBCP are also applicable for EDB, which is present at much lower concentrations than DBCP and is much less persistent in soils.

The vertical distribution of residual pesticides in soil, subsoil, and saprolite was also determined from sampling deep boreholes in the Pearl Harbor basin of central and southern Oahu. The highest concentration of pesticides occur in the surface soil layer (about 3 feet) due to strong sorption by the high content of organic carbon (4%). No pesticides were detected in the subsoil layer (3 to 20-foot depth) plausibly due to a sharply lower organic carbon content of less than 1% (below 3 to 7-foot depth) and 0.1% at a depth of 20 feet. Surprisingly, below the subsoil layer in the saprolite layer (20 to 45-foot depths) residual pesticides reappeared and is believed to be due to the presence of kaolinite and halloysite clay minerals. Lau (1987) surmises that the entrapment of pesticides in the micropores of halloysite is temporary and such residual pesticides can be released very slowly.

In two boreholes located in the southernmost and lowest rainfall area of investigation, residual pesticides were completely absent at all depths. This absence, which could not be explained, was contrary to expectations of high retention of pesticides associated with the abundant occurrence of the clay mineral, nontronite, which has a high surface area. However, Lau suggests that the absence of pesticides in the two boreholes may be related to their location in a low rainfall area (30-inch annual rainfall) resulting in high volatile losses and insignificant leaching of pesticides from the surface soil layer into the nontronite clay zone.

Vertical Infiltration Rate of Rainfall

As mentioned earlier, the subsurface strata of soil, saprolite, and basalt lava flows beneath the project site is similar to that of all central Oahu, including the Pearl Harbor area where numerous groundwater hydrology studies have been conducted.

Eyre (1987) estimated that the average vertical infiltration rate of rainfall, downward through soil-saprolite, is 15 feet per year. This value is considered to be a gross average, because during dry periods infiltration may cease completely and during a rainstorm event in which three inches of rainfall may occur in a few hours, the rate may be considerably more than the average rate. Eyre's estimate was based upon soil

boring data collected in a pineapple field located in the Mililani area, where rainfall averages about 100 inches a year.

The average vertical infiltration rate through unsaturated permeable basalts underlying the soil-saprolite strata is considerably greater. Eyre (1987) estimated an infiltration rate of 400 feet per year for permeable Koolau basalts, based upon a statistical analysis of 22 years (1937-1958) of monthly rainfall and water level data in the Wahiawa area.

EXISTING WELLS AND WATER USE

Wells

A total of 29 wells and one test hole have been drilled in the Wahiawa High-Level Aquifer, according to records of the State Water Commission on Water Resource Management.

The aquifer was first discovered and developed by the U.S. Army in 1936 at the Schofield Shaft. Other wells were gradually developed over the next several decades by the U.S. Navy for its Wahiawa facilities, Del Monte Corp. for pineapple irrigation, Waialua Sugar Co. for sugar cane irrigation, and the Honolulu Board of Water Supply for municipal use. The location of all existing wells is shown on Map 2 and a summary of the records of these wells are shown in Table 1.

Reported Water Use

Currently, there are only four water users in the Wahiawa Aquifer System developing a total of 10.067 mgd (1991) of potable ground water. The U.S. Army is the largest user (42%) and has the Schofield Shaft (which has four wells) located about a mile south of the project site at the south edge of Wahiawa town. The Honolulu Board of Water Supply is the second largest user (36%) and has three wells located in Wahiawa town near the Schofield Shaft. Dole Foods' and Del Monte's usage for irrigation of their pineapple fields account for 10% and 12%, respectively, of the total water use from the aquifer. Dole Foods utilizes one of Waialua Sugar Co.'s well located north of the project site (see Map 2, Well I.D. No. 8) and Del Monte utilizes its well which is located in the western part of the project site (see Map 2, Well I.D. No. 5). A breakdown of the water use from the aquifer is shown in Figure 4.

Table 1. RECORD OF WELLS IN THE WAHIAWA AQUIFER SYSTEM

Map 1 ID No.	Well Name	Owner or User	State Well No.	Year Drilled	Ground Elev. (ft.)	Cag. Dia. (in.)	Cag. Depth (ft.)	Well Depth (ft.)	Initial Static Head (ft)	Pump Cap. (mgd)	Draft (mgd)	Chl. (ppm)	Use
1	Waikele Dev Tun	Del Monte	2805-01	1910	950	--	--	--	--	.18	--	67-86	Unu
2	Waianae Uka	Del Monte	2904-01	1941	950	12	170	170	--	.04	--	19-28	Unu
3	Kunia	US Navy	2803-01	1957	866	1	1020	1020	192.2	--	--	--	--
3	Kunia Batt.	US Navy	2803-02	1958	860	16	892	1020	191.8	--	1.8	26	--
3	Kunia Batt.	US Navy	2803-03	1958	863	16	897	1020	203.6	--	--	25-28	Unu
3	Kunia Batt.	Del Monte	2803-05	1959	857	16	887	1020	277.4	--	--	26-30	Irr
3	Kunia	Del Monte	2803-07	1979	872	16	830	990	201.0	2.16	--	62	Irr
4	Kunia	US Navy	2803-04	1959	757	--	--	757	273.0	--	--	--	--
4	Kunia Batt.	US Navy	2803-06	1959	757	16	604	646	276.8	--	--	28-37	Unu
5	Del Monte 5	Del Monte	3103-01	1988	965	18	834	1066	280	--	--	--	Mun
6	Helemano P25	Waialua Sugar	3203-01	1974	860	20	910	1070	123.3(a)	4.46	--	19	Irr
7	Helemano P26	Waialua Sugar	3203-02	1975	927	20	973	1123	165.5	4.50	--	14	Irr
8	Helemano	Waialua Sugar	3102-01	1972	965	20	860	960	265.2	--	--	--	Sld
8	Helemano	Waialua Sugar	3102-02	1973	960	20	867	977	269.0(a)	--	--	18	Irr
9	Wahiawa Exp 1	Honolulu BWS	2902-01	1974	866	20	836	968	275.8	--	--	18	Obs
10	Wahiawa Wells	Honolulu BWS	2901-08	1941	870	16	650	880	275.4	3.46	3.6	19-23	Mun
10	Wahiawa Wells	Honolulu BWS	2901-09	1947	873	18	633	990	275.0	3.46	--	20-22	Mun
10	Wahiawa Wells	Honolulu BWS	2901-11	1962	873	20	652	821	272.9	2.16	--	21	Mun
11	Schofield Batt	US Army	2901-01	1936	287	17	36	140	--	--	--	19-26	Obs
11	Schofield Batt	US Army	2901-02	1936	287	17	--	150	284.0	2.30		19	Dom
11	Schofield Batt	US Army	2901-03	1936	287	17	86	140	--	2.88		18-36	Dom
11	Schofield Batt	US Army	2901-04	1936	287	17	203	264	--	2.88		18-36	Dom
11	Schofield	US Army	2901-05	1936	276	--	43	300	--	--	--	--	--
11	Schofield Batt	US Army	2901-06	1938	276	17	80	264	--	--	--	--	--
11	Schofield	US Army	2901-07	1938	850	90	--	1080	550.1	--	--	18	Mun
11	Schofield	US Army	2901-10	1956	287	16	278	287	--	2.88	--	19	Dom
12	Wahiawa	US Navy	3100-01	1941	1145	18	--	548	--	--	--	--	Unu
12	Wahiawa	US Navy	3100-02	1942	1145	14	968	970	288.0	--	--	22-29	Dom
13	Wahiawa	Wahiawa Water	3059-01	1940	966	18	--	209	--	--	--	--	Unu
13	Wahiawa	Wahiawa Water	3059-02	1941	966	16	162	765	304.0	--	--	--	Unu

(a) Static head reading, after well in service.
Source of Data: Commission on Water Resource Management

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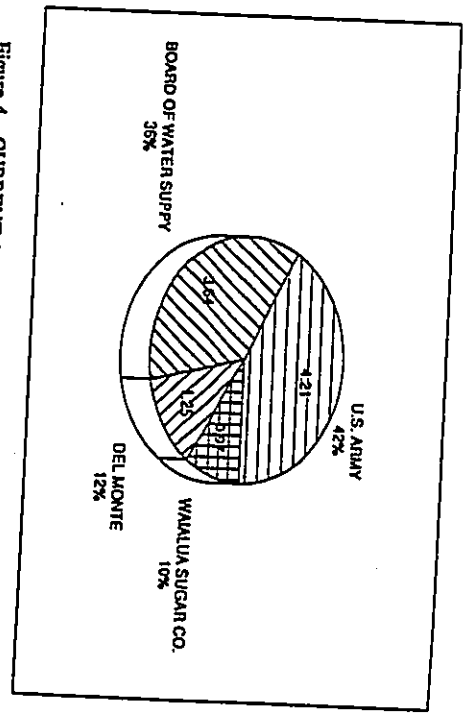

Figure 4. CURRENT (1991) WATER USE, Wahiawa Aquifer System (million gallons per day)

Authorized Water Use

The Commission on Water Resource Management has designated the Wahiawa Aquifer System for groundwater resource management. Consequently, all groundwater development and use is regulated by the Commission through the permitting process for Well Construction Permits, Pump Installation Permits, and Water Use Permits. Fourteen wells have been given authorized water uses totaling 22.531 mgd. However, the reported actual water use from these wells amounted to only 10.067 mgd in 1991 and has averaged 9.748 mgd during the five-year period 1987-1991 (see Table 2).

PROJECT WATER REQUIREMENTS

The anticipated future potable water requirements for the proposed project have been estimated by Sam O. Hirota, Inc., the project's engineering consultant, to be 2.9 mgd (average day demand).

Table 2. EXISTING GROUNDWATER USE AND ALLOCATIONS IN THE WAHIAWA AQUIFER SYSTEM

Map 1 ID No.	Well Source (Owner)	State Well No.	Sus. Yield (mgd)	Authorized Use (mgd)	Reported Water Use (mgd) 1987	1988	1989	1990	1991	1987-91 Ave. Water Use (mgd)
3	Del Monte Corp (Private)	2803-05,07		2.121	-	1.575	1.495	1.249	1.225	1.386[a]
5	Del Monte Corp (Private)	3103-01		2.000	-	-	-	0.045	0.024	b
6	Pump 25 (Waialua Sugar)	3203-01		3.100	0.132	0	0	0	0	c
7	Pump 26 (Waialua Sugar)	3203-02		2.760	0.556	0.022	0	0	0	d
8	Pump 24 (Waialua Sugar)	3102-02		2.580	0.580	0.552	0.867	0.351	0.969	0.744
9	Wahiawa II (BWS)	2902-01		1.000	0	0	0	0.398	0.864	e
10	Wahiawa (BWS)	2901-08,09,11		3.270	3.549	3.878	3.591	3.255	2.772	3.409
11	Schofield Shaft (Army)	2901-02,03,04,10		5.700	3.491	4.134	4.535	3.918	4.213	4.058
	Total		23.0	22.531	8.408	10.581	10.488	9.216	10.067	9.748

Source of Data: Commission on Water Resource Management

a 1988-91 average water use.
b Pumpage commenced in 1990.
c Water usage for one month only in 1987.
d Water usage for one month only in 1988.
e Pumpage commenced in 1990.

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AVAILABILITY OF GROUND WATER

The availability of ground water to meet the potable water requirements of the proposed project depends upon the regulations of the State Commission on Water Resource Management (CWRM) because all of the aquifers of central Oahu have been designated as water management areas for the control of groundwater use and development. Hydrologically, however, ground water can be readily developed from wells tapping the high level aquifer that underlies the project site and the Wahiawa Plateau.

The CWRM regulates groundwater use in water management areas primarily by establishing the sustainable yield and issuing water use permits for each well source within an aquifer. The Wahiawa Aquifer, in which the project site is located, has an established sustainable yield of 23.0 mgd and permits have been issued for a total authorized use of 22.531 mgd, leaving a balance of only 0.469 mgd of unallocated water use, which is available through the issuance of a water use permit assigned to an existing or new well source.

However, to have water available for the project the CWRM must first adjust (lower) the authorized water use of wells in the Wahiawa Aquifer by reason of partial or total nonuse for a period of four continuous years or more. The Commission has taken such actions in the Pearl Harbor Hydrologic Sector where existing authorized uses and requested new water uses have exceeded the sustainable yield. As shown in the bar graph (Figure 5), the actual water use (1991) reported to the CWRM in the Wahiawa aquifer totals 10.067 mgd, or 12.464 mgd less than the authorized use. Thus, ground water for the proposed project could possibly be made available from the CWRM by applying for a new water use permit.

PROPOSED WELL SITES

No water system is available to provide the anticipated potable water requirements of the project and, therefore, a new water system must be developed, including well sources, reservoirs, and transmission/distribution pipelines. Assuming that the new water system will be dedicated to the Honolulu Board of Water Supply (BWS), all facilities must meet their requirements and approval. The water system will

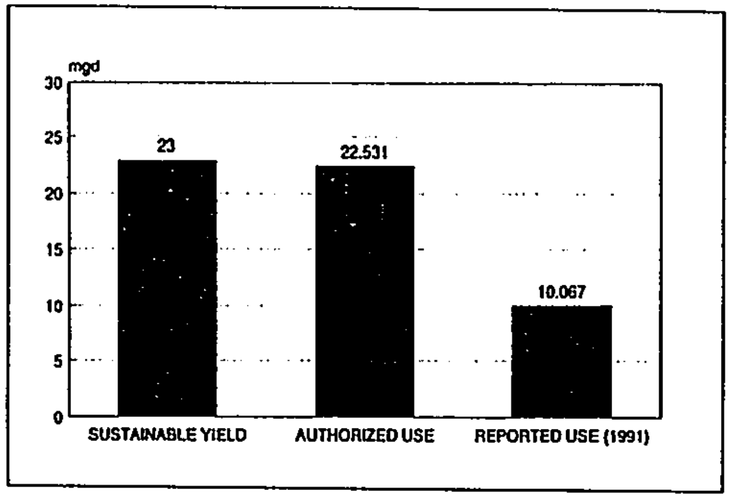


Figure 5. WATER SUPPLY AND WATER USE, Wahiawa Aquifer System (million gallons per day)

be planned by Sam O. Hirota, Inc., engineering consultant for the project. However, the location of alternative well sites are covered in this report.

Normally, the BWS requires a source pump capacity equal to 2.25 times the average day demand. Based on an estimated 2.9 mgd average day demand, a total source pump capacity of 6.5 mgd will be required for the proposed project at full build-out. Hydrologic indications are that this total capacity can be provided by four wells having a pump capacity of 1.6 mgd each, or possibly by three wells having a pump capacity of 2.2 mgd each..

Alternative I

From an engineering and economic standpoint, it would be preferable to locate the wells in the required storage tank. According to Sam O. Hirota, Inc., preliminary indications are that two storage tanks will be needed and will have to be located off-site at an elevation of approximately 1,080 ft. Two potential tank sites meeting this elevation requirement, are located in the vicinities of Helemano Military Reservation and Whitmore Village (see Figure 6). The first alternative would be to locate the two

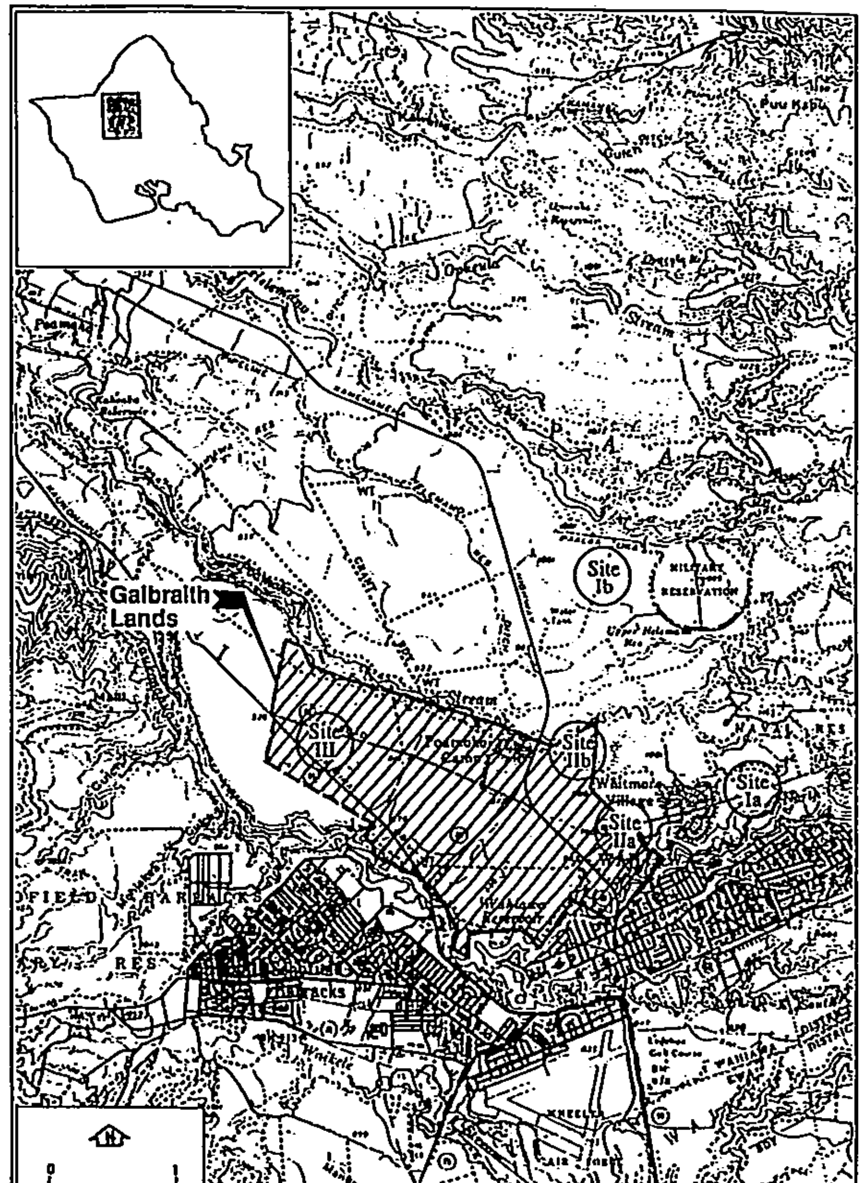


Figure 6. PROPOSED ALTERNATIVE WELL SITES
Galbraith Project, Wahiawa, Oahu

required tanks east of Whitmore Village and acquire sites large enough to accommodate the drilling and development of three wells (Site Ia). Access and easements would be facilitated along Whitmore Road. Site Ib is an alternate to Site Ia.

Alternative II

Should it not be possible to acquire such combined well and tank sites, the second alternative would be to locate the necessary wells within the project site as shown in Figure 6 (Well Sites IIa and IIb). This alternative would require separate pipelines to boost the water approximately 3,000 feet from the wells to the required storage tanks.

Alternative III

An existing well (3103-01) with a capacity of approximately three mgd, is located in the western part of the project site (see Figure 6, Well Site III). The well was drilled by Del Monte in 1988 for irrigation of its pineapple fields and was placed in production in 1990. The well has an authorized water use of 2.000 mgd, but the reported water use has averaged only 0.0345 mgd during 1990-91. If the current use for irrigation is not expected to increase significantly in the future and the excess authorized use can be reallocated to the proposed project, approximately 1.9 mgd, or 65% of the 2.9 mgd average day water requirement of the project could be provided from this well or transferred as an authorized water use to new wells located elsewhere. The alternative of using this well, however, may not be feasible based upon economic and engineering considerations. Well 3103-01 was constructed and grouted in a manner acceptable for municipal wells as shown in the as-built sectional drawing in Figure 7. The cost of drilling a new well would be saved, but such saving probably would be more than offset by the added cost of installing over two miles of additional transmission pipeline, compared to Alternative II.

POTENTIAL IMPACTS ON GROUND WATER

The proposed residential and mixed use development of 900 acres of Galbraith Trust lands north of Wahiawa town lies over the Wahiawa High-Level Aquifer which occurs approximately 650 feet below the surface. Consequently, any use of the project

lands, whether for the proposed urban development or for its current use of pineapple cultivation, has the potential to result in contamination of the ground water below. This is true for other areas which overlie the aquifers of central Oahu.

However, as discussed below it is expected that the proposed project will not pose any significant threat to the supply and quality of the underlying groundwater aquifer if developed within existing environmental guidelines and appropriate mitigative measures.

Impact on Sustainable Yield

The withdrawal of an average of 2.9 mgd of potable ground water from the Wahiawa High-Level Aquifer at full build-out of the proposed project is expected to be included as a part of the 23.0 mgd sustainable yield limit that has been set by the State Commission on Water Resource Management (CWRM). Although permits have been issued for almost all of the 23.0 mgd, actual water use during the past five years (1987-1991) has averaged only 10 mgd. In this situation, the CWRM may adjust the existing authorized use and reallocate the unused portion to existing and/or new wells.

The impact on sustainable yield will be mitigated through conservation efforts and installation of low-flow water fixtures to reduce water consumption.

Existing Well Sources

The BWS wells and Schofield Shaft located a half to one mile south of the project site are the nearest drinking water wells. These wells are located in the vicinity of Wahiawa town and Wahiawa Reservoir. Based upon a westward direction of groundwater flow, the zone of groundwater contribution to these sources probably extends little, if at all, into the project site. Therefore, any potential contaminants associated with the proposed project are not expected to have any significant impact on these drinking water sources.

Several irrigation wells currently used for pineapple are located north of the project site. DBCP and TCP have been found in these wells and presumably come from soil fumigants used in surrounding pineapple fields and possibly those in the project site. However, the levels of contamination detected are well below existing standards established to protect health (Department of Health, Groundwater Contamination Maps for the State of Hawaii, March 1989). This low level of contamination may be due in part to significant dilution of leachate by rainfall and groundwater recharge in the aquifer below.

Residual Pesticides in Soils

Urban development of the project site will eliminate any use of pesticides in the pineapple fields currently being cultivated in the project site. However, residual pesticides (DBCP and TCP) probably occur in the soils and saprolites in the project site, similar to occurrences in former pineapple fields in the Pearl Harbor region. Based upon studies there, Lau (1987) concluded that such residual pesticides would not constitute a significant source for future groundwater contamination because the residual pesticides are held tightly in the sorbed state by the organic material in the soils. Such studies indicated that the amount of residual pesticide capable of contributing to groundwater contamination during any one rainfall event would be on the order of one thousandth to one millionth of the amount of residual pesticide retained in the soil. Furthermore, the leachate from such a rainfall event would likely be diluted by large quantities of uncontaminated water from other sources, thus, reducing even further any impact of residual pesticides in soils on groundwater quality (Lau, 1987, p. 61).

Therefore, no significant leaching or contamination of the underlying groundwater aquifer is expected to occur because of the presence of residual pesticides.

Water Quality

Residential Development. Residential development and use of the project lands are not expected to have any significant impact on underlying groundwater resources because all environmental guidelines and regulations will be followed. Because the project site is located inland of the Underground Injection Control (UIC) line established by the Department of Health and because the underlying groundwater aquifer must be protected, the proposed project will not use injection wells to dispose of any kind of wastewaters.

All wastewater generated by the project will be disposed of to a municipal sewer system or to a private wastewater treatment plant (WWTP), conforming to Department of Health Administrative Rules, Chapter 11-62, Wastewater Systems. If a WWTP is considered, the proposed project will generate an estimated maximum flow of 4.61 mgd (Sam O. Hirota report). Of this amount, only 0.78 mgd could be utilized to meet the

irrigation requirements of the proposed project (including golf course). The balance of 3.83 mgd of treated effluent would be available for use by neighboring agricultural operators or be discharged into Lake Wilson.

All stormwater runoff resulting from construction activities will be appropriately handled, in compliance with a National Pollutant Discharge Elimination System (NPDES) storm water permit issued by the Department of Health. Stormwater runoff from the completed development will be variously discharged into lakes and drainage basins in the golf course and into Lake Wilson.

Industrial Development. The proposed project is expected to include a light industrial area. Because various contaminants such as petroleum products and chemicals would be used in such an area, strict environmentally related development guidelines are recommended. Chemical handling and usage, equipment maintenance, or manufacturing activities should not be allowed over bare ground.

With the objective of preventing any accidental spills or discharges of deleterious material on the ground and into the underlying aquifer, the Galbraith Trust should require and enforce covenants on industrial use of the land containing, as a minimum, the following conditions:

a. All cleaning, repairs and maintenance of equipment involving the use of industrial liquids, such as gasoline, diesel, solvent, motor oil, hydraulic oil, gear oil, brake fluid, acidic or caustic liquids, antifreeze, detergents, degreasers, etc., shall be conducted on a concrete floor, whether roofed or unroofed. The concrete floor shall be constructed so as to be able to contain any drips or spills and to provide for the recovery of any spilled liquid. Water drainage from these concrete floors, if necessary, shall pass through a separator sump before being discharged.

b. Storage of all new and used petroleum oil lubricants and other industrial liquids shall be on a concrete surface. The surface shall be bermed to prevent the loss of liquid in the event of spills or leaks. Applicable sections of the Department of Labor and Industrial Relations' Occupational Safety and Health regulations, entitled "Housekeeping Standards" and "Storage of Flammable or Combustible Liquids" shall be followed.

c. All employees shall be informed to immediately collect and contain any industrial liquid spills on the concrete floor and should be informed against discharging or spilling any industrial liquids. Employees shall be aware to prevent any industrial liquid spills onto the bare ground.

Golf Course Development

The proposed golf course is located over the central portion of the Wahiawa High-Level Aquifer and the potential exists for chemicals used on golf courses to leach downward through approximately 140 feet of soil and saprolite and 540 feet of permeable basalt flows.

Fertilizers, pesticides, and herbicides are the major chemicals used on golf courses which may have potential impact on the basal aquifer. Their use is regulated by the State Department of Agriculture and State Department of Health. All chemicals used must be biodegradable and approved by the U.S. Environmental Protection Agency. These chemicals may be subject to movement from the point of application due to runoff and infiltration during rain storms or by infiltration due to excess irrigation. An assessment of the use of these chemicals is discussed below and in greater detail in other consultant reports.

Fertilizers are normally applied only to the greens, tees, fairways, and parts of the roughs of a golf course; and consist of nitrogen (N), phosphorus (P), and potassium (K). Nitrogen and phosphorus are the elements of concern regarding contamination of surface and ground waters. However, phosphorus attaches tightly to clay soils and exhibits little movement from the point of application. Consequently, phosphorus is not expected to be a problem with regard to contamination of ground water or surface water runoff. Nitrogen, in the form of nitrate, is not bound by clays and moves easily with water and is the only element of fertilizers which might contaminate runoff or ground water. However, nitrogen is assimilated by turfgrasses at a high rate immediately after application which results in complete use of nitrogen under normal conditions of application and weather.

Only when over irrigation or heavy rainfall occurs soon after application of nitrogen would there be potential movement of nitrogen from the point of application by runoff or percolation below the root zone. With regard to contamination of runoff, since the project site is part of a much larger watershed, any movement of nitrogen by runoff from the golf course will likely be diluted by waters from the mauka watershed areas. The potential impact of nitrogen movement, by runoff or by percolation below the root zone, can be mitigated by: (1) using a slow-release nitrogen fertilizer in which the nitrogen is in an insoluble form when applied, and (2) avoiding nitrogen applications

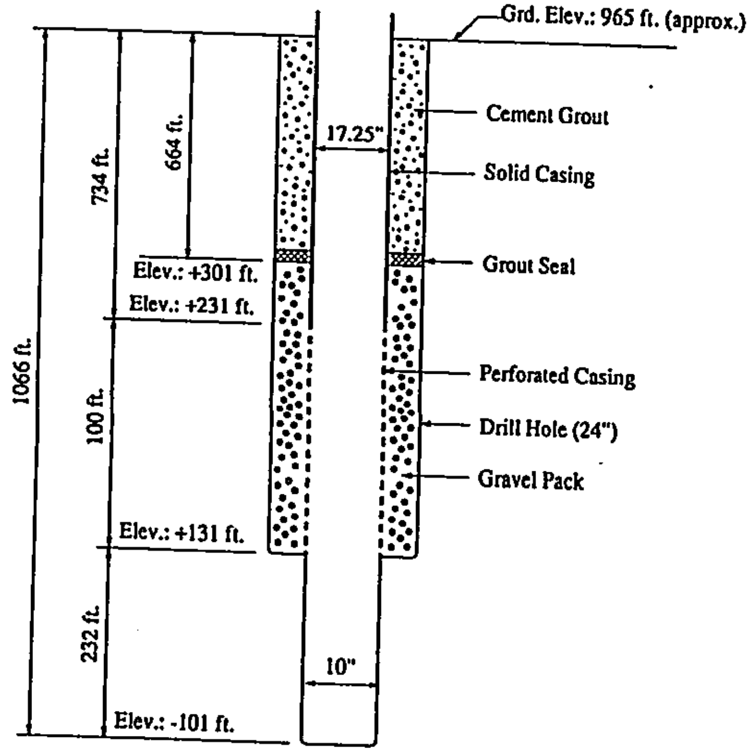
immediately prior to and during periods of anticipated heavy rainfall, which usually occur in the winter months.

Pesticides are normally applied on an as-needed basis in response to an outbreak of pests on the greens, tees and fairways. The pesticides used are of low toxicity and are rapidly degradable in soil and/or become attached to clayey soils and organic matter. Therefore, movement of pesticides from the point of application is not expected to be a problem.

Through the use of best management practices, the use of fertilizers and pesticides on the proposed golf course is not expected to have any significant effect on underlying potable groundwater resources. It is unlikely that any leached contaminants which may reach the aquifer will be in sufficient concentration to adversely impact water quality or pose a threat to human health. Any contaminants which might reach the aquifer can be expected to be diluted by millions of gallons per day of groundwater recharge through the aquifer.

The potential impact of the proposed golf course will be mitigated by implementing the recommended guidelines of the State Department of Health for new golf courses (see Appendix, Twelve Conditions Applicable to All New Golf Course Development).

Figure 7. AS-BUILT SECTION, Del Monte Well 5 (3103-01)
Poamoho, North Wahiawa, Oahu



Not to Scale

Source of Data: DOWALD (Driller's Report, 9/19/88)

Water Resource Associates
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REFERENCES

City & County of Honolulu, Department of General Planning, September 1989, Oahu Water Use and Development Plan. Prepared by Wilson Okamoto & Associates, Inc.

________, May 1992, Oahu Water Management Plan (Review Draft). Prepared by Wilson Okamoto & Associates, Inc.

Commission on Water Resource Management, Department of Land and Natural Resources, May 1992, Oahu Water Management Plan (Review Draft).

________, February 1990, State Water Resources Protection Plan, Volume I. Prepared by George A.L. Yuen & Associates, Inc.

________, 1988, Review and Reevaluation of Groundwater Conditions in the Pearl Harbor Groundwater Control Area, Oahu, Hawaii, Report R-78. Prepared by J.F. Mink, George Yuen, and John Chang.

Date, R.H., 1978, A Groundwater Inventory of the Waialua Basal Water Body, Island of Oahu, Hawaii. U.S. Geological Survey Open File Report 78-24. Prepared in cooperation with Honolulu Board of Water Supply.

Dale, R.H. and K.J. Takasaki, May 1976, Probable Effects of Increasing Pumpage from the Schofield Ground-Water Body, Island of Oahu, Hawaii, USGS Water-Resources Investigations Report 76-47. Prepared in cooperation with the Honolulu Board of Water Supply.

Eyre, Paul R., 1987, Source of Salts in the Waianae Part of the Pearl Harbor Aquifer Near Barbers Point Water Tunnel, Oahu, Hawaii, USGS Water-Resources Investigations Report 87-4247. Prepared in cooperation with the U.S. Department of the Navy.

Hirota, Sam O. Inc., December 1992, Wahiawa Lands Infrastructure Report, Draft Concept Development Plan, Galbraith Trust Estate, Hawaiian Trust Company, Ltd., Trustee.

Kauahikaua, J. and K.V. Shettigara, 1984, Electrical-Resistivity Investigation of the Schofield High Level Water Body, Oahu, Hawaii. USGS Open File Report 84-646.

Lau, L. Stephen, July 1987, Organic Chemical Contamination of Oahu Groundwater, Technical Report No. 181, Water Resources Research Center, University of Hawaii at Manoa, Honolulu.

Lau, L. Stephen and J.F. Mink, 1987, Organic Contamination of Groundwater: A Learning Experience. J. Am. Water Works Association 79(8):37-42 (August).

Miller, M.E., R.E. Green, F.L. Peterson, R.C. Jones, and K. Loague, 1988, Hydrogeologic Characteristics of Subsoil and Saprolite and their Relation to Contaminant Transport, Central Oahu, Hawaii, Technical Report No. 178, Water Resources Research Center, University of Hawaii at Manoa, Honolulu.

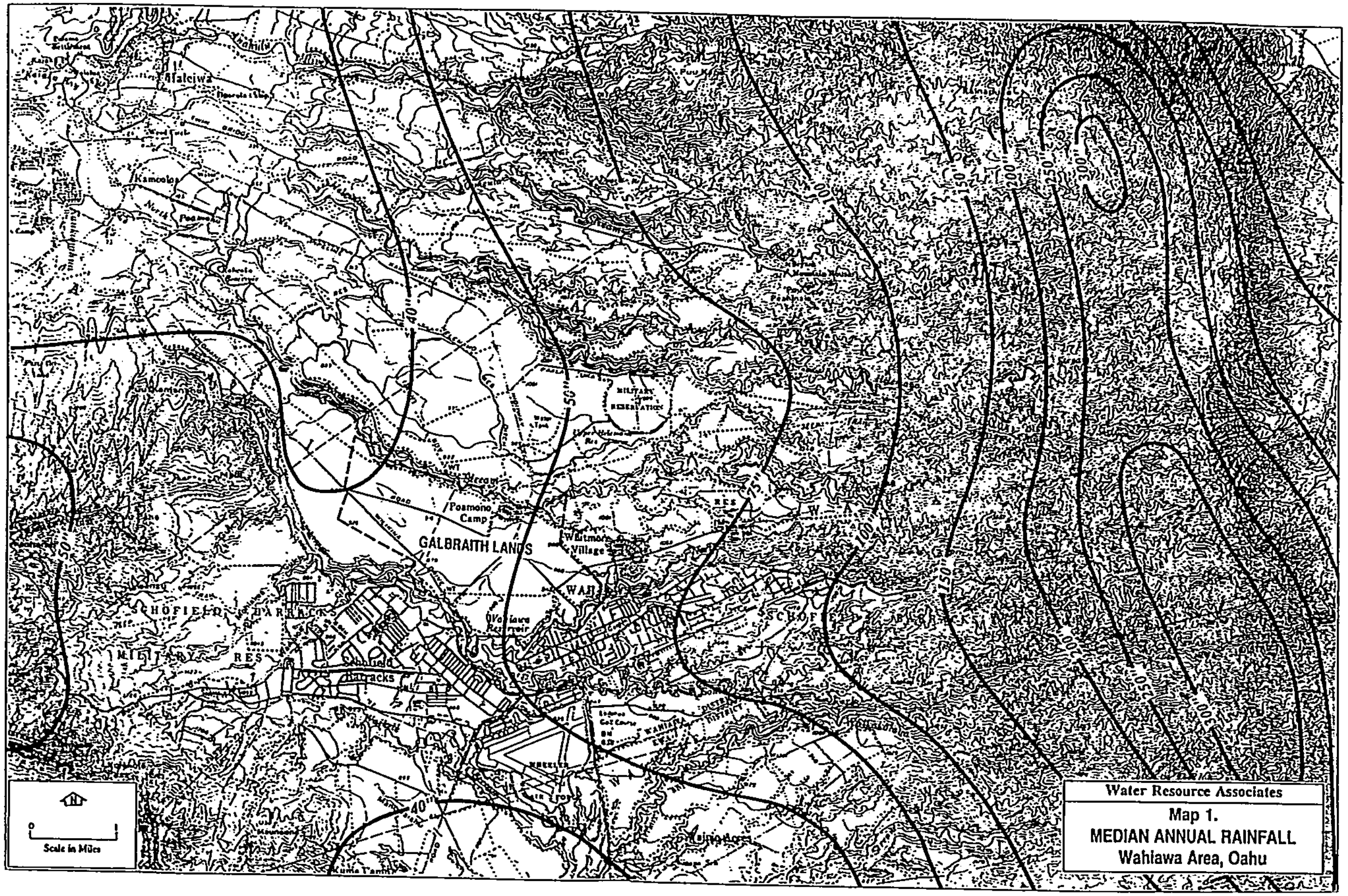
Orr, S. and L.S. Lau, 1987, Trace Organic (DBCP) Transport Simulation of Pearl Harbor Aquifer, Oahu, Hawaii: Multiple Mixing Cell Model, Phase 1, Technical Report No. 174, Water Resources Research Center, University of Hawaii at Manoa.

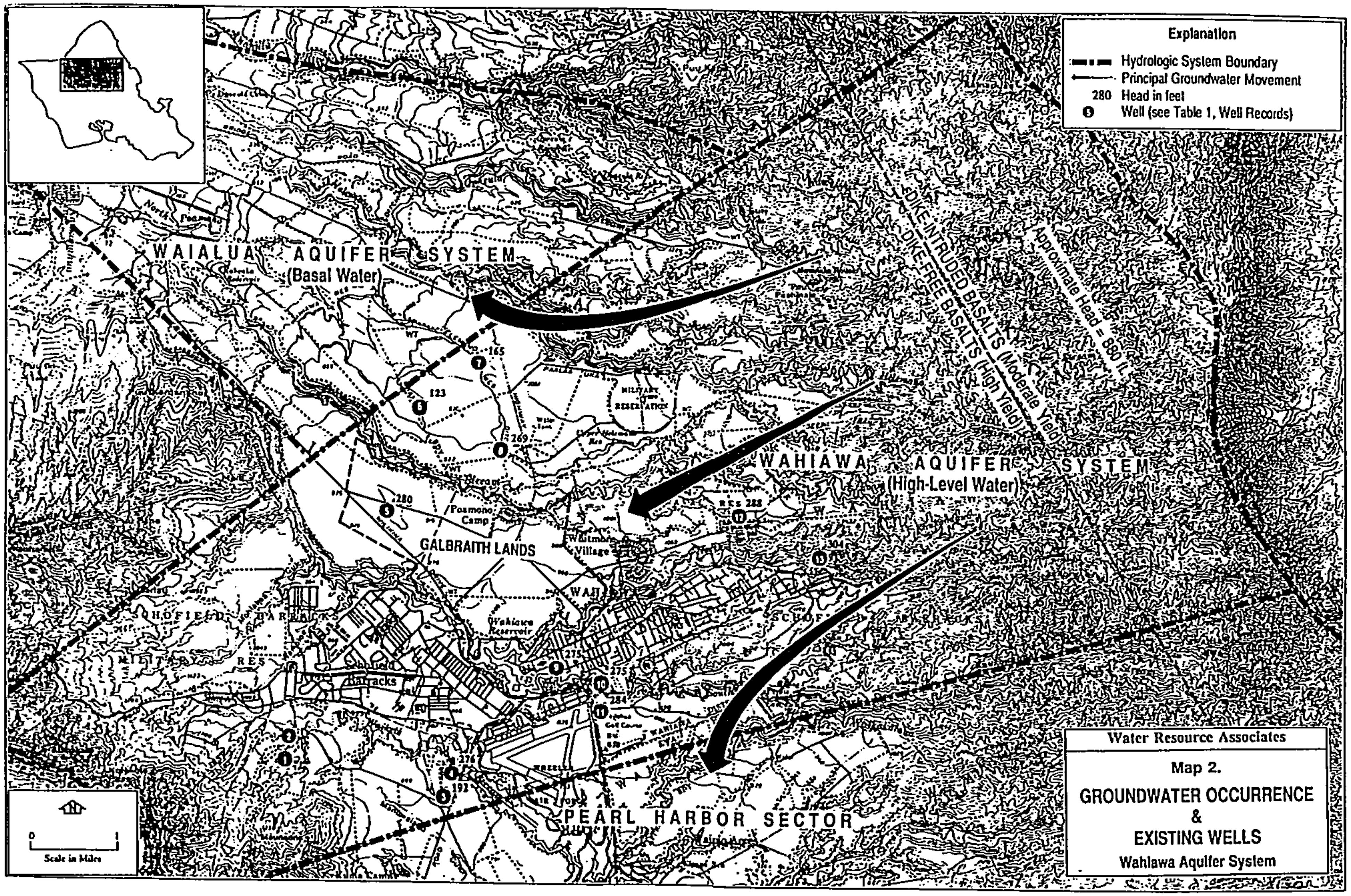
________ and ________, 1988, Modeling of Trace Organics (DBCP) Transport in Pearl Harbor Aquifer, Oahu, Hawaii: Methods of Characteristics, Phase II, Technical Report No. 175, Water Resources Research Center, University of Hawaii at Manoa, Honolulu.

Shade, P.J., 1991, Distribution of Ground-Water Recharge, Oahu, Hawaii, USGS Open-File Report 91-79.

Stearns, H.T., K.N. Vaksvik, 1935, Geology and Ground-Water Resources of the Island of Oahu, Hawaii. Territory of Hawaii, Division of Hydrography Bulletin 1.

Swartz, J.H., 1940, Resistivity Survey of Schofield Plateau: Chapter in Stearns, H.T., 1940, Supplement to Geology and Ground-Water Resources of the Island of Oahu, Hawaii: Hawaii Division of Hydrography Bulletin 5, p. 56-59.


Water Resource Associates
Map 1.
MEDIAN ANNUAL RAINFALL
Wahiawa Area, Oahu
Scale in Miles
0
1
GALBRAITH LANDS
Poamoho Camp
Wahiawa Reservoir
Schofield Barracks
SCHOFIELD BARRACKS
MILITARY RES
MILITARY RESERVATION
Haleiwa
Kamooloa
40
50
75
100
150
200
250
300


Explanation
Hydrologic System Boundary
Principal Groundwater Movement
280 Head in feet
Well (see Table 1, Well Records)
WAIALUA AQUIFER SYSTEM
(Basal Water)
WAHIAWA AQUIFER SYSTEM
(High-Level Water)
DIKE-INTRUDED BASALTS (Moderate Yield)
DIKE-FREE BASALTS (High Yield)
Approximate Head = 880 ft.
GALBRAITH LANDS
PEARL HARBOR SECTOR
Scale in Miles
Water Resource Associates
Map 2.
GROUNDWATER OCCURRENCE
&
EXISTING WELLS
Wahiawa Aquifer System

APPENDIX

STATE OF HAWAII
DEPARTMENT OF HEALTH

January, 1992 (Version 4)

TWELVE (12) CONDITIONS APPLICABLE TO ALL NEW GOLF COURSE DEVELOPMENT

The following conditions are recommended for all new golf course development in Hawaii to assure that environmental quality is preserved and enhanced as it relates to human health and the protection of sensitive ecosystems. Additional conditions may be imposed based on site-specific considerations.

1. Baseline groundwater/vadose zone and/or, if appropriate, coastal water quality shall be established. Once the sampling plan has been determined and approved by the State Department of Health, the owner/developer shall establish the baseline groundwater/vadose zone water quality, and, if appropriate, nearshore water quality, and report the findings to the State Department of Health. Analyses shall be done by a laboratory approved by the Department of Health.

2. The owner/developer and all subsequent owners shall establish a groundwater monitoring plan and system which shall be presented to the State Department of Health for its approval. The groundwater monitoring plan and system shall minimally describe the following components:

   a. A monitoring system tailored to fit site conditions and circumstances. The system shall include, and not be limited to, the use of monitoring wells, lysimeters, and vadose zone monitoring technologies. If monitoring wells are used, the monitoring wells shall generally extend 10 to 15 feet below the water table.

   b. A routine groundwater monitoring schedule of at least once every six (6) months, or more frequently, if required by the State Department of Health in the event that the monitoring data indicates a need for more frequent monitoring.

   c. A list of compounds which shall be tested for as agreed to by the State Department of Health. This list shall include, but not be limited to the following: total dissolved solids; chlorides; PH; nitrogen; phosphorus; and other compounds associated with fertilizers, biocides, or effluent irrigation.

3. If the data from the monitoring system indicate increased levels of a contaminate that poses, or may pose, a threat to public health and the environment, the State Department of Health shall require the owner to take immediate action to stop the source of contamination. Subsequently, the owner shall mitigate any adverse effects caused by the contamination.

4. Owner/developer shall provide sewage disposal for the clubhouse and other facilities by connecting to the public sewer system or by means of a treatment individual wastewater system approved by the Department of Health in conformance with Administrative Rules, Title 11, Chapter 62, Wastewater Treatment Systems. The use of wastewater for irrigation will be generally encouraged, with appropriate controls (see Condition 5).

5. If a wastewater treatment works with effluent reuse becomes the choice of wastewater disposal, then the owner/developer, and all subsequent owners, shall develop and adhere to a Wastewater Reuse Plan which shall incorporate the provisions of the Department of Health's Guidelines for the Use of Reclaimed Water which includes:

   a. An Irrigation Plan encompassing buffer distances, pipe and appurtenance placement, and labeling.

   b. An Engineering Report encompassing treatment options and treatment levels.

   c. Hydro-geologic and hydrologic surveys to determine application rates, sizing and storage needs.

   d. A monitoring plan.

   e. A management plan.

   f. Public and employee education plans.

6. Underground storage tanks (USTs) used to store petroleum products for fueling golf carts, maintenance vehicles, and emergency power generators that pose potential risk to groundwater shall be discouraged. Use of electric golf carts and above-ground storage tanks for emergency power generators shall be encouraged.

   Should the owner/developer/operator plan to install USTs that contain or other regulated substances, the owner/developer/operator must comply with the federal UST technical and financial responsibility requirements setforth in Title 40 of the Code of Federal Regulations Part 280. These federal rules require, among other things, owners and operators of USTs to meet specific requirements in release detection and response, and subsequent corrective action. Also, the owner/developer/operator must comply with all State UST rules and regulations pursuant to the Hawaii Revised Statutes, Chapter 342-L, Underground Storage Tanks.

7. Buildings designed to house the fertilizer and biocides shall be bermed to a height sufficient to contain a catastrophic leak of all fluid containers. It is also recommended that the floor of this room be made waterproof so that all leaks can be contained within the structure for cleanup.

8. A golf course maintenance plan and program will be established based on "Best Management Practices (BMP)" in regards to utilization of fertilizers and biocides as well as the irrigation schedule. BMP's will be reviewed by the State Department of Health prior to implementation.

9. Every effort shall be made to minimize the amount of noise from golf course maintenance activities. Essential maintenance activities (e.g., mowing of greens and fairways) shall be conducted at times that do not disturb nearby residents.

10. Solid waste shall be managed in a manner that does not create a nuisance. Whenever possible, composting of green wastes for subsequent use as a soil conditioner or mulching material is encouraged. The composting and reuse should be confined to the golf course property to eliminate the necessity for offsite transport of the raw or processed material.
    In addition, during construction, the developer should utilize locally-produced compost and soil amendments whenever available.

11. Fugitive dust shall be controlled during construction in accordance with Hawaii Administrative Rules, Title 11, Chapter 60, Air Pollution Control. Pesticides and other agricultural chemicals should be applied in a manner that precludes the offsite drift of spray material. The State Department of Agriculture should be consulted in this regard.

12. To avoid soil runoff during construction, the developer should consult with the U.S. Department of Agriculture, Soil Conservation Service to assure that best management practices are utilized. If the total project area is five (5) acres or more and the development activities include clearing, grading, and excavation, a National Pollutant Discharge Elimination System (NPDES) stormwater permit application shall be submitted to the Department of Health in accordance with the Federal Clean Water Act requirements.

If there are any questions regarding the twelve (12) conditions mentioned here, please contact the Environmental Planning Office at 586-4337. We appreciate your cooperation in preserving and protecting environmental quality in Hawaii.

APPENDIX C

Botanical Survey

Evangeline J. Funk, Ph.D.

BOTANICAL SURVEY REPORT FOR THE GALBRAITH TRUSTS

WAHIAWA LANDS, WAHIAWA, HAWAII

for

Helber Hastert and Fee, Planners
733 Bishop Street, Suite 2590
Honolulu, Hi 96813

by

Evangeline J. Funk, Ph.D.
Botanical Consultants
1992

TABLE OF CONTENTS

FIGURES

INTRODUCTION

The Galbraith Trust's Wahiawa Lands are located just north of the town of Wahiawa, Hawaii. Along their southern and eastern boundaries, the Galbraith Lands partially abut Lake Wilson, and on the north they are bounded by Poamoho Stream.

The study site is made up of approximately three thousand acres of mostly agricultural lands. A botanical survey of the undeveloped areas along Lake Wilson and Poamoho Stream was carried out in early July, 1992 (Figure 1). The purposes of the survey were to ascertain the species composition of the vegetation cover of the undeveloped area, describe the vegetation, prepare an inventory of the extant species, and to determine if proposed or listed endangered species are present on the site.

METHODS

Because the undeveloped portions of the study site are irregular in both shape and size, the walk through method was used during the data collection phase of this study. Access was gained by way of forays from existing roads and trails. All non-agricultural parts of the site were surveyed by a two person team over a three day period.

BOTANICAL HISTORY

In 1840, William Brackenridge, plant collector with the U.S. Exploring Expedition, in describing his journey from Waialua to Honolulu wrote, "Our path lay across the plain which connects the East and Western range of Mts - in the rainy season this plain affords abundance of feed for cattle in three or four kinds of grasses - several streams of water desending from the eastern range and intersect this plain and which might if properly managed irrigate the greater part of, and I have no doubt that ere long sugar and indigo plantations will take place of the scraggy bushes of Sandalwood and other shrubs which you now find thinly scattered over its surface..." (Funk 1988).

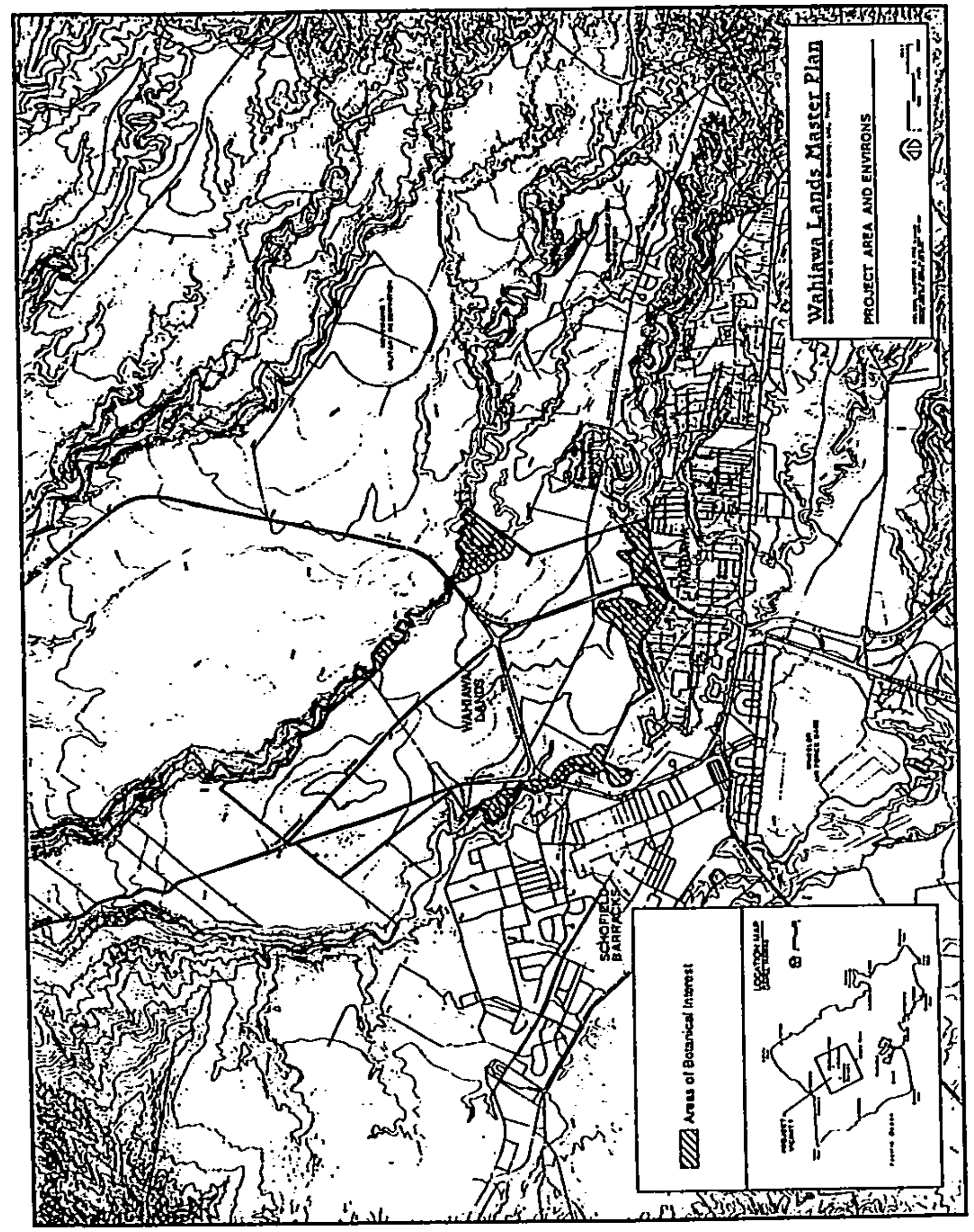


Figure 1. Location of the Galbraith Lands

Rock (1913) and Gagne and Cuddihy (In Wagner et al 1990) in describing the vegetation of the Hawaiian Islands did not consider the Wahiawa Plain, probably because the area had been under cultivation for such a long time. Others (Ripperton and Hosaka 1942, Muller-Dombois 1984) discussed the lower mountain zone or vegetation type that could occupy this area based on factors such as temperature, rainfall, and soils. This area is referred to as the C Zone by Ripperton and Hosaka and as mixed mesophic scrub by Muller-Dombois. All of these writers suggest that the area would revert to guava scrub if it were released from agriculture.

Interestingly, the slopes leading to Lake Wilson and Poamoho Stream were used by Territorial Forestry as sites for experimental reforestation plantings (Skolman 1980). These plantings have been so successful that today, Trema trees (*Trema orientalis* Blume), 35-40 m in height and Eucalyptus trees, 25-30 m in height are not unusual. These experimental plantings along with the local practice of disposing garden trimmings down these long, steep, slopes, have resulted in an extremely diverse flora. More than one-hundred-sixty-two species of ferns, gymnosperms and flowering plants were found on this site which is primarily planted in pineapple (*Ananas comosus* Merr.). Of the one-hundred-sixty-two species, nine or six percent are endemic to the Hawaiian Islands, one of which is sandalwood (*Santalum freycinetianum* Gaud.).

VEGETATION TYPES

Essentially there are two vegetation types on this site, Agricultural Fields and Mixed Introduced Vegetation.

Agricultural Fields are, by far, the most important vegetation type found on this site. The crop is pineapple and the fields are well tended and the usual fringe community of ruderal (weed) vegetation is absent.

Mixed Introduced Vegetation is found on the steep slopes leading to Lake Wilson

and along both sides of Poamoho Stream. It is a rich mosaic of trees, vines, grasses and forbs (Figure 2). The original Forestry plantings have matured and many of the plants, clippings, and refuse that had been disposed of along the cliffs, have taken root and have filled much of the understory. Only under the Eucalyptus trees is the ground layer missing (Eucalyptus trees and leaves have allelopathic qualities which prevent the germination of most plant seeds). The mix is even richer along Poamoho Stream (Figure 3) where small farmers grow bananas and other vegetables.

Around Lake Wilson where, because of the low rainfall this year, there are wide swaths of exposed shoreline, lacustrine or lake wetland vegetation is now evident (Figure 4). This is regarded as temporary and will disappear as soon as more normal weather conditions return.

Endemic Hawaiian Plants. The most interesting of the endemic Hawaiian plants were the three individuals of *Santalum freycinetianum*. They are located northwest of Wilikina Drive at the upper rim of Kaukonahua Stream. The plants are similar to those described by Brackenridge as "scraggy bushes".

The remaining endemic and indigenous plants, pukiawe (*Styphelia tameiameiae* Muell.), 'ulei (*Osteomeles anthyllidifolia* Sm.), huehue vine (*Cocculus trilobus* (Thunb.) DC), moa (*Psilotum nudum* (L.) Griseb), kou (*Cordia subcordata* Lam.), kukui (*Aleurites moluccana* (L.) Willd.) and ti (*Cordyline fruticosa* (L.) A. Chev) are all found along the rim of Poamoho Stream.

ENDANGERED SPECIES

No proposed or listed U.S. Dept. of Fish & Wildlife Service (USFWS 1991) or State of State of Hawaii listed plant taxa (DLNR 1991) were found during this study. Introduced plants make up the vegetation of this site and as such should not prevent future development of the area.

Figure 2. Vegetation of the Steep North Slopes of the Lake Wilson.

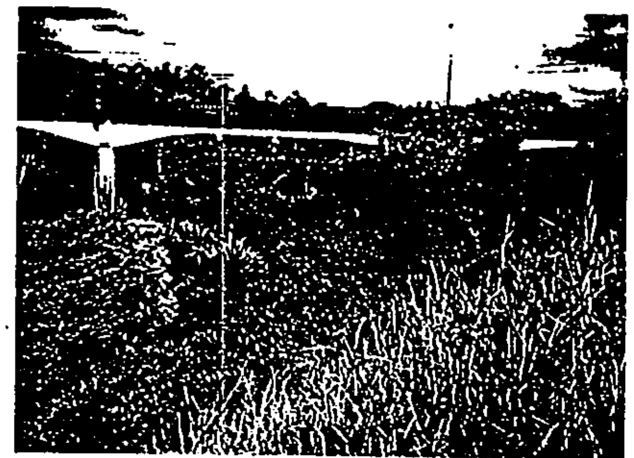


Figure 3. Mixed Vegetation of Poamoho Stream.

Figure 4. Small Island in Lake Wilson and Lacustrine Vegetation.

SPECIES LIST

The plant families in the following species list have been alphabetically arranged within four groups, Ferns and Fern Allies, Gymnosperms, Monocotyledons, and Dicotyledons. The genera and species are arranged alphabetically within families. The taxonomy and nomenclature follow that of St. John (1973) and Wagner, Herbst and Sohmer (1990). For each taxon the following information is provided:

1. An asterisk before the plant name indicates a plant introduced to the Hawaiian Islands since Cook or by the aborigines.
2. The scientific name.
3. The Hawaiian name and or the most widely used common name.
4. <u>Abundance ratings are for this site only</u> and they have the following meanings:

   Uncommon = a plant that was found less than five times.

   Occasional = a plant that was found between five to ten times.

   Common = a plant considered an important part of the vegetation.

   Locally abundant = plants found in large numbers over a limited area. For example the plants found in grassy patches.

This species list is the result of an extensive survey of this site under summer conditions (July 1992) and it reflects the vegetative composition of the flora during a single season. Minor changes in the vegetation will occur due to introductions and losses and a slightly different species list would result from a survey conducted during a different growing season.

CHECKLIST OF PLANTS FOUND ON THE GALBRAITH TRUST LANDS, WAHIAWA, HAWAII

<u>Scientific Name</u>	<u>Common Name</u>	<u>Abundance</u>
FERNS AND FERN ALLIES		
PSILOTACEAE - Psilotum Family		
Psilotum nudum (L.) Griseb	Moa	Uncommon
POLYPODIACEAE - Common Ferns		
Cyclosorus dentatus (Frosk.) Ching	Downy wood-fern	Occasional
*_Blechnum occidentale_ L.	Blechnum	Locally abundant
*_Microsorium scolopendria_ (Burm.) Copel		Occasional
*_Nephrolepis exaltata_ (L.) Schott.	Sword fern	Occasional
*_Pteridium_ sp.	Bracken fern	Locally abundant
GYMNOSPERMS		
ARAUCARIACEAE - Araucaris Family		
*_Araucaria heterophylla_ Franco	Norfolk Island pine	Uncommon
CUPRESSACEAE - Cypress Family		
*_Cupressus_ sp.	Cypress	Locally abundant
MONOCOTYLEDONES		
AGAVACEAE - Agave Family		
*_Agave sisalana_ Perrine	Sisal	Uncommon
Cordyline fruticosa (L.) A. Chev.	Ti	Uncommon
*_Pleomele fragrans_ (L.) Salisb.		Uncommon
ARACEAE - Philodendron Family		
*_Aglaonema_ sp.		Uncommon
*_Monstera deliciosa_ Liebm	Monstera	Uncommon
*_Philodendron radiatum_ Schott		Locally abundant
*_Scindapsus aureus_ Engl.	Taro vine	Locally abundant
*_Syngonium auritum_ (L.) Schott		Locally abundant
BROMELIACEAE - Pineapple Family		
*_Ananas comosus_ (Stickm.) Merr.	Pineapple	Abundant
*Portea petropolitana(Wawra) Mez.		Locally abundant
COMMELINACEAE - Spiderwort Family		
*_Commelina diffusa_ N. L. Burm.	Honohono	Locally abundant

Scientific Name	Common Name	Abundance
CYPERACEAE - Sedge Family		
**Cyperus alternifolius* L.	Umbrella plant	Locally abundant
**Cyperus kyllinga* Endl.	White kyllinga	Locally abundant
**Cyperus rotundus* L.	Nut grass	Ocassional
**Eliocharis geniculata* (L.) R. & S.		Common
DICOTYLEDONS		
ACANTHACEAE - Acanthus Family		
**Asystasia gangetica* (L.) Anders	Chinese violet	Occasional
**Justicia betonica*	White shrimp plant	Locally abundant
**Thunbergia grandiflora* Roxb.	Bengal trumpet	Locally abundant
AIZOACEAE - Carpetweed Family		
**Tetragonia tetragonioides* Ktze	New Zealand Spinach	Uncommon
AMARANTHACEA - Amarnth Family		
**Alternanthera repens* (L.) Ktze.	Khaki weed	Occasional
**Amaranthus spinous* L.	Spiny amaranth	Occasional
**Amaranthus viridus* L.	Slender amarnth	Occasional
ANACARDIACEAE - Mango Family		
**Mangifera indica* L.	Mango	Locally abundant
**Schinus terebinthifolius* Raddi	Christmas berry	Occasional
APOCYNACEAE - Dogbane Family		
**Casabela thevetia* (L.) Lippod	Be-still tree	Uncommon
**Plumeria* L.	Plumeria	Occasional
ARALIACEAE - Ginseng Family		
**Brassaia actinophylla* Endl.	Octopus tree	Common
BALSAMINACEAE - Touch-me-not Family		
**Impatiens oliveri* ex Will. Wats	Impatiens	Locally abundant
BASELLACEAE - Basella Family		
**Boussingaultia gracilis* Miers	Madeira vine	Ocassional
BIGNONIACEAE - Bignonia Family		
**Jacaranda mimosifolia* D. Don		Occasional
**Spathodica campanulata* Beauv.	African tulip tree	Occasional

Scientific Name	Common Name	Abundance
BORAGINACEAE - Heliotrope Family		
Cordia subcordata	Kou	Uncommon
**Heliotropium procumbens* Mill.		Occasional
CARICACEAE - Papaya Family		
**Carica papaya* L.	Papaya	Uncommon
CARYOPHYLLACEAE - Carnation Family		
**Spergula arvensis* L.	Corn spurry	Uncommon
CASUARINACEAE - Casuarina Family		
**Casuarina equisetifolia* L.	Ironwood	Common
CELASTRACEAE - Bittersweet Family		
**Elaeodendron orientale* Jacq.	False olive	Uncommon
CHENOPODIACEAE - Goosefoot Family		
**Chenopodium carinatum* R. Br.	Keeled goosefoot	Uncommon
**Chenopodium murale* L.	Prickly goosefoot	Uncommon
CLUSIACEAE - Mangosteen Family		
**Clusia rosea* Jacq.	Autograph tree	Occasional
COMPOSITAE - Sunflower Family		
**Ageratum conyzoides* L.	Maile hohono	Common
**Bidens alba* (L.) DC		Common
**Bidens pilosa* L.	Spanish needle	Common
**Conyza canadensis* Cronq.	Canadian fleabane	Occasional
**Echinochloa colona* (L.) Link.	Jungle-rice	Uncommon
**Eclipta alba* L.	False daisy	Common
**Elephantopus spicatus* Juss. ex Aubl.		Uncommon
**Erechtites hieracifolia* (L.) Raf.		Occasional
**Galinsoga parviflora* Cav.		Uncommon
**Emilia sonchifolia* (L.) DC	Lalac puale	Common
**Pluchea indica* (L.) Cass.	Pluchea	Common
**Pluchea symphytifolia* (Mill.) Gillis		Sourbush Common
**Sonchus olerarceus*L.	Pualele	Occasional
**Tridax procumbens* L.	Coat buttons	Locally abundant
**Verbesina encelioides* Cav.	Golden crown-beard	Occasional
**Vernonia cinerea* (L.) Less.	Little ironweed	Occasional
**Wedelia trilobata* (L.) Hitchc.	Wedelia	Abundant
**Youngia japonica* (L.) DC	Hawksbeard	Occasional
**Xanthium strumarium* L.	Kikania	Occasional

Scientific Name	Common Name	Abundance
CONVOLVULACEAE - Morning glory Family		
**Ipomoea alba* L.	Moonflower	Occasional
**Ipomoea cairica* (L.) Sweet	Koali-ai	Uncommon
**Ipomoea indica* (J. Burm.) Merr.	Koali	Occasional
**Ipomoea obscura* (L.) Ker-Gawl.		Occasional
**Ipomoea triloba* L.	Little Bell	Occasional
**Merremia tuberosa* (L.) Rendle	Wood rose	Locally abundant
CRASSULACEAE - Orpine Family		
**Bryophyllum pinnatum* (Lam.) Kurz.	Mother-of-thousands	Locally abundant
CUCURBITACEAE - Cucumber Family		
**Momordica charantia* Crantz	Balsam apple	Occasional
EPACRIDACEAE - Epacris Family		
Styphelia tameiameiae Muell.	Pukiawe	Locally abundant
EUPHORBIACEAE - Spurge Family		
Aleurites moluccana (L.) Willd.	Kukui	Occasional
**Chamaesyce hirta* L.	Hairy spurge	Common
**Chamaesyce hypericifolia* Mellsp.	Graceful spurge	Common
**Chamaesyce prostrata* (Ait) Millsp.	Prostrate spurge	Occasional
**Phyllanthus niruri* L.	Niruri	Occasional
**Ricinus communis* L.	Castor bean	Occasional
GENTIANACEAE - Gentian Family		
**Centaurium erythraea* Raf.	Bitter herb	Uncommon
LAMIACEAE - Mint Family		
**Hyptis pectinata* (L.) Poit.	Wild basil	Uncommon
**Leonotis nepetifolia* (L.) R. Br.	Lion's ear	Occasional
LAURACEAE - Laurel Family		
**Cinnamomum cassoa* Bl.	Cassia bark	Occasional
**Persia americana* Mill.	Avocado	Uncommon
LEGUMINOSAE - Bean Family		
**Acacia confusa* Merr.	Formosa koa	Common
**Acacia farnesiana* L.	Klu	Uncommon
**Albizia lebbeck* (L.) Benth.	Siris tree	Common
**Alysicarpus vaginalis* (L.) DC.	One-leaved Clover	Locally abundant

Scientific Name	Common Name	Abundance
LEGUMINOSAE - Bean Family Con't		
**Caesalpinnia decapetala* (Roth.)Merr.	Wait-a-bit	Uncommon
**Canavalia cathartica* Thouars	Maunaloa	Occasional
**Cassia leschenaultiana* DC.	Japanese tea	Locally abundant
**Crotalaria incana* L.	Fuzzy rattle-pod	Occasional
**Crotalaria mucronata* L.	Smooth rattle-pod	Common
**Desmanthus virgatus* Willd.	Virgate mimosa	Occasional
**Desmodium triflorum* (L.) DC		Common
**Enterolobium cyclocarpum* (Jacq.) Griseb.	Earpod	Occasional
**Glycine wightii* Verdc.		Occasional
**Indigofera spicata* Forssk	Creeping indigo	Occasional
**Indigofera suffruticoas* Mill.	Indigo	Locally abundant
**Leucaena leucocephala* deWit	Koa-haole	Occasional
**Medicago polymorpha* L.	Bur clover	Locally abundant
**Mimosa pudica* L.	Sensitive plant	Locally abundant
**Pithecellobium dulce* Benth.	Madras thorn	Occasional
**Samanea saman* (Jacq.) Merr.	Monkeypod	Occasional
**Senna pendula* H. Irwin & Barn.		Occasional
**Senna surattensis* H. Irwin & Barn.	Kolomona	Locally abundant
LOGANIACEAE - Strychine Family		
**Buddleja asiatica* Lour.	Dogtail	Common
LYTHRACEAE - Loosefoot Family		
**Cuphea carthagenensis* (Jacq.) Macbr..	Tarweed	Uncommon
MALPIGHIACEAE - Malpighia Family		
**Malpighia punicifolia* L.	Acerola cherry	Occasional
MALVACEAE - Hibiscus Family		
**Abutilon grandifolium* Sweet	Hairy abutilon	Uncommon
**Malvastrum coromandelianum* Garcke	False marrow	Common
**Sida fallax* Walp.	'Ilima	Common
**Sida rhombifolia* L.	Cuba jute	Occasional
**Sida spinosa* L.	Prickly sida	Occasional
MELASTOMATACEAE - Melastoma Family		
**Clidemia hirta* (L.) D. Don	Koster's curse	Occasional
**Heterocentron subtriplinervium* Braun & Bouche		Occasional
MELIACEAE - Mahogany Family		
**Melia azedarach* L.	Neem tree	Occasional

Scientific Name	Common Name	Abundance
MENISPERMACEAE - Moonseed Family		
Cocculus trilobus (Thunb.) DC	Huehue vine	Occasional
MORACEAE - Fig Family		
**Artocarpus heterophyllus* Lam.	Jack fruit	Uncommon
**Ficus retusa* L.	Chinese banyan	Uncommon
MYRTACEAE - Myrtle Family		
**Eucalyptus citriodora* Hook.	Argyle apple	Common
**Eucalyptus robusta* Sm.	Swamp mahogany	Common
**Eucalyptus sideroxylon* A. Cunn	Eucalyptus	Occasional
**Melaleuca quinquenervia* Blake	Paperbark	Uncommon
**Pimenta dioica* (L.) Merr.	Allspice	Uncommon
**Psidium cattleianum* Sabine	Strawberry guava	Common
**Psidium guajava* L.	Guava	Occasional
**Syzygium cumini* L.	Java plum	Occasional
NYCTAGINACEAE - Four o'clock Family		
**Boerhavia coccinia* Mill.		Occasional
**Bougainvillea* sp.	Bougainvillea	Occasional
**Mirabilis jalapa* L.	Four-o'clock	Occasional
OLEACEAE - Olive Family		
**Fraxinus americana* L.	White ash	Uncommon
ONAGRACEAE - Evening primrose Family		
**Ludwigia octovalvis* (L.) Elliot	Marsh purslane	Uncommon
OXALIDACEAE - Wood sorrel Family		
**Oxalis corniculat* L.	'Ihi	Occasional
PASSIFLORACEAE - Passionflower Family		
**Passiflora edulis* Sims	Lilikoi	Occasional
**Passiflora suberosa* L.	Huehue haole	Occasional
**Passiflora foetida* L.	Love-in-a-mist	Occasional
PLANTAGINACEAE - Plantain Family		
Plantago lanceolata L.	Buckthorn	Occasional
PORTULACACEAE Purslane Family		
**Portulaca oleracea* L.	Pig weed	Uncommon

Scientific Name	Common Name	Abundance
PROTEACEAE - Silk Oak Family		
**Grevillea robusta* A. Cunn	Silk oak	Common
PHYTOLACCACEAE - Pokeweed FAmily		
**Rivina humilis* L.	Coral berry	Occasional
ROSACEAE - Rose Family		
Osteomeles anthyllidifolia (Sm.)	'Ulei	Uncommon
RUBIACEAE - Coffee Family		
**Spermacose assurgens* Ruiz & Pav.	Buttonweed	Occasional
RUTACEAE - Citrus Family		
**Murraya paniculata* L.	Mock orange	Uncommon
SANTALACEAE - Sandalwood Family		
Santalum freycinetianum Gaud.	Sandalwood	Uncommon
SAPINDACEAE - Soapberry Family		
Dodonaea viscosa Jacq.	'A'ali'i	Occasional
SOLANACEAE - Tomato Family		
**Lycopersicon esculentum* Mill.	Tomato	Occasional
**Physalis peruviana* L.	Poha	Uncommon
**Solandra hartwegii* N. E. Br.	Cup of Gold	Uncommon
Solanium americanum Mill.	Popolo	Occasional
STERCULIACEAE - Stink tree Family		
**Waltheria indica* L.	Hi'aloa, uha-loa	Common
ULMACEAE - Elm Family		
**Trema orientalis* (L.) Blume	Gunpowder tree	Common
UMBELLIFERAE - Parsley Family		
**Centella asiatica* (L.) Urban	Asiatic pennywort	Occasional
**Daucus carota* L.	Carrot	Occasional

Scientific Name	Common Name	Abundance
VERBENACEAE - Verbena Family		
**Citharexylum caudatum* L.	Fiddlewood	Occasional
**Lantana camara* L.	Lantana	Occasional
**Stachytarpheta indica* Vahl		Uncommon
**Stachytarpheta jamaicensis* Vahl.	Vervain	Common
**Verbena litoralis* Kunth	Owi	Common

Bibliography

Armstrong, R. W. 1983. Atlas of Hawaii. University of Hawaii Press.

DLNR. 1991. Endangered and Threatened Animals and Plants of Hawaii. Div. of Forestry and Wildlife.

Funk, E. J. 1988. The notes of William Brackenridge made during his Sandwich Island sojourn 1840 - 1841. Hawaiian Botanical Society Newsletter. Vol. 27:3-35.

Gagne, W. & L. Cuddihy 1990 (in) Wagner, W.L., D. R. Herbst and S. H. Sohmer. 1990. Manual of the Flowering Plants of Hawaii. Bishop Museum Special Publication #83. Univer. Hawaii Press. Vols. 1 & 2.

Mueller-Dombois, D. 1984. Classification and mapping of plant communities: a review with emphasis on tropical vegetation. (in) Woodwell, G. M. 1984. The role of terrestrial vegetation in the global carbon cycle: measurement by remote sensing. John Wiley & Sons Ltd.

Ripperton, J. C. & E. Y. Hosaka 1942. Vegetation Zones of Hawaii. Bull. 89 University of Hawaii.

Skolman, R. G. 1980. Plantings on the Forest Reserves of Hawaii 1910 - 1960. Institute of Pacific Islands Forestry.

St. John, H. 1973. List and Summary of the Flowering Plants of the Hawaiian Islands. PTBG. Lawai, Kauai, Hawaii.

USFWS. 1990. Endangered and Threatened Wildlife and Plants. 50 CFR 17.11 & 17.12

Wagner, W. L., D. R. Herbst and S. H. Sohmer. 1990. Manual of the Flowering Plants of Hawaii. Bishop Museum Special Publication #83. Univer. Hawaii Press. Vols. 1 & 2.

APPENDIX D

Survey of Avifauna and Feral Mammals

Phillip L. Bruner

SURVEY OF THE AVIFAUNA AND FERAL MAMMALS AT GALBRAITH TRUST LANDS WAHIAWA, OAHU

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24 July 1992

INTRODUCTION

The purpose of this report is to summarize the findings of a two day (11,15 July 1992) bird and mammal field survey of Galbraith Trust Lands at Wahiawa, Oahu (Fig.1). Also included are references to pertinent literature as well as unpublished faunal reports.

The objectives of the field survey were to:

1- Document what bird and mammal species occur on the property or may likely be found there given the type of habitats available.

2- Provide some baseline data on the relative (estimated abundance of each species).

3- Determine the presence or likely occurrence of any native fauna particularly any that are considered "Endangered" or "Threatened".

4- If any special or unique wildlife habitat occurs on the property locate such sites and note their possible value for birds and mammals in this region of the island.

GENERAL SITE DESCRIPTION

Figure One indicates the area surveyed for birds and mammals. Much of the site is cultivated in pineapple. Poamoho gulch with an intermittant stream mark the north boundary. Portions of Lake Wilson define the southern limits. Vegetation in the gulches and adjoining Lake Wilson is largely introduced non-native trees and brush.

Weather during the field survey was variable with periods of passing light rain showers on day one and partly cloudy conditions on day two.

STUDY METHODS

Field observations were made with binoculars and by listening for vocalizations. These observations were concentrated during the peak bird activity periods of early morning. Attention was also paid to the presence of tracks and scats as indicators of bird and mammal activity. At various locations, along roads and trails, eight minute counts were made of all birds seen or heard (Fig.1). Between these count (census) stations any unusual observations of birds were also noted. These data provide the basis for the relative (estimated) abundance figures given in this report (Table 1). Published and

unpublished reports of birds known from this region were also consulted in order to acquire a more complete picture of the possible species that might be expected (Bremer 1987; Bruner 1987, 1988; Pratt et al. 1987; Hawaii Audubon Society 1989). Observations of feral mammals were limited to visual sightings and evidence in the form of scats and tracks. No attempts were made to trap mammals in order to obtain data on their relative (estimated) abundance and distribution.

Scientific names used herein follow those given in Hawaii's Birds (Hawaii Audubon Society 1989); Field Guide to the Birds of Hawaii and the Tropical Pacific (Pratt et al. 1987) and Mammal Species of the World (Honacki et al. 1982).

RESULTS AND DISCUSSION

Resident Endemic (Native) Land Birds:

No endemic land birds were recorded on the survey. The Short-eared Owl or Pueo (*Asio flammeus sandwichensis*) is the only endemic land bird that may on occasion occur in this area (Pratt et al. 1987; Hawaii Audubon Society 1989). Pueo are listed as an endangered species on Oahu by the State of Hawaii Division of Forestry and Wildlife. This species forages in pastures and agricultural fields as well as forested habitats.

Resident Endemic (Native) Waterbirds:

Two species of endemic and endangered waterbirds were recorded on the survey: American Coot (Fulica americana alai) and Common Moorhen (Gallinula chloropus sandvicensis). Three coot and one moorhen were observed on Lake Wilson along the southern edge of the property. Two other potential native waterbirds the Black-necked Stilt (Himantopus mexicanus knudseni) and Hawaiian Duck or Koloa (Anas wyvilliana) were not observed but likely occur in and around Lake Wilson.
The number of waterbirds found on this survey were relatively few given the amount of available wetland habitat. A more exhaustive search of the shoreline of Lake Wilson by boat might reveal additional birds.

Migratory Indigenous (Native) Birds:

Migratory shorebirds winter in Hawaii between the months of August through May. Some juveniles will stay through the summer as well (Johnson and Johnson 1983). Of all the shorebirds species which winter in Hawaii the Pacific Golden Plover (Pluvialis fulva) is the most abundant. Plover prefer open areas such as exposed intertidal reef, rocky shorelines, mud flats, lawns, plowed fields and pastures. They arrive in Hawaii in early August and depart to their arctic breeding grounds during the last week of April (Johnson et al. 1981). Johnson et al. (1989) have shown that plover are extremely site-faithful on their wintering grounds and most establish foraging territories which they defend vigorously. Such behavior makes it possible to acquire a fairly good estimate of the abundance of plover in any one area. These

populations likewise remain relatively stable over many years.

Only six plover were recorded on the survey. At this time of year most plover are on their arctic breeding grounds.

Ruddy Turnstone (Arenaria interpres) is another common migrant that utilizes lawns and fields as well as shoreline habitat. Two turnstone were observed on the property. One other potential shorebird that may occur along the Lake Wilson shoreline is the Wandering Tattler (Heteroscelus incanus). Migratory ducks such as Northern Pintail (Anas acuta) and Northern Shoveler (Anas clypeata) are common winter migrants to Hawaii (Pratt et al. 1987; Hawaii Audubon Society 1989). It would not be unusual to find these birds at Lake Wilson during the winter months.

Resident Indigenous (Native) Birds:

A total of three Black-crowned Night Heron (Nycticorax nycticorax) were tallied over the course of the survey. This species is the only native waterbird that is not listed as endangered. Night heron forage in a wide variety of wetlands from streams and ponds to ditches and flooded fields.

Resident Indigenous (Native) Seabirds:

No nesting seabirds were observed on the property. The presence of predators such as cats, dogs and mongoose make this site unsuitable for nesting or roosting seabirds. Great Frigatebird (Fregata minor) are known to take fresh drinking water from ponds and may utilize

Lake Wilson for this purpose.

Exotic (Introduced) Birds:

A total of 17 species of exotic birds were recorded during the field survey (Table 1). The most abundant birds were: Japanese White-eye (*Zosterops japonicus*), Zebra Dove (*Geopelia striata*), Red-crested Cardinal (*Paroaria coronata*), Red-vented Bulbul (*Lonchura punctulata*) and Chestnut Mannikin (*Lonchura malacca*).

Based on the location of the property and type of habitats available as well as information provided in Bruner 1987, 1988; Pratt et al. 1987 and Hawaii Audubon Society 1989 the following exotic species may also occur at this site: Common Barn Owl (*Tyto alba*), Northern Mockingbird (*Mimus polyglottos*), Eurasian Skylark (*Alauda arvensis*), Hwamei (*Garrulax canorus*), Red Avadavat (*Amandava amandava*) and Japanese Bush-warbler (*Cettia diphone*).

Feral Mammals:

Small Indian Mongoose (*Herpestes auropunctatus*) and feral cats were observed. No trapping was conducted in order to assess the relative abundance of mammals.

Records of the endemic and endangered Hawaiian Hoary Bat (*Lasiurus cinereus semotus*) are sketchy, however, the species has been reported from Oahu (Tomich 1986; Kepler and Scott 1990). No bats were found on this survey.

CONCLUSION

A brief field survey such as this one can provide only a limited perspective of the wildlife which utilize the area. The number and relative abundance of each species may vary throughout the year and from year to year due to available food resources and reproductive success. Species which are migratory will normally be found between August and May. Exotic species sometimes prosper only to later disappear or become a less significant part of the ecosystem (Williams 1987; Moulton et al. 1990). Thus only long term studies can provide a comprehensive view of the bird and mammal populations in a particular area. Nevertheless some general conclusions related to bird and mammal activity at this site can be drawn. The following comments summarize the findings of this survey:

1- All major habitats on the property were visited and census stations were distributed along roads and trails so as to provide a reasonable sample from which estimates of bird populations could be derived.

2- For the most part Lake Wilson's shoreline is exposed and does not provide the cover of emergent vegetation that waterbirds prefer. However, there are some patches of suitable wetland habitat. Disturbance by fisherman also limits the usefulness of this area for waterbirds. The Oahu population of the endemic

Hawaiian Owl or Pueo is listed by the State of Hawaii as an endangered species. This bird was not recorded on the survey. Pueo, however, do forage in agricultural lands and may on occasion occur in this area.

3- The numbers of migratory shorebirds recorded on this survey were low which is to be expected given the time of year. It is likely that more of these birds would be found on the property during the winter months.

4- The Galbraith Trust Lands covered by this faunal survey support the typical array of exotic birds one would expect in this type of environment on Oahu. Finches were especially abundant due to the availability of grass seed along the roadsides.

5- A trapping program would be required in order to obtain more definitive data on mammals. Feral mammal populations were comparable with similar habitat surveyed elsewhere on Oahu (Bruner 1987, 1988). The Hawaiian Hoary Bat was not recorded at this site, but is known from Oahu. This species often forages in forests as well as over open bodies of water such as Lake Wilson.

RECOMMENDATIONS

The proposed park fronting Lake Wilson and the ridgeline park along a portion of Poamoho Gulch should provide a sufficient buffer between these habitats and the proposed developments. Patches of emergent vegetation occur along the shoreline of Lake Wilson. These areas provide refuge to waterbirds such as American Coot. This habitat should not be disturbed.

The proposed commercial/light industrial project located south of Kamehameha Highway and adjoining the parkland that fronts Lake Wilson may pose a problem if industrial wastes such as oil or other toxic chemicals move from this upslope location into Lake Wilson. The development plan should show how this potential problem can be controlled.

Finally, the proposed golf course will provide habitat, beyond that which presently occurs on the property, for migratory birds such as Pacific Golden Plover and Ruddy Turnstone. These two species readily forage on open lawns. One end of the planned golf course adjoins the park fronting Lake Wilson. The concern here would be whether or not the drainage from the golf course will carry herbicides and pesticides into the lake. The development plan will need to show how this problem can be prevented.

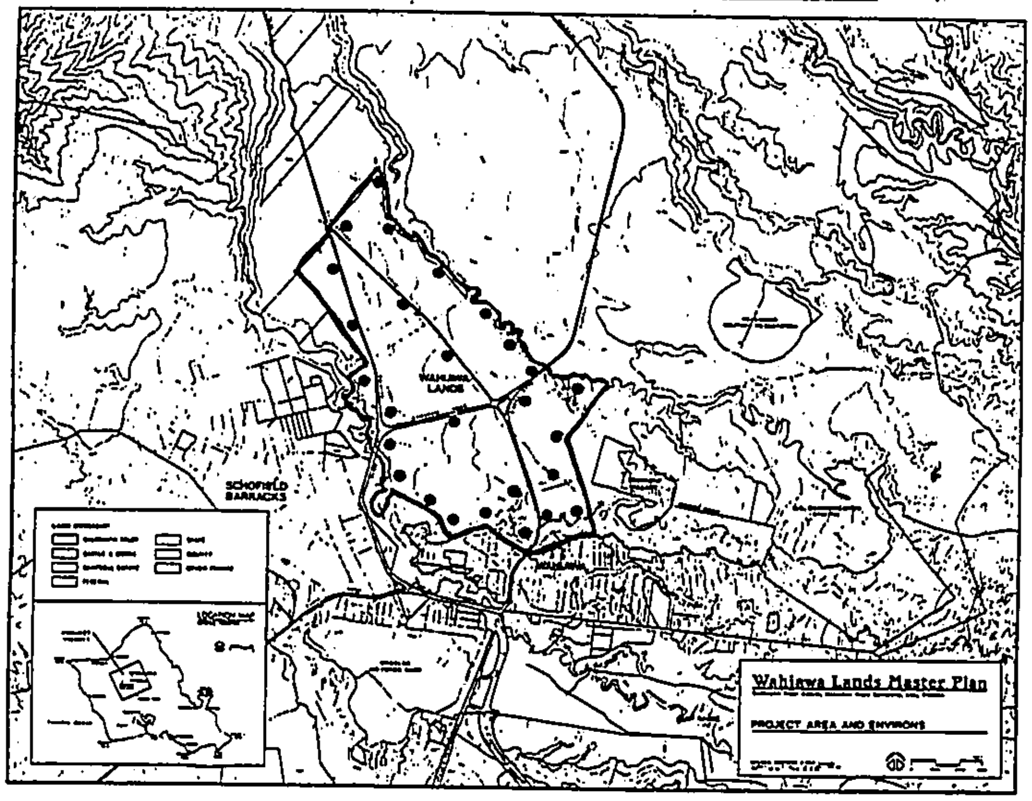

Fig. 1. Location of faunal survey with census stations shown as solid circles.

TABLE 1

Exotic (introduced) birds recorded at Galbraith Trust Lands, Wahiawa, Oahu.

COMMON NAME	SCIENTIFIC NAME	RELATIVE ABUNDANCE*
Cattle Egret	Bubulcus ibis	R= 6
Chicken	Gallus gallus	U= 4
Ring-necked Pheasant	Phasianus colchicus	R= 2
Spotted Dove	Streptopelia chinensis	C= 8
Zebra Dove	Geopelia striata	A= 11
Common Myna	Acridotheres tristis	C= 7
Red-vented Bulbul	Pycnonotus cafer	A= 18
White-rumped Shama	Copsychus malabaricus	U= 4
Northern Cardinal	Cardinalis cardinalis	U= 3
Red-crested Cardinal	Paroaria coronata	C= 8
Japanese White-eye	Zosterops japonicus	A= 12
Java Sparrow	Padda oryzivora	R= 2
Chestnut Mannikin	Lonchura malacca	A= 15
Nutmeg Mannikin	Lonchura punctulata	A= 13
Common Waxbill	Estrilda astrild	A= 10
House Finch	Carpodacus mexicanus	A= 11
House Sparrow	Passer domesticus	C= 7

*(see page 12 for key to symbols)

KEY TO TABLE 1

Relative (estimate) abundance = Number of times observed during survey or average number on eight minute counts in appropriate habitat.

A = abundant (ave. 10+)

C = common (ave. 5-10)

U = uncommon (ave. less than 5)

R = recorded (seen or heard at times other than on 8 min. counts or on one count only). Number which follows is the total number seen or heard over the duration of the survey.

SOURCES CITED

Bremer, D. 1987. The Waipio, Oahu, Christmas Bird Count: 1986 results and a review of the first decade, 1977-1986. 'Elepaio 47(5):53-58.

Bruner, P.L. 1987. Avifaunal and feral mammal survey of property located near Kunia, Central Oahu. Unpubl. ms. prep. for William E. Wanket Inc., Honolulu.

______ 1988. Avifaunal and feral mammal survey of Royal Kunia - Phase II Property located at Kunia, Central Oahu. Unpubl. ms. prep. for William E. Wanket Inc., Honolulu.

Hawaii Audubon Society. 1989. Hawaii's Birds. Fourth Edition. Hawaii Audubon Society, Honolulu.

Honacki, J.H., K.E. Kinman and J.W. Koeppl ed. 1982. Mammal species of the world: A taxonomic and geographic reference. Allen Press, Inc. and the Association of Systematic Collections. Lawrence, kansas.

Johnson, O.W., P.M. Johnson and P.L. Bruner. 1981. Wintering behavior and site-faithfulness of Golden Plovers on Oahu. 'Elepaio 41(12):123-130.

Johnson, O.W., and P.M. Johnson. 1983. Plumage-molt-age relationships in"over-summering" and migratory Lesser Golden-Plovers. Condor 85:406-419.

Johnson, O.W., M.L. Morton, P.L. Bruner and P.M. Johnson. 1989. Winter range fat cyclicity in Pacific Golden-Plovers (Pluvialis fulva) and predicted migratory flight ranges. Condor 91:156-177.

Kepler, C.B. and J.M. Scott. 1990. Notes on distribution and behavior of the endangered Hawaiian Hoary Bat (Lasiurus cinereus semotus) 1974-1983. 'Elepaio 50(7):59-64.

Moulton, M.P., S.L. Pimm and M.W. Krissinger. 1990. Nutmeg Mannikin (Lonchura punctulata): a comparison of abundance in Oahu Vs. Maui sugarcane fields: evidence for competitive exclusion? 'Elepaio 50)10):83-85.

Pratt, H.D., P.L. Bruner and D.G. Berrett. 1987. A field guide to the birds of Hawaii and the Tropical Pacific. Princeton Univ. Press.

Tomich, P.Q. 1986. Mammals in Hawaii. Bishop Museum Press. Honolulu.

Williams, R.N. 1987. Alien Birds on Oahu 1944-1985. 'Elepaio 47(9):87-92.

APPENDIX E

Air Quality Impact Report
J. W. Morrow

AIR QUALITY IMPACT REPORT

WAHIAWA LANDS DEVELOPMENT
GALBRAITH TRUST

December 23, 1992

PREPARED FOR

Helber Hastert & Fee

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1. INTRODUCTION

The Hawaiian Trust Company, trustee for the Galbraith Trust Estate, is proposing to develop approximately 900 of the Trust's 2,200 acres located north of Wahiawa town in central Oahu (Figure 1). The project will consist of the following major components:

Land Use	Acres	Units
Residential	367	2,952
Commercial/Mixed Use	93	148
18-Hole Golf Course	204	
Parks, Schools, Civic, Open	228	

The property exists on a gentle grade between Whitmore Village (c. 980' elevation) and Wilikina Drive (c. 900' elevation) and is currently used for pineapple cultivation by the Dole Corporation (Figure 2).

The purpose of this report is to assess the air quality impact of the proposed development. The project can be considered an "indirect source" of air pollution as defined in the federal Clean Air Act [1] since it will attract mobile sources of air pollution, i.e., motor vehicles. Thus, much of the focus of this analysis is on the project's ability to generate traffic and the resultant impact on air quality. Air quality impact was evaluated for existing (1992) and future (2010) conditions.

The following direct and indirect impacts have also been addressed:

- offsite impacts due to electrical generation
- refuse disposal at a resource recovery facility
- pesticide use at the proposed golf course
- wastewater treatment facility
- onsite and offsite construction impacts

2. AIR QUALITY STANDARDS

A summary of State of Hawaii and national ambient air quality standards is presented in Table 1 [2,3]. Note that Hawaii's standards are not divided into primary and secondary standards as are the Federal standards.

Primary standards are intended to protect public health with an adequate margin of safety while secondary standards are intended to protect public welfare through the prevention of damage to soils, water, vegetation, man-made materials, animals, wildlife, visibility, climate, and economic values [4].

Some of Hawaii's standards are clearly more stringent than their Federal counterparts but, like their Federal counterparts, may be exceeded once per year. It should also be noted that in April, 1986, the Governor signed amendments to Chapter 59 (Ambient Air Quality Standards) making the State's standards for particulate matter and sulfur dioxide the same as national standards. In the case of particulate matter, however, this uniformity did not last long. On July 1, 1987, the EPA revised the Federal particulate standard to apply only to particles 10 microns or less in diameter (PM-10) [5], leaving the State once again with standards different than the Federal ones.

In the case of the automotive pollutants [carbon monoxide (CO), oxides of nitrogen (NOx), and photochemical oxidants (Ox)], there are only primary standards. Until 1983, there was also a hydrocarbons standard which was based on the precursor role hydrocarbons play in the formation of photochemical oxidants rather than any unique toxicological effect they had at ambient levels. The hydrocarbons standard was formally eliminated in January 1983 [6].

The U.S. Environmental Protection Agency (EPA) is mandated by Congress to periodically review and re-evaluate the Federal standards in light of new research findings [7]. The last review resulted in the relaxation of the oxidant standard from 160 to 235 micrograms/cubic meter (ug/m3) [8]. The carbon monoxide (CO), particulate matter, sulfur dioxide (SO2), and nitrogen dioxide (NO2) standards have been reviewed, but no new standards were proposed.

Finally, the State of Hawaii also has fugitive dust regulations for particulate matter (PM) emanating from construction activities [9]. There simply can be no visible emissions from fugitive dust sources.

3. EXISTING AIR QUALITY

3.1 General. The State Department of Health maintains a network of air monitoring stations around the state to gather data on the following regulated pollutants:

- o total suspended particulates (TSP)

- o particulate matter <10 microns (PM-10)
- o sulfur dioxide (SO2)
- o carbon monoxide (CO)
- o ozone (O3)
- o lead (Pb)

Unfortunately, the State conducts no routine monitoring in the project area; the nearest monitoring station is at Pearl City, some nine miles southeast of the site. Nevertheless, it is believed that all state and federal standards are being met in the project area simply due to the lack of major air pollution source activity.

The two principal existing sources in the area are motor vehicle traffic which is evaluated in a subsequent section of this report and agricultural field burning which is a periodic occurrence. Both sources have typically short-term impacts with the former producing elevated carbon monoxide (CO) levels during peak traffic hours and the latter producing high particulate matter concentrations during individual field burns. Field burning onsite will, of course, cease with development.

3.2 Onsite Carbon Monoxide Sampling. In conjunction with this study, air sampling was conducted in October 1992 at two sites predicted by the traffic consultant to experience increases in traffic congestion in the future [10]:

- Kunia Road @ Wilikina Drive
- Kamehameha Highway @ California Avenue

In each case, the actual sampling site was within 10 meters of the road edge and on the southwest side due to the winds prevailing at the time. A continuous carbon monoxide (CO) instrument was set up and operated during the a.m. and p.m. peak traffic hours. An anemometer and vane were installed to record onsite surface winds. A simultaneous manual count of traffic was also performed. The variability of each of the parameters measured during the peak hours is clearly seen in Figures 3 - 6.

A summary of the average values is presented in Table 6. Onsite surface winds were generally light and variable during both the a.m. and p.m. peak hours with mean wind speeds less than 1 m/sec. Atmospheric stability was neutral [11] in the morning and afternoon due to overcast conditions. Traffic counts were comparable to those reported by the traffic consultant. CO concentrations were comparable with the computer-predicted concentrations discussed in Section 6.

4. CLIMATE & METEOROLOGY

4.1 Temperature & Rainfall. While there was no onsite meteorological data available, the project area may be considered typical of Hawaii's climate with little seasonal or diurnal temperature variation. Monthly temperature averages vary by only a few degrees from the warmest months (July and August) to the coolest (January and February) [12]. Mean annual temperature is 72° F [12].

Rainfall in the project area ranges from 40 to 60 inches per year [13,14]. In accordance with Thornwaite's scheme for climatic classification [15], the area thus ranges from subhumid grassland to humid forest.

4.2 Surface Winds. While the area would be subjected on an annual basis to the prevailing northeasterly trade winds, it is the winds during peak traffic hours that are of primary interest. Figures 2 and 3 depict 0700 HST and 1600 HST wind roses for the nearby Wheeler Air Force Base. The predominance of northeasterly trades in the afternoon is quite evident, but during the early morning there appears to be over 50% calm conditions or northwesterly winds. Tables 3 and 4 offer further insight into the joint frequency distribution of wind speed and direction at the two peak traffic hours.

5. HIGHWAYS AND TRAFFIC

The principal roads in the project area include Kamehameha Highway, Wilikina Drive, Kaukonahua Highway, and Kamananui Road. Kamehameha Highway is a 2-lane rural roadway north of Wahiawa but provides 6 lanes within Wahiawa proper. Speed limits range from 25 to 45 mph. Wilikina Drive is a 4-lane highway from the H-2 Freeway to Macomb Gate at Schofield Barracks but becomes 2-lane north of that point. Speed limits range 25 - 35 mph. Kaukonahua Highway is a 2-lane rural roadway transecting the site and having a posted 45-mph speed limit. Kamananui Road runs approximately east to west forming the northern boundary of the site and is also a 45-mph rural highway.

The traffic study provided by Wilbur Smith Associates, Inc. [10] indicates that these roads and their intersections are generally operating without congestion or delay. Only Kamananui Road at

its intersections with Wilikina Drive (Figure 9) and Kamehameha Highway is experiencing queueing and delays in some turning movements.

In the future, with regional growth as well as project-generated traffic, those intersections as well as others such as Wilikina Drive at Kunia Road and several along Kamehameha Highway in Wahiawa Town will experience greater congestion. Photographs of the existing conditions at some of these intersections are presented in Figures 9 and 10.

6. MOBILE SOURCE IMPACT

6.1 Emission Factors. Automotive emission factors for carbon monoxide (CO) were generated for calendar years 1992 and 2010 using the Mobile Source Emissions Model (MOBILE-3) [16]. To localize emission factors as much as possible, the August, 1988 age distribution for the City & County of Honolulu [17] was input in lieu of the national statistics normally used.

6.2 Microscale Analysis. Analyses such as this generally involve estimation of concentrations of non-reactive pollutants. This is due to the complexity of modeling pollutants which undergo chemical reactions in the atmosphere and are subject to the effects of numerous physical and chemical factors which affect reaction rates and products. For projects involving motor vehicles as the principal air pollution source, carbon monoxide is normally selected for modeling because it has a relatively long half-life in the atmosphere (about 1 month) [18], and it comprises the largest fraction of automotive emissions.

In this instance, a microscale screening analysis was performed for the Wilikina Drive - Kunia Road, Kamehameha Highway - California Avenue, and Wilikina Drive - Kamananui Road intersections. These are intended to be representative of the "worst case" traffic and air quality impacts; other intersections would be the same or less ,in terms of impacts. The updated version of an EPA guideline model CALINE-4 [19,20] was employed with an array of receptors spaced at distances of 10 - 30 meters from the road edge. Due to the differences in surrounding motor vehicle activity, a background CO concentration of 1.0 milligram per cubic meter (mg/m3) was assumed at the California Avenue intersection while a 0.1 mg/m3 level was assumed at th e other two intersections studied.

Worst case meteorological conditions were selected for the a.m. and p.m. peak traffic hours. A wind speed of 1 meter per second, an acute wind/road angle, very stable atmosphere (Pasquill-Gifford Class "F")[11] in the morning, and neutral stability (Pasquill-Gifford Class "D") in the afternoon, were all selected to maximize concentration estimates in the vicinity of the intersections. Review of the traffic data and preliminary modeling indicated that northeasterly and northwesterly winds were most likely to produce the maximum CO concentrations near the intersections under study; thus, these wind direction were input for the modeling.

Maximum one-hour carbon monoxide (CO) concentrations were then computed for the peak traffic hours. The analyses were performed for existing conditions (1992) and future conditions (2010) both with and without the proposed project. The results are summarized in Figures 11 - 13.

6.3 Results. The indicate compliance with federal and state 1-hour CO standards at all locations under both current and projected peak traffic conditions. The general trend is towards a decline in near-roadway CO concentrations without the project but little change with the project. Depending on where estimates are made the 1992 to 2010 change with the project can increase, remain about the same, or decrease slightly due to tighter emission controls on new vehicles.

Compliance with the federal and state 8-hour standards can also be determined by applying an EPA-recommended "persistence" factor of 0.6 to the 1-hour maximum CO values [29]. When using this approach, any CO concentrations greater than 8.4 mg/m3 indicate exceedance of the State's 8-hour standard. Similarly, any 1-hour concentration over 15.7 mg/m3 would indicate exceedance of the federal 8-hour standard. In this case, both the existing and 2010 "with project" results indicate possible exceedances of the state 8-hour standards within close proximity (<<10 meters) to the Kamehameha Highway - California Avenue intersection.

7. OFF-SITE STATIONARY SOURCE IMPACT

7.1 Electrical Generation. Based on average consumption by residential and commercial users, an annual electrical demand of 56 million kilowatt hours is estimated for the project.

This demand will obviously necessitate the generation of electricity by power plants. Currently, most of Oahu's electrical energy is generated at Hawaiian Electric Company's (HECO) Kahe Generating Station. This is currently a six-unit, approximately 650-megawatt facility firing low-sulfur fuel oil. A seventh 150-megawatt unit was proposed by HECO [21], but two out-of-state companies proposed and have since built and put into service a gas turbine and coal-fired power plant at Campbell Industrial Park to sell power to the utility [22]. For the

purposes of this analysis, low sulfur (0.5%) fuel oil-firing was assumed. Estimates of annual emissions were computed based on EPA emission factors [23] and the fuel required to meet a 56 million kWhr demand. The results are presented in Table 5.

7.2 Solid Waste Disposal. The refuse generated by the residents of the 3.100 new homes as well as the commercial establishments and public facilities in the project will require disposal. Historically, about 80% of Oahu's refuse was being landfilled with the remaining 20% being burned at the Waipahu Incinerator [24]. With the recent opening of the City's new resource recovery facility (HPOWER) at Campbell Industrial Park, most refuse will be pre-processed and burned leaving less mass to be landfilled. This facility was originally designed to handle most of Oahu's domestic refuse (1,800 tons/day). Estimates of annual emissions attributable to the combustion of project-generated refuse at HPOWER are included in Table 5.

7.3 Discussion. The emissions estimates for electrical generation and solid waste disposal may be compared to the latest available county emissions inventory in Table 6 in order to provide some perspective on their significance. The project's contribution to county emissions appears to be less than 0.6%.

8. OTHER LONG-TERM IMPACTS

8.1 Agricultural Burning. As noted earlier, the development of this project will eliminate field burning on the site itself thereby resulting in a positive air quality impact. Future residents, however, may at times be exposed to the smoke from such fires on the remaining 1,300 acres which will continue in agriculture. These fields are north of the project site and thus generally upwind.

8.2 Pesticide Use. Pesticides are routinely required at golf courses in order to maintain fairways and greens. Typical pesticide use at a 18-hole golf course was obtained from another report prepared for this project [13].

The herbicides bensulide, DCPA, Dicamba, and 2,4-D all have relatively low mammalian toxicities with oral LD_{50} values on the order of hundreds or thousands of milligrams active agent per kilogram body weight (mg/kg) [25]. 2,4-D has a OSHA air standard of 10 mg/m3 [25]. This is an 8-hour time-weighted average.

The insecticides bendiocarb, chlorpyrifos and trichlorfon are moderately toxic carbamates (bendiocarb) or organophosphates which can affect the normal functioning of mammalian nervous systems through inhibition of the enzyme cholinesterase. They have oral LD_{50} values in the range of 40 - 250 mg/kg. The OSHA standard for airborne concentrations of chlorpyrifos is 0.2 mg/m3 as an 8-hour average [25].

The nematocide Fenamiphos is also an organophosphate but more toxic with an LD_{50} of 8 mg/m3 and an OSHA standard of 0.1 mg/m3.

The fungicides metalaxyl, benomyl and chlorothalonil have relatively low acute toxicities with oral LD_{50} values in the hundreds and thousands of mg/kg. Chlorothalonil, however, has also demonstrated some carcinogenic potential in animals. Benomyl has OSHA 8-hour standards of 10 mg/m3 total concentration and 5 mg/m3 for the respirable fraction [25].

If properly used in accordance with label instructions, all of the aforementioned chemicals should present no hazard to the properties or owners of properties adjoining the proposed golf course. In fact, the greatest risk in using such chemicals is generally to the users themselves if they do not strictly follow label instructions. This is because the user may come in contact with the concentrated product while nearby properties and people may only be exposed to the greatly diluted and dispersed application solution.

The potential for significant airborne concentrations of these chemicals is relatively slight when one considers the dilution factor in application solutions plus the coarse spray that is normally used to assure adequate coverage in the desired area and avoidance of drift. Should a user improperly apply these chemicals under wind conditions which would contribute to drift, then there would be an increased possibility of downwind exposure of property and people.

8.3 Wastewater Treatment Facility. It may be necessary to construct a wastewater treatment facility (WWTF) to serve the proposed development, and a draft concept plan has been prepared [14]. WWTF are potential sources of air pollution including viable and nonviable particles, odors, and gases depending on the specific plant design.

9. CONSTRUCTION IMPACT

The principal source of short-term air quality impact will be construction activity. Construction vehicle activity will increase automotive pollutant concentrations along the principal access roads as well as in the vicinity of the project site itself. During off-peak hours, the additional construction vehicle traffic should not exceed road capacities although the

presence of large trucks can reduce a roadway's capacity as well as lower average travel speeds thereby contributing to additional air pollution emissions.

The site preparation and earth moving will create particulate emissions as will building and on-site road construction. Construction vehicles movement on unpaved on-site roads will also generate particulate emissions. EPA studies on fugitive dust emissions from construction sites indicate that about 1.2 tons/acre per month of activity may be expected under conditions of medium activity, moderate soil silt content (30%), and precipitation/evaporation (P/E) index of 50 [23].

The majority of the onsite soils were silty clays, in all probability having silt contents greater than the 30% cited above, and thus implying greater dust potential. This, however, is somewhat offset by the computed P/E Indices for the area which were 53 - 83 implying wetter conditions than in the EPA case and thus less dust potential.

The potential for fugitive dust during the drier months due to the high silt content of the soils makes adequate dust control measures important during those times. Dust control could be accomplished, for example, through frequent watering of unpaved roads and areas of exposed soil. The EPA estimates that twice daily watering can reduce fugitive dust emissions by as much as 50%.

In addition to the onsite impacts attributable to construction activity, there will also be offsite impacts due to the operation of concrete batching plants needed for construction. Since it is also too early to identify specific facilities that will be providing the concrete, the discussion of air quality impacts is necessarily generic.

Design and operating features of a typical concrete batching plant were obtained for this analysis. This plant (Rex Transit Mix Batch Plant, Model LO GO 5) [26], is a portable unit capable of producing up to 100 cubic yards of concrete per hour.

Assuming 8 hours/day operation and published EPA emission factors [23] for both direct plant emissions and fugitive dust emissions, estimates of worst case ambient impact were derived using the PTPLU screening model [27]. Ninety percent control of particulate emissions from the plant itself and 60% control of fugitive dust emissions from the process were assumed. One-hour concentration estimates were adjusted to 8-hour averages using an EPA-recommended factor [28] and then to 24-hour averages based on a weighted averaging technique. The worst case concentration of total suspended particulates (TSP) was thus estimated to be 105 micrograms/cubic meter (ug/m3) due to the plant operation.

Since it is not known where exactly the plant(s) will be located and thus what the background concentration of TSP will be, it is somewhat difficult to predict cumulative concentrations for comparison with standards. However, if the batch plant's 105 ug/m3 were assumed to be all < 10 microns and were added to typical PM-10 values of 30 - 40 ug/m3, then the standard of 150 ug/m3 would be met.

10. CONCLUSIONS AND MITIGATION.

10.1 Conclusions. Based on the foregoing analysis, the following conclusions may be drawn:

- Traffic generated by the proposed project will contribute to a slight decline in air quality along the major roadways serving the area. State and federal air quality standards will generally be met, but there is a low probability of the state's 8-hour standard being exceeded in close proximity to the Kamehameha Highway - California Avenue intersection under worst case traffic and meteorological conditions.
- Electrical demand and solid waste disposal resulting from the project will cause an increase in county emissions amounting to less than 0.6% of the latest available county emissions inventory.
- Project residents may at times be affected by emissions from the surrounding environment, specifically:
  - infrequent agricultural burning in the fields north of the project; and
  - pesticide use
- If a wastewater treatment facility is eventually built, it will have the potential for some air quality impact.
- Construction activities will have a short-term impact on local air quality due to the additional construction vehicle activity and fugitive dust from construction activities.

10.2 Mitigation

10.2.1 Motor vehicle activity: The types of measures that could help reduce the predicted traffic-related impacts include:

- additional highway improvements to increase capacity
- increased bus service to the project area
- encouragement of car-pooling
- limited parking facilities to encourage use of public transportation

10.2.2 Electrical generation: Measures that will reduce offsite emissions at electrical power plants and save energy include the following recommendations of the State Department of Business, Economic Development and Tourism:

- east/west orientation of streets for the long dimensions of houses to minimize heat gains in the morning and afternoon.
- adequate system of walkways and bikeways to encourage walking and bicycling between home, school, park and commercial areas.
- selection and placement of landscape materials to provide shading for minimization of heat gains in the morning and afternoon.
- maximize shading of paved areas by trees, awnings, trellises, roofing or houses.
- provide enclosed yards where clotheslines can be used.
- use drought-resistant plants for landscaping to reduce energy use associated with irrigation.
- install operable windows and orient opening towards prevailing winds.
- install eves (minimum 30 inches), louvers, trellises, or shade screen to shade windows, especially on west, south, and east sides.
- include attics ventilated by devices such as louvers at or near the roof ridge.
- include radiant barriers in attics.

- use light colored finishes on roofs and walls.
- install heat pump water heaters, or
- install solar water heaters or provide for future installation by pre-plumbing and pre-wiring.
- install the most energy efficient appliances.
- install ceiling fans or provide for future installation by pre-wiring.
- install time switches to high-usage applications or equipment such as electric water heaters.
- install fluorescent lights with high efficiency ballasts.

10.2.3 Agricultural Burning: Burning should be limited to times when wind direction is not towards the most heavily populated areas and when atmospheric conditions favor rise and mixing of the plume.

10.2.4 Pesticide use: The following measures will help reduce any possible air quality impacts associated with pesticide use:

- full compliance with label use instructions
- use of integrated pest control measures
- minimize pesticide use
- maximize use of non-chemical pest control measures
- use of low-toxicity/nonpersistent chemicals

10.2.5 Solid waste disposal: The following measures will help reduce emissions resulting from burning of solid wastes:

- provide a recycling program for the project
- provide a composting facility for the project

10.2.6 Wastewater Treatment Facility: Any WWTP should be properly designed with air pollution controls appropriate for the particular plant design. Well-trained operators adhering to standard operating procedures will also insure minimal impact. The suggested site on the west side of Wilikina Drive is downwind of the development in terms of prevailing trade winds thus

further reducing any possible impacts.

10.2.7 Construction impacts: The following measures will help reduce the short-term impacts associated with construction activities:

- compliance with state/county dust control requirements
- covers for open trucks transporting dusty materials
- frequent watering of exposed soil areas
- soonest possible landscaping of exposed soil areas
- concrete and asphalt plants in compliance with DOH permits

REFERENCES

1. U. S. Congress. Clean Air Act Amendments of 1977 (P.L. 95-95, Section 110, Implementation Plans, August, 1977.

2. U. S. Government. Code of Federal Regulations, Title 40, Protection of Environment, Part 50, National Primary and Secondary Ambient Air Quality Standards.

3. State of Hawaii. Title 11, Administrative Rules, Chapter 59 Ambient Air Quality Standards, as amended, April, 1986.

4. Library of Congress, Congressional Research Service. A Legislative History of the Clean Air Amendments of 1970, Volume 1, p. 411, January, 1974.

5. U.S. Environmental Protection Agency. Revisions to National Ambient Air Quality Standards for Particulate Matter, Federal Register, Vol. 52, p. 2463, July 1, 1987.

6. U. S. Environmental Protection Agency. National Ambient Air Quality Standards for Hydrocarbons: Final Rulemaking, Federal Register, Volume 48, No. 3, p. 628, January, 1983.

7. U. S. Congress. Clean Air Act Amendments of 1977 (P.L. 95-95) Section 109, National Ambient Air Quality Standards, August, 1977

8. U. S. Environmental Protection Agency. National Ambient Air Quality Standards for Photochemical Oxidants: Final Rulemaking, Federal Register, Volume 44, No. 28, p. 8202, February 8, 1979

9. State of Hawaii. Title 11, Administrative Rules, Chapter 60, Air Pollution Control.

10. Wilbur Smith Associates. Wahiawa Galbraith Trust Lands Traffic Study (Draft), 3 November 1992.

11. U. S. Environmental Protection Agency. Workbook of Atmospheric Dispersion Estimates, AP-26 (Sixth Edition), 1973.

12. U.S. Department of Commerce, National Oceanographic and Atmospheric Administration, Environmental Data Service. Hawaii and Pacific Annual Summary, 1974.

13. Walker, W. J. Environmental Impact Assessment for the Proposed Golf Course at Wahiawa Lands/Galbraith Trust Draft Development Plan, 25 November 1992.

14. Hirota, S. O. Wahiawa Lands Infrastructure Report, Draft Concept Development Plan, 27 November 1992.

15. Thornwaite, C. W. Climates of North America According to a New Classification, Geog. Rev. 21: 633-655, 1931.

16. U. S. Environmental Protection Agency. User's Guide to MOBILE-3 (Mobile Source Emissions Model), EPA-460/3-84-002, June, 1984.

17. City & County of Honolulu, Department of Data Systems. Age Distribution of Registered Vehicles in the City & County of Honolulu (unpublished report), August, 1988.

18. Seinfeld, John H. Air Pollution: Physical and Chemical Fundamentals, p. 69, McGraw-Hill Book Company, 1975

19. U.S. Environmental Protection Agency. Guideline on Air Quality Models (Revised), EPA-450/2-78-027R, July, 1986.

20. California Department of Transportation. CALINE4 - A Dispersion Model for Predicting Air Pollutant Concentrations Near Roadways (Final Report), November, 1984 (revised June, 1989).

21. Hawaiian Electric Company. Environmental Impact Statement Preparation Notice: Kahe Unit 7 Project, July 2, 1987.

22. Kaser, Thomas. "HECO Planning to Buy Power", Honolulu Advertiser, October 3, 1987.

23. U.S. Environmental Protection Agency. Compilation of Air Pollutant Emission Factors, Fourth Edition, September, 1985.

24. City and County of Honolulu, Department of Public Works. Revised Environmental Impact Statement for the Proposed Solid Waste Processing and Resource Recovery Facility, August, 1983.

25. National Institutes of Occupational Safety and Health, Registery of Toxic Effects of Chemical Substances (RTECS), July, 1992.

26. Rexworks, Inc. LO GO 5 Transit Mix Batch Plant, Bulletin No. 1017-283.

27. U.S. Environmental Protection Agency. User's Network for Applied Modeling of Air Pollution (UNAMAP), Version 6, 1986.

28. U.S. Environmental Protection Agency. Guidelines for Air Quality Maintenance Planning and Analysis, Volume 10 (Revised): Procedures for Evaluating Air Quality Impact of New Stationary Sources, EPA-450/4-77-001, October, 1977.

29. U.S. Environmental Protection Agency. Guidelines for Air Quality Maintenance Planning and Analysis, Volume 9 (Revised): Indirect Sources, EPA-450/4-78-001, September 1978

TABLES

TABLE 1

SUMMARY OF STATE OF HAWAII AND FEDERAL
AMBIENT AIR QUALITY STANDARDS

POLLUTANT	SAMPLING PERIOD	FEDERAL STANDARDS PRIMARY	FEDERAL STANDARDS SECONDARY	STATE STANDARDS
1. Total Suspended Particulate Matter (TSP)	Annual Geometric Mean	--	--	60
(micrograms per cubic meter)	Maximum Average in Any 24 Hours	--	--	150
2. PM-10	Annual	50	50	--
(micrograms per cubic meter	Maximum Average in Any 24 Hours	150	150	--
3. Sulfur Dioxide (SO2)	Annual Arithmetic Mean	80	--	80
(micrograms per cubic meter)	Maximum Average in Any 24 Hours	365	--	365
	Maximum Average in Any 3 Hours		1,300	1,300
4. Nitrogen Dioxide (NO2)	Annual Arithmetic Mean	100		70
(micrograms per cubic meter)				
5. Carbon Monoxide (CO)	Maximum Average in Any 8 Hours	10		5
(milligrams per cubic meter)	Maximum Average in Any 1 Hour	40		10
6. Ozone (O3)	Maximum Average in Any 1 Hour	235		100
(micrograms per cubic meter)				
7. Lead (Pb)	Maximum Average in Any Calendar Quarter	1.5		1.5
(micrograms per cubic meter)				

TABLE 2

ONSITE CARBON MONOXIDE SAMPLING RESULTS
WILIKINA DRIVE AND KAMEHAMEHA HIGHWAY
OCTOBER, 1992

Date	Day of Week	Time	Location	CO mg/m3	Onsite Weather WD	Onsite Weather WS m/s
28 Oct 92	Wed	6:00 - 7:00 am	Wilikina Dr @ Kunia Rd	2.7	ENE	<1
		7:00 - 8:00		2.3	ENE	<1
		3:35 - 4:00 pm	Wilikina Dr @ Kunia Rd	2.5	S	<1
		4:00 - 5:00		2.3	S	<1
29 Oct 92	Thu	6:00 - 7:00 am	Kam Hwy @ California Ave	3.8	Calm	
		7:00 - 8:00		4.1	NE	<1
30 Oct 92	Fri	3:30 - 4:00 pm	Kam Hwy @ California Ave	5.6	NE	<1
		4:00 - 5:00		4.6	NE	<1

TABLE 3

JOINT FREQUENCY DISTRIBUTION
OF WIND SPEED AND DIRECTION
0700 HST, WHEELER AFB, HAWAII
1975

Direction	Wind Speed (kts) 0 - 3	4 - 7	8 - 12	>12	Total
N	0.0083	0.0028			0.0111
NNE	0.0250	0.0250			0.0500
NE	0.0250	0.0194	0.0083		0.0527
ENE	0.0056	0.0361	0.0194		0.0611
E	0.0139	0.0278	0.0056		0.0473
ESE		0.0083			0.0083
SE		0.0056	0.0028		0.0084
SSE		0.0056	0.0056		0.0112
S					0.0000
SSW	0.0028	0.0028			0.0056
SW	0.0083	0.0028			0.0111
WSW	0.0028				0.0028
W	0.0111	0.0056	0.0028		0.0195
WNW	0.0250	0.0139			0.0389
NW	0.0667	0.0639			0.1306
NNW	0.0167	0.0194			0.0361
TOTAL	0.2112	0.2390	0.0445		0.4947
	CALMS:	0.5053			1.0000

TABLE 4

JOINT FREQUENCY DISTRIBUTION
OF WIND SPEED AND DIRECTION
1600 HST, WHEELER AFB, HAWAII
1975

Direction	Wind Speed (kts) 0 - 3	4 - 7	8 - 12	13 - 18	Total
N	0.0028	0.0223	0.0084		0.0335
NNE	0.0028	0.0279	0.0195		0.0502
NE	0.0167	0.1309	0.1281	0.0195	0.2952
ENE		0.0919	0.1727	0.0195	0.2841
E		0.0362	0.0696	0.0056	0.1114
ESE	0.0028	0.0167	0.0139		0.0334
SE	0.0028	0.0195	0.0084		0.0307
SSE	0.0028	0.0279	0.0111	0.0028	0.0446
S	0.0028	0.0056	0.0028		0.0112
SSW		0.0111			0.0111
SW		0.0028			0.0028
WSW					0.0000
W		0.0028	0.0028		0.0056
WNW	0.0028	0.0028			0.0056
NW		0.0139	0.0084		0.0223
NNW	0.0084	0.0279	0.0028		0.0391
TOTAL	0.0447	0.4402	0.4485	0.0474	0.9808
	CALMS:	0.0192			1.0000

TABLE 5

Estimates of Annual Emissions Due to Electrical Generation and Solid Waste Disposal
Wahiawa Lands Project
2010

Pollutant	Emissions (T/Yr) Electrical Generation	Solid Waste Disposal
Nitrogen oxides	206	18.9
Sulfur oxides	156	3.9
Particulate matter	16	1.6
Carbon monoxide	10	16.6
Volatile Organics	2	1.0

TABLE 6

1980 EMISSIONS INVENTORY
CITY & COUNTY OF HONOLULU

SOURCE CATEGORY	EMISSIONS (Tons/Year) PM	SOx	NOx	CO	HC
Steam Electric Power Plants	2092	36,736	12,455	1,065	184
Gas Utilities	14	0	199	0	0
Fuel Combustion in Agricultural Industry	1088	579	358	0	31
Refinery Industry	622	7,096	2,149	266	2,584
Petroleum Storage	0	0	0	0	1,261
Metallurgical Industries	28	96	40	0	0
Mineral Products Industry	6,884	1,883	597	0	31
Municipal Incineration	42	145	2,029	0	184
Motor Vehicles	1,413	1,014	17,270	239,198	22,853
Construction, Farm and Industrial Vehicles	184	193	2,507	3,729	338
Aircraft	382	145	1,751	5,594	1,476
Vessels	42	386	438	533	123
Agricultural Field Burning	1,399	0	0	15,982	1,692
TOTAL:	14,191	48,274	39,792	266,367	30,758

SOURCE: State Department of Health

FIGURES

FIGURE 1

PROJECT LOCATION

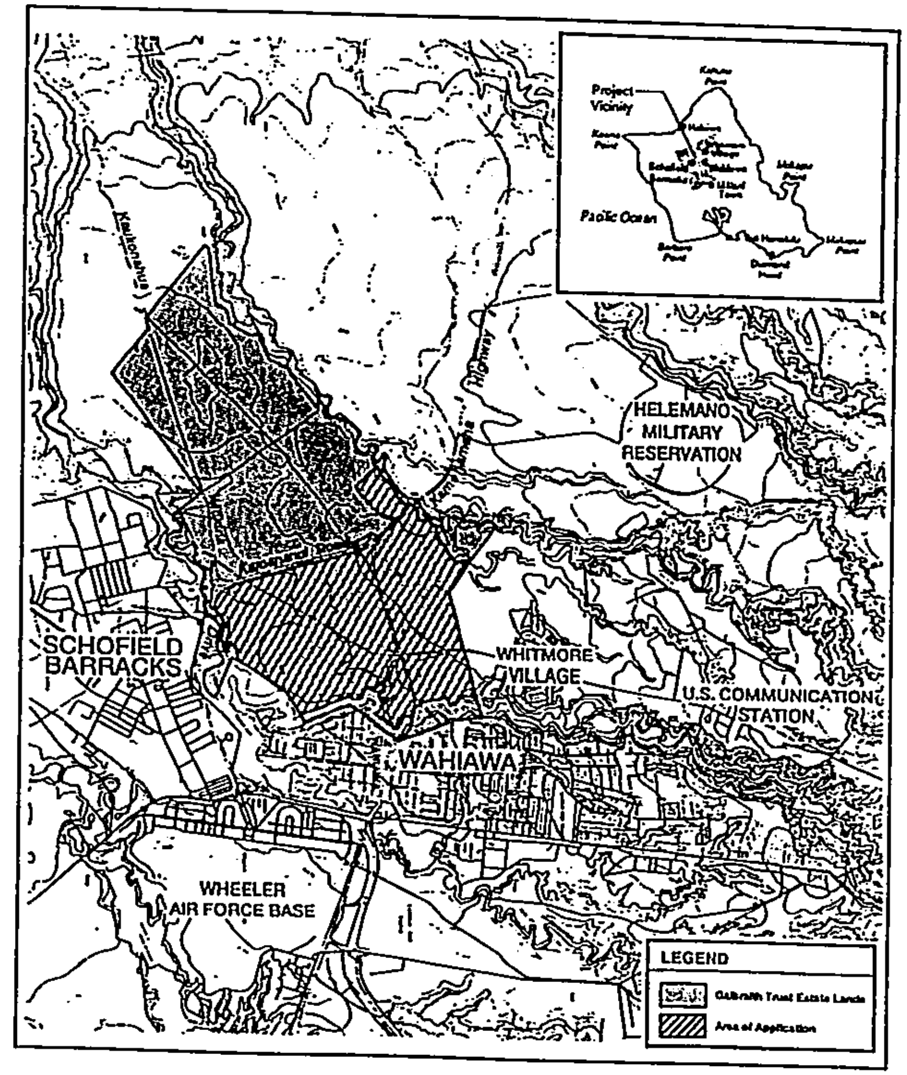


FIGURE 2

EXISTING SITE CONDITIONS
OCTOBER 1992

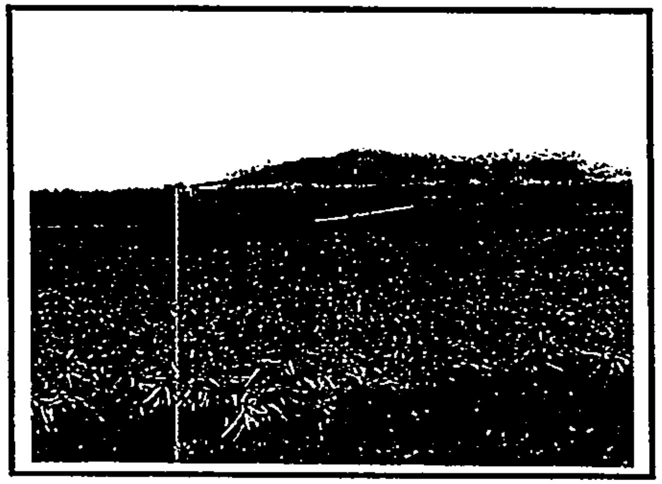


FIGURE 3

A.M. PEAK HOUR CONDITIONS
KUNIA ROAD AT WILIKINA DRIVE
October 28, 1992

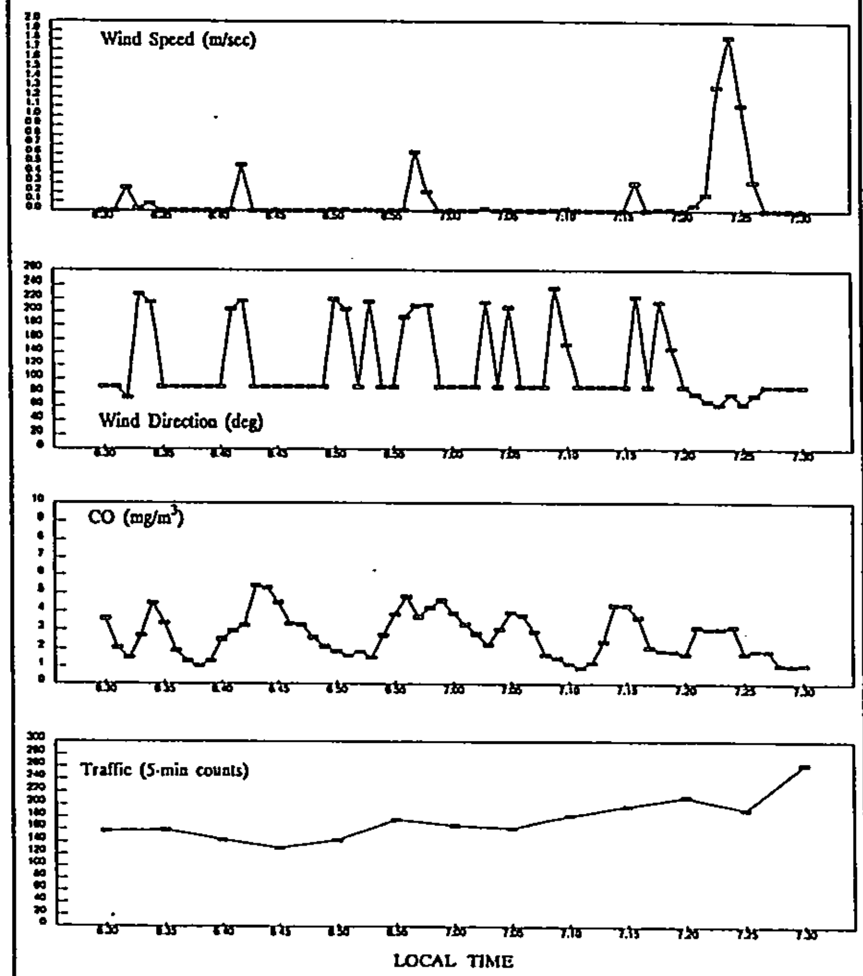


FIGURE 4

P.M. PEAK HOUR CONDITIONS
KUNIA ROAD AT WILIKINA DRIVE
October 28, 1992

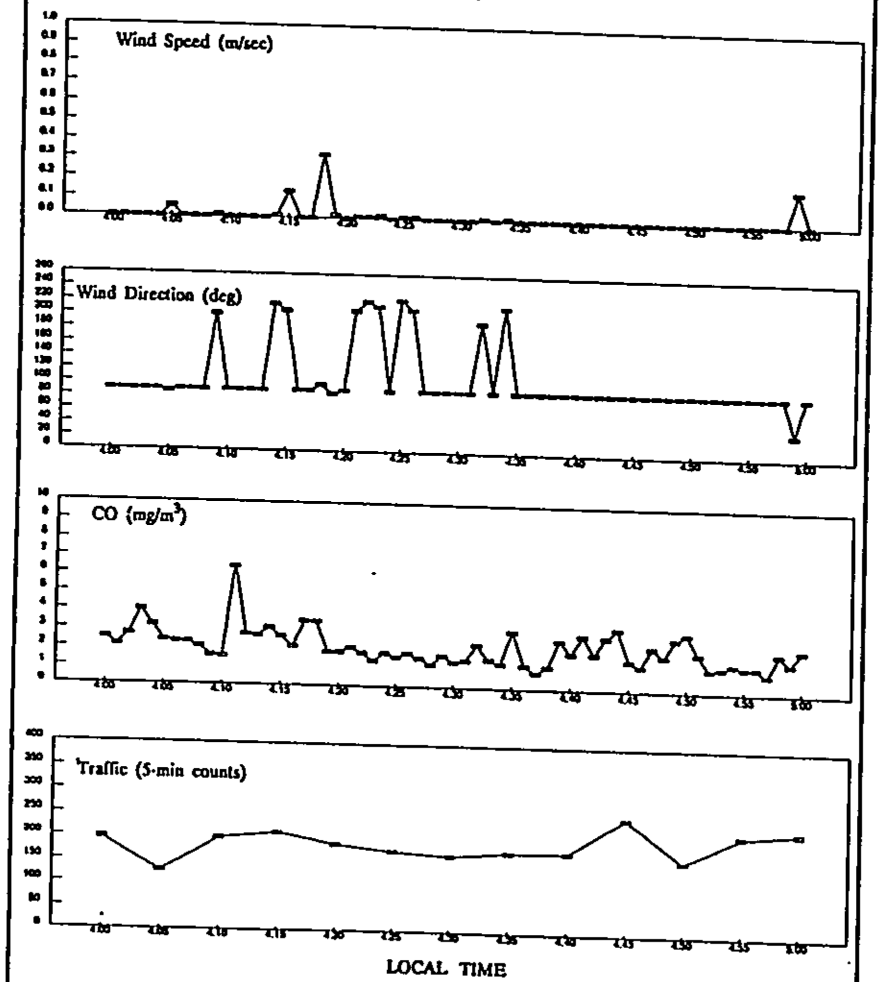


FIGURE 5

A.M. PEAK HOUR CONDITIONS
KAMEHAMEHA HIGHWAY AT CALIFORNIA AVENUE
October 29, 1992

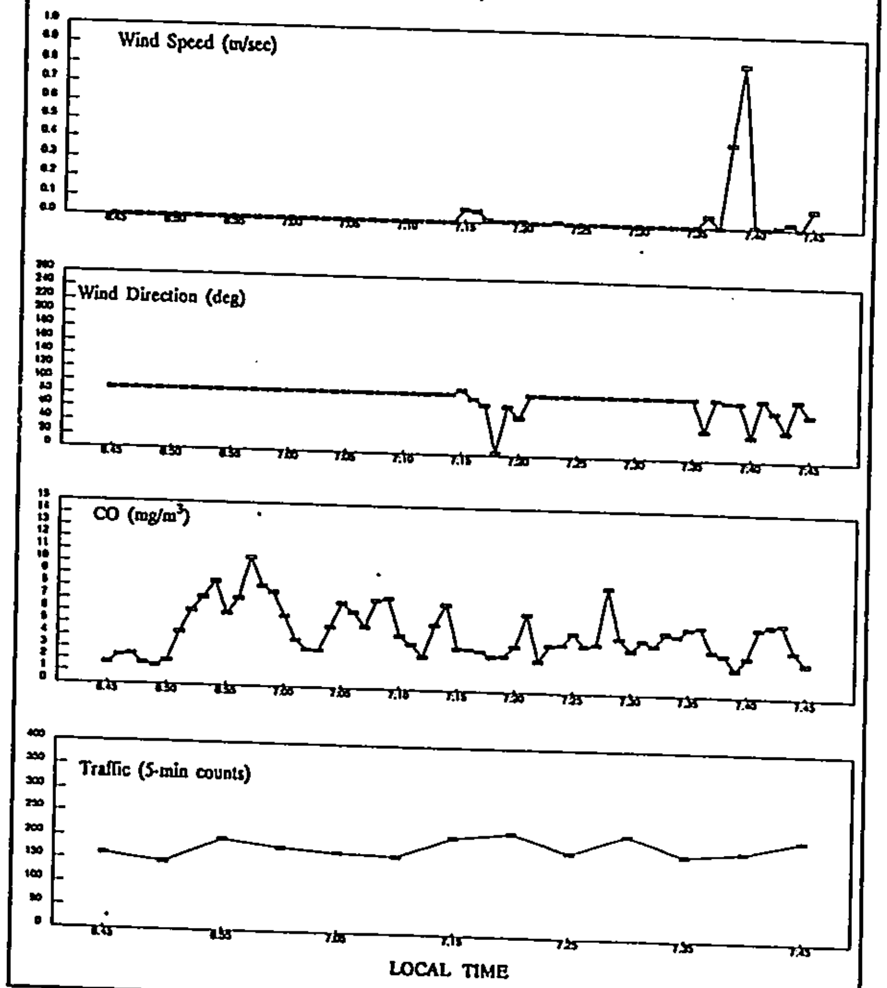


FIGURE 6

P.M. PEAK HOUR CONDITIONS
KAMEHAMEHA HIGHWAY AT CALIFORNIA AVENUE
October 30, 1992

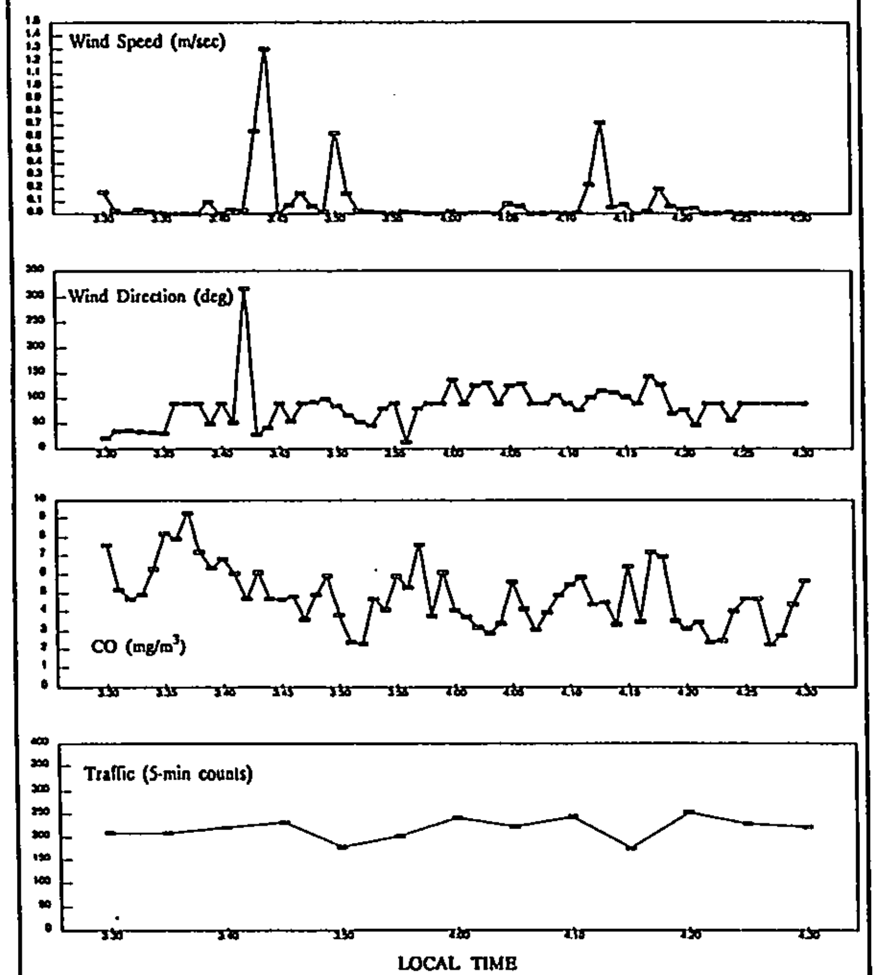
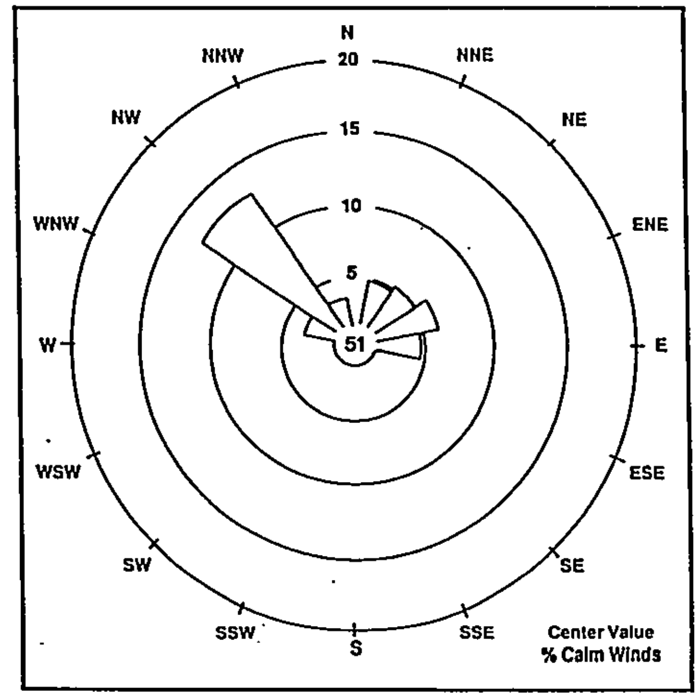


FIGURE 7

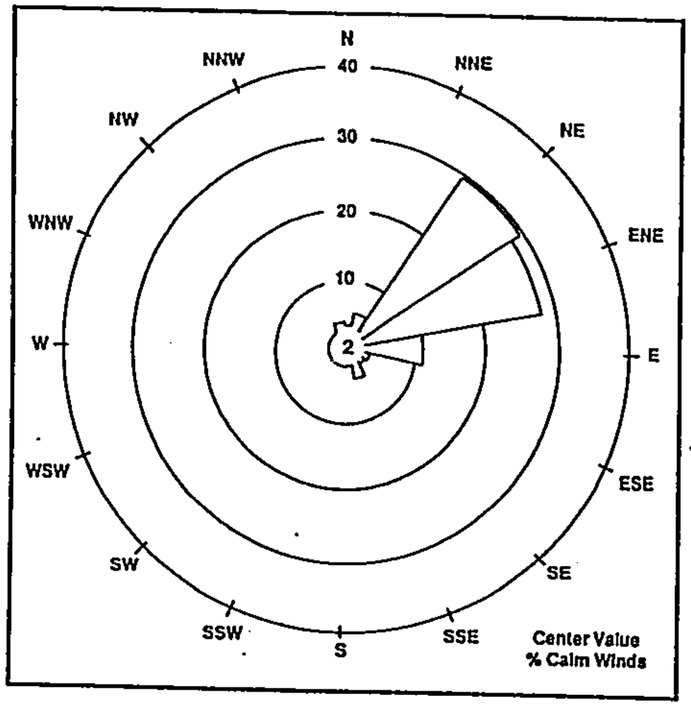
0700 HST WINDROSE
WHEELER AFB, HAWAII
1975



SOURCE: National Weather Service

FIGURE 8

**1600 HST WINDROSE
WHEELER AFB, HAWAII
1975**



SOURCE: National Weather Service

FIGURE 9

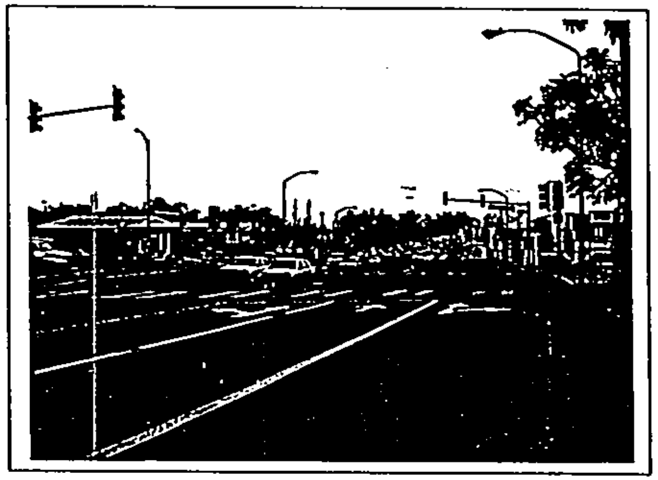
**WILIKINA DRIVE AT KUNIA ROAD
AND KAMANANUI ROAD**

Wilikina Drive
at Kunia Road
(facing southeast)

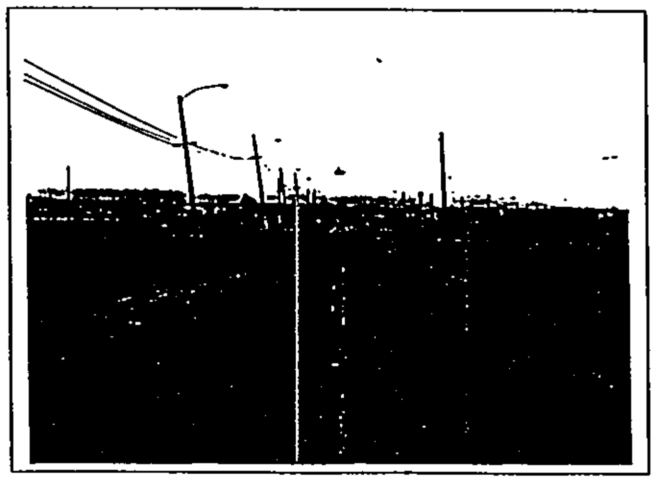
Kamananui Road
at Wilikina Drive
(facing northeast)

FIGURE 10

KAMEHAMEHA HIGHWAY AT CALIFORNIA AVENUE AND KAUKONHUA HIGHWAY AT KAMANANUI ROAD



Kamehameha Highway at California Avenue (facing south))

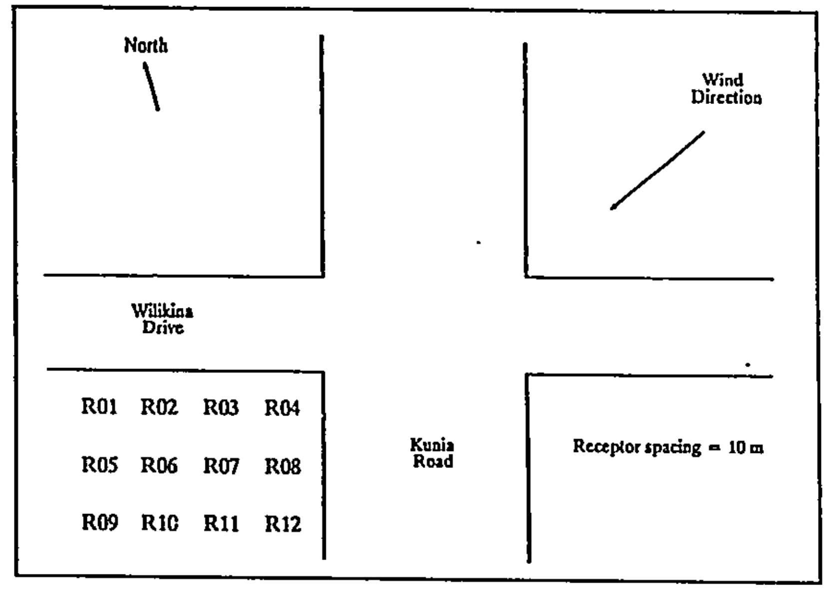


Kaukonahua Highway at Kamananui Road (facing southeast)

FIGURE 11

ESTIMATES OF MAXIMUM 1-HOUR CARBON MONOXIDE CONCENTRATIONS

Wilikina Drive at Kunia Road
Peak Traffic Hours
1992 - 2010

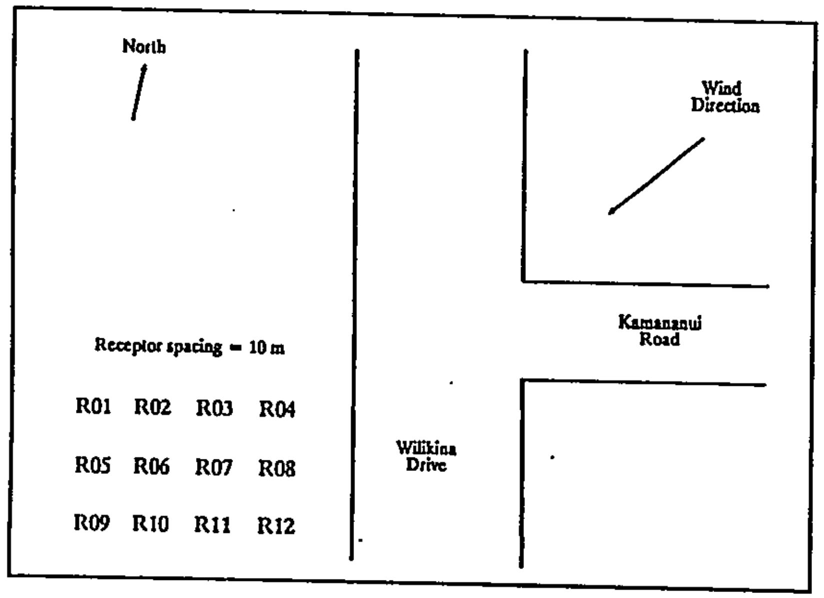


	Concentration (mg/m³)					
		A.M.			P.M.	
Receptor	1992	2010 w/o	2010 w/proj	1992	2010 w/o	2010 w/proj
R01	5.2	4.3	5.0	6.2	5.2	6.2
R02	5.2	4.3	5.0	6.0	5.2	6.2
R03	5.1	4.3	4.6	6.0	5.2	6.2
R04	5.1	4.3	5.0	6.0	5.1	6.2
R05	4.1	3.4	3.9	4.6	4.0	4.6
R06	4.0	3.4	3.9	4.6	3.9	4.6
R07	4.0	3.4	3.9	4.6	3.9	4.6
R08	4.0	3.3	3.9	4.4	3.9	4.6
R09	3.4	3.0	3.3	3.8	3.3	3.8
R10	3.4	2.8	3.3	3.8	3.2	3.8
R11	3.4	2.8	3.3	3.6	3.2	3.6
R12	3.3	2.8	3.2	3.6	3.2	3.6

FIGURE 12

ESTIMATES OF MAXIMUM 1-HOUR CARBON MONOXIDE CONCENTRATIONS

Wilikina Drive at Kamananui Road
Peak Traffic Hours
1992 - 2010

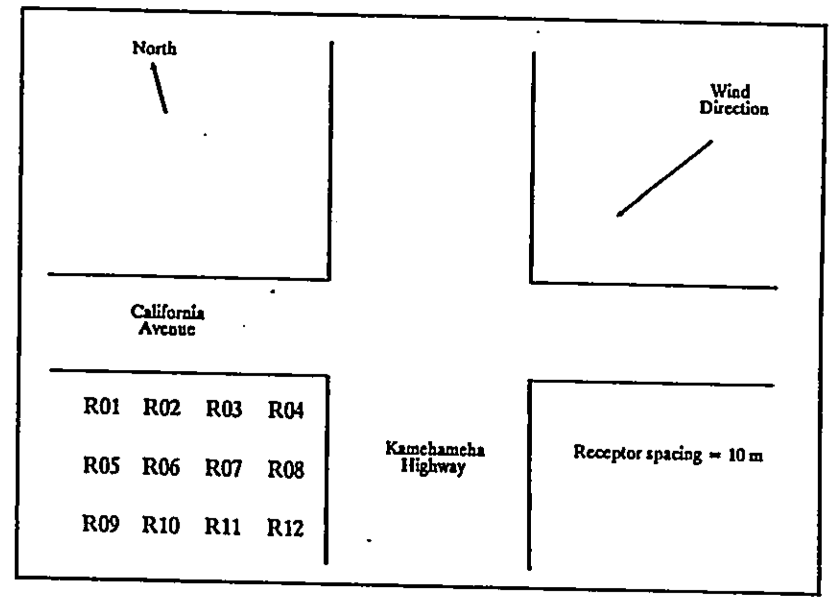


		Concentration (mg/m³)				
Receptor	1992	A.M. 2010 w/o	2010 w/proj	1992	P.M. 2010 w/o	2010 w/proj
R01	0.9	0.7	1.1	2.1	1.5	3.0
R02	1.1	0.8	1.6	2.2	1.4	3.2
R03	1.6	1.0	2.3	2.1	1.4	3.3
R04	2.4	1.6	3.8	2.1	1.4	3.3
R05	1.1	0.8	1.6	1.7	1.3	2.4
R06	1.4	0.9	2.1	1.5	1.0	2.2
R07	1.8	1.3	2.7	1.5	1.0	2.2
R08	2.3	1.6	3.5	1.6	1.0	2.3
R09	1.3	0.9	1.8	1.6	1.1	2.2
R10	1.5	1.0	2.3	1.3	0.9	1.7
R11	1.7	1.1	2.6	1.1	0.8	1.6
R12	2.1	1.5	3.2	1.1	0.8	1.7

FIGURE 13

ESTIMATES OF MAXIMUM 1-HOUR CARBON MONOXIDE CONCENTRATIONS

Kamehameha Highway at California Avenue
Peak Traffic Hours
1992 - 2010



		Concentration (mg/m³)				
Receptor	1992	A.M. 2010 w/o	2010 w/proj	1992	P.M. 2010 w/o	2010 w/proj
R01	4.7	4.1	4.7	4.8	4.1	4.7
R02	5.1	4.6	5.1	5.5	4.7	5.5
R03	6.0	5.2	6.0	6.7	5.7	6.7
R04	8.1	7.2	8.2	9.7	8.2	9.8
R05	4.4	4.0	4.4	4.8	4.1	4.7
R06	5.0	4.4	5.0	5.6	4.8	5.5
R07	5.8	5.1	5.8	6.7	5.7	6.6
R08	7.5	6.7	7.8	9.1	7.8	9.2
R09	4.4	3.9	4.3	4.8	4.1	4.7
R10	5.0	4.4	4.9	5.6	4.8	5.5
R11	5.7	5.0	5.7	6.6	5.6	6.5
R12	7.3	6.5	7.5	8.8	7.5	8.9

APPENDIX F

Environmental Noise Assessment
Darby & Associates

D.L. ADAMS ASSOCIATES, LTD.
dba
DARBY
& ASSOCIATES
ACOUSTICAL CONSULTANTS

#92-25

ENVIRONMENTAL NOISE ASSESSMENT
GALBRAITH TRUST LANDS
EWA, OAHU, HAWAII

December 8, 1992

Prepared for
HELBER HASTERT & FEE
Honolulu, Hawaii

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CONTENTS

1.0 SUMMARY

1.1 The proposed project site is currently exposed to noise levels of less than 45 dBA, typical of rural or semi-rural areas. The dominant noise sources include wind, traffic, and occasional aircraft.

1.2 Nearby noise sensitive areas include the residential areas within Wahiawa town which are currently exposed to noise levels of approximately 44 dBA, typical of quiet residential areas.

1.3 Traffic noise level increases along Kaukonahua Road, Kamehameha Highway, and Wilikina Drive due to additional traffic generated by the project should offer minimal impact to nearby noise sensitive locations.

1.4 Provided appropriate noise control measures are incorporated, noise levels due to activities within the industrial and commercial facilities (e.g., mechanical equipment, air-conditioning equipment, etc.) should not significantly impact noise sensitive locations within and nearby the project site.

1.5 The dominant noise source during project construction will probably be earth moving equipment, such as bulldozers and diesel-powered trucks. Any noise impact from such activity on the Wahiawa town residential areas should, however, be relatively short-term.

Blasting, if required, could also have noise impacts. However, with the appropriate blast design techniques, the noise from blasting can be controlled within acceptable limits at the closest noise sensitive locations.

1.6 Although at times audible, the aircraft operations associated with Wheeler Air Force Base airfield are fairly infrequent and, therefore, aircraft noise should not significantly impact the proposed development.

1.7 Some of the proposed residential areas closest to Kamananui Road, Kamehameha Highway, and Wilikina Drive may be exposed to future hourly Leq noise levels greater than the FHWA recommended limit of 67 dBA if located too close to the roadways. If appropriate residential home setbacks cannot be achieved, other noise mitigation should be implemented to conform with FHWA traffic noise exposure guidelines.

1.8 Much of the proposed project site and nearby lands will remain as pineapple fields and, thus, continue with normal pineapple

growing operations. However, pineapple operations are periodic and, therefore, should not significantly impact the proposed project.

1.9 Noise associated with the operation of the proposed golf clubhouse may impact the closest proposed homes if not properly mitigated. Additionally, equipment associated with grounds maintenance of the proposed 18-hole golf course may impact nearby residential homes, however, such activities take place during the daytime and are usually of short duration. Therefore, they should not be objectionable.

1.10 The project site is bordered on the southeast by the Wahiawa Industrial Center which is allowed by DOH to generate a maximum noise level of 70 dBA, 24 hours a day. A Commercial/Industrial Mixed Use area is planned to border the industrial center and, therefore, should buffer the noise sensitive areas within the project site from noise generated at the Wahiawa Industrial Center.

2.0 PROJECT DESCRIPTION

The Galbraith Trust Lands project involves approximately 2,000 acres of land within the plateau of Central Oahu. The project site and vicinity is shown in Figure 1. Currently, the project area is used for agriculture, specifically pineapple growing. The project site is bounded on its south side by Wahiawa town with the Lake Wahiawa Reservoir running between the project site and Wahiawa town. Schofield Barracks borders the west side of the project site and Wheeler Air Force Base is less than one mile south of the project site. The lands north as well as east of the project site are currently pineapple fields.

The current development plan encompass only about half of the project site; approximately 900 acres in the southern portion of the project site. The proposed development includes single and multi-family residences, an 18-hole public golf course, commercial areas, a mixed commercial/light industrial area, lake front parks, as well as civic and public facilities. The Wahiawa Lands Development Plan and Schedule are shown in Figures 2 and 3.

3.0 NOISE STANDARDS

Various local and federal agencies specify guidelines in assessing environmental noise and set noise limits as a function of land use. Federal agencies, however, do not have the authority to enforce such noise limits and, thus, present them as recommended guidelines only. A brief description of acoustic terminology is presented in Appendix A.

3.1 State Department of Health - DOH specifies allowable property line noise levels that shall not be exceeded for more than 10% of the time during any 20-minute period [Reference 1]. These are enforced for any location at or beyond the property line. The specified noise limits vary depending on the land use and time of day as shown in Figure 4. DOH also specifies the following with respect to adjacent zoning and order of precedence.

> "Where the allowable noise level between two adjacent zoning districts differ, the lower allowable noise level shall be used. For example, the allowable noise level for the residential district shall be used at the property line between residential and business districts.
>
> The limits specified in the allowable noise levels table shall apply subject to the order of precedence in which uses were initiated after the effective date of this rule; provided that a new order of precedence is established when any use is discontinued. The initiation of use shall be measured by the date of rezoning. For example, if agricultural or industrial operations are conducted next to a lot used as residence, the agricultural or industrial limits would apply if the agricultural or industrial operations had been initiated after the effective date of this rule. Residential limits would apply if the building permit for the residence was obtained before agricultural or industrial operations had been initiated."

3.2 City and County of Honolulu Land Use Ordinance (LUO) - The Department of Land Utilization specifies maximum allowable levels at the property line [Reference 2]. The LUO criteria differ from those of the DOH in that they use octave band sound levels instead of A-weighted levels and no temporal factor is involved. The specific octave band levels are shown in Figure 5. LUO noise regulations are theoretically enforced by the Building Department; but since they do not have noise measurement capability, noise complaints are usually handled by DOH.

3.3 U.S. Federal Highway Administration - The Federal Highway Administration (FHWA) has established a set of design goals for traffic noise exposure [Reference 3]. The FHWA defines four land use categories and assigns corresponding maximum hourly equivalent sound levels, Leq. For example, Category B, defined as picnic and recreation areas, parks, residences, motels, hotels, schools, churches, libraries, and hospitals, has a corresponding maximum exterior Leq of 67 dBA and a maximum interior Leq of 52 dBA. These limits are viewed as design goals, and all projects which are developed to meet these limits are deemed in conformance with the FHWA noise standards.

3.4 U.S. Department of Housing and Urban Development - The U.S. Department of Housing and Urban Development (HUD) has established Site Acceptability Standards for interior and exterior noise for housing [Reference 4]. These standards are based on day-night equivalent sound levels, Ldn, and identify the need for noise abatement, either at the site property line or in the building construction. HUD Site Acceptability Criteria rank sites as Acceptable, Normally Unacceptable, or Unacceptable. "Acceptable" sites are those where noise levels do not exceed an Ldn of 65 dB. Housing on acceptable sites do not require additional noise attenuation other than that provided in customary building techniques. "Normally unacceptable" sites are those where the Ldn is above 65 dB but does not exceed 75 dB. Housing on normally unacceptable sites requires some means of noise abatement, either at the property line or in the building construction, to assure the interior noise levels are acceptable. "Unacceptable" sites are those where the Ldn is 75 dB or higher. The term "unacceptable" does not necessarily mean that housing cannot be built on these sites, but rather that more sophisticated sound attenuation would likely be needed.

3.5 U.S. Environmental Protection Agency - The U.S. Environmental Protection Agency (EPA) has identified a range of yearly day-night equivalent sound levels, Ldn, sufficient to protect public health and welfare from the effects of environmental noise [Reference 5]. The EPA has established a goal to reduce exterior environmental noise to an Ldn not exceeding 65 dB and a future goal to further reduce exterior environmental noise to an Ldn not exceeding 55 dB. Additionally, the EPA states that to protect against hearing damage, one's 24-hour equivalent sound level exposure, Leq, at the ear should not exceed 70 dB. The EPA emphasizes that these goals are not intended as regulations as they have no authority to regulate noise levels, but rather these goals are intended to be viewed as levels below which the general population will not be at risk from any of the identified effects of noise.

4.0 EXISTING ACOUSTICAL ENVIRONMENT

4.1 General - Ambient noise measurements were conducted on August 18, 1992 to assess the existing acoustical environment within and adjacent to the project site. The measurement locations are shown in Figure 6 and are described below.

- A1 In the park/playground area centered in Poamoho Camp
- A2 Near the west edge of Lake Wilson
- A3 In the back parking lot of Horizon Industries in Wahiawa Industrial Center near Wahiawa reservoir

A4 At the corner of California Avenue and Lauone Loop in the residential area

A5 In the pineapple field along Kaukonahua Road just north of the project site

A6 In the pineapple field along Kamehameha Highway within project site

Noise level measurements were taken over 8-minute sampling periods using a Larson-Davis Laboratories Model 700 Sound Level Meter. The noise measurement results, in terms of the Equivalent Continuous Noise Level (Leq), the minimum noise level (Lmin), the maximum noise level (Lmax), and the noise levels exceeded 90%, 50%, 10%, and 1% of the time (L90, L50, L10 and L1, respectively), are summarized in Table 1. These statistical noise levels are commonly used to describe environmental noise. For example, the 90-Percentile Exceedence Sound Level, L90, represents a measure of the residual or background noise, minimally influenced by nearby discrete events. A brief description of acoustical terminology is presented in Appendix A.

4.2 Project Site - The proposed project site currently experiences relatively low noise levels. The existing background noise level (L90) is between 43 and 45 dBA within the project site, which is typical of rural or semi-rural areas. The dominant noise sources included wind, traffic movements, and occasional aircraft fly-overs. The occasional aircraft included both fixed and rotary wing aircraft and the maximum sound levels (Lmax) due to the aircraft ranged from 63 to 75 dBA. An additional noise source within the project site is the periodic pineapple growing operations, however, no operations were experienced during the field measurements. Pineapple operations may include land preparation, fruit harvesting, truck transport, etc.

4.3 Project Vicinity - The pineapple fields to the north and also to the east of the proposed project site experience an acoustical environment similar to the project site with wind, aircraft, traffic, and pineapple growing operations being the dominant noise sources. The Wahiawa Reservoir approximately forms the south border between the project site and Wahiawa town. The portion of Wahiawa town nearest the project site is comprised mostly of residential areas, however, a small portion bordering the project site is zoned General Industrial (I-2). The residential areas in Wahiawa Town, which border the project site, experience a background noise level (L90) of approximately 44 dBA while the Wahiawa Industrial Center experiences a background noise level (L90) of approximately 48 dBA.

Schofield Barracks borders the project site to the southwest and the area nearest the project site experiences a background noise of approximately 50 dBA due primarily to traffic along Wilikina Drive.

5.0 POTENTIAL NOISE IMPACT DUE TO PROJECT

5.1 Additional Traffic Generated by the Project - Measured traffic noise levels and predicted traffic volumes [Reference 6] were used in conjunction with the Federal Highway Administration (FHWA) noise prediction model [Reference 7] to estimate the traffic noise created as a result of the project. The traffic noise was predicted at the locations shown in Figure 7. The existing (1992) and projected future (2010) traffic noise levels during peak traffic hours are listed in Table 2. Additionally, the projected future (2010) traffic noise level increases during peak traffic hours are summarized in Table 3. The predicted traffic noise level increases at the assessed locations due to additional traffic generated by the project were less than approximately 3.0 dBA. In general, a 3.0 dBA increase in sound pressure level corresponds to a small perceptible change in apparent loudness. Therefore, the traffic noise level increase due to project generated traffic should minimally impact noise sensitive locations in the project site vicinity.

5.2 Noise Generated by Activities Within the Project Site - Activities in the proposed industrial, commercial, and civic areas may be potential sources of noise affecting nearby noise sensitive areas. Noise from these sources may cause annoyance and even exceed the DOH noise limits if not properly controlled. Such noise sources may include activities within industrial facilities, mechanical equipment associated with commercial or industrial buildings such as air-conditioning and ventilating equipment, or parking lot activity.

The owners of all potential noise sources within the project site must implement measures so that DOH noise regulations are met. These noise regulations can be met for stationary equipment by providing mitigation where required, e.g. acoustic enclosures, noise barrier walls, etc.

5.3 Construction Noise - Development of the project will involve excavation, grading and the construction of infrastructure and buildings. The various construction phases of a development project may generate significant amounts of noise. The actual amounts are dependent upon the methods employed during each stage of the construction process. Typical ranges of construction equipment noise are shown in Figure 8. Earthmoving equipment, such as bulldozers and diesel-powered trucks, will probably be the loudest equipment used during construction.

In cases where construction noise exceeds, or is expected to exceed, the DOH's "allowable" property line limits, a permit must be obtained from the DOH to allow the operation of vehicles, construction equipment, power tools, etc. which emit noise levels in excess of the "allowable" limits. Required permit conditions for construction activities are:

> "No permit shall allow construction activities creating excessive noise...before 7:00 am and after 6:00 pm of the same day."
>
> "No permit shall allow construction activities which emit noise in excess of ninety-five dB(A)...except between 9:00 am and 5:30 pm of the same day."
>
> "No permit shall allow construction activities which exceed the allowable noise levels on Sundays and on... [certain] holidays. Activities exceeding ninety-five dB(A) shall [also] be prohibited on Saturdays."

In addition, construction equipment and on-site vehicles or devices requiring an exhaust of gas or air must be equipped with mufflers. Also, construction vehicles using traffic-ways must satisfy the DOH's vehicular noise requirements [Reference 8].

Blasting, if required, could also produce noise impacts. However, blasting at construction sites near populated areas is usually accomplished by using numerous small charges detonated with small time delays. Blast mats can also be used to assist in directing the explosive energy into the rock, control flying debris and muffle the noise. Thus, with the appropriate blast design techniques, the noise from blasting can be controlled within acceptable limits at the closest noise sensitive locations.

6.0 POTENTIAL NOISE IMPACT ON THE PROJECT

6.1 Aircraft Noise - The proposed project site is approximately one mile from the Wheeler Air Force Base and within flight tracks 24D and 06E6 of the WAFB airfield as shown in Figure 9. Currently, WAFB handles only fixed wing propeller aircraft and rotary wing aircraft operations. The most recent and available Air Installation Compatible Use Zone (AICUZ) study [Reference 9] shows flight tracks 24D and 06E6 conduct less than 1% of the total daily aircraft operations, which corresponds to approximately two aircraft fly-overs daily. Additionally, no aircraft operations are conducted along flight tracks 24D and 06E6 during the nighttime hours (10:00 pm to 7:00 am). The Hickam/Wheeler Aero Club general aviation aircraft consisting of a C152 Skymaster, a C172/182 Skyhawk/Skylane, and a BE-24 Sierra,

account for the majority of these fly-overs. The noise levels associated with such fixed wing propeller aircraft range from 65 to 72 dBA. Although at times audible, the aircraft operations are fairly infrequent and, therefore, aircraft noise should not significantly impact the proposed development.

6.2 Traffic Noise - The Federal Highway Administration (FHWA) has specified a design goal of Leq = 67 dBA for traffic noise exposure for land uses defined under Category B, as previously discussed. The proposed residential areas closest to Kamananui Road, Kamehameha Highway, and Wilikina Drive will be exposed to predicted (future 2010) hourly equivalent continuous noise levels, Leq, of approximately 67 dBA during peak hours at the various distances from each roadway listed in Figure 10. Therefore, if residential home setbacks as listed in Figure 10 cannot be achieved, other noise mitigative measures should be implemented.

Feasible noise mitigation would include sound barriers along the roadways (such as walls or landscaped earth berms, which must be high enough to clearly blockline-of-sight to the traffic), and appropriate building orientation and design, such as:

1. Avoiding the use of multi-story homes in these areas, and orienting the buildings so that bedroom windows do not directly face the road.
2. Restricting the use of jalousie windows to non-critical areas, such as bathrooms, laundries, etc.
3. Air-conditioning noise sensitive areas within the homes, such as bedrooms, so that windows may be kept closed for noise reduction purposes.
4. Providing additional sound absorptive treatment in bedrooms (carpets with padding, louvered closet doors, etc.), to reduce build-up in the reverberant sound field.

6.3 Pineapple Growing Activities - Nearly half of the proposed project site, as well as bordering lands, will remain as pineapple fields, and thus continue with normal pineapple growing operations. Pineapple growing activities include land preparation, fruit harvesting, truck transport, etc. and may be audible at nearby residential areas; particularly, in the proposed single family residential area along Kamanani Road directly adjacent to the pineapple fields. However, pineapple operations are only periodic and, therefore, should not significantly impact the proposed project.

6.4 Golf Course Operations - An 18-hole public golf course is proposed for 183 acres of the project site. Potential noise sources at the golf course include the mechanical equipment at the clubhouse, the public address system, and ground maintenance activities. Single family residential areas are proposed within approximately 125 feet of the golf clubhouse. If noise sources at and near the clubhouse (e.g., golf cart chargers, pumps, refrigeration and air-conditioning equipment, exhaust fans, and other stationary equipment) are not controlled properly, they could impact the closest proposed homes. Additionally, a public address system near the clubhouse could also impact nearby residential areas. In order to minimize the noise impact on the homes, public address speakers should be oriented such that announcements are not projected directly into the nearby residential areas. Equipment associated with ground maintenance activities (e.g., tractors, lawn mowers, leaf blowers, etc.) may also impact on nearby residential areas; however, such activities are transient about the golf course and for short periods. Therefore, they should not be objectionable.

6.5 Wahiawa Industrial Center - The project site is bordered on the southeast, across the Wahiawa Reservoir, by the Wahiawa Industrial Center (see location A3 shown in Figure 6) which is zoned General Industrial I-2. The State Department of Health maximum allowable noise level (see Figure 4) for zone I-2 is 70 dBA during both the daytime hours and the nighttime hours, which could impact nearby noise sensitive locations. However, the Wahiawa Lands Development Plan (Figure 2) indicates a Commercial/Industrial Mixed Use land use planned nearest the Wahiawa Industrial Center. Therefore, due to the "buffer" zone offered by the planned Commercial/Industrial Mixed Use area, the Wahiawa Industrial Center should only minimally impact noise sensitive locations within the project site.

REFERENCES

1. *Chapter 43 - Community Noise Control for Oahu*, Department of Health, State of Hawaii, Administrative Rules, Title 11, November 6, 1981.

2. *Section 3.11, Noise Regulations*, Land Use Ordinance, City and County of Honolulu, Oahu 22, 1986.

3. *Department of Transportation, Federal Highway Administration Procedures for Abatement of Highway Traffic Noise*, Title 23, CFR, Chapter 1, Subchapter J, Part 772, 38 FR 15953, June 19, 1973, Revised at 47 FR 29654, July 8, 1982.

4. *HUD Environment Criteria and Standards*, 24 CFR 51, Federal Register, Volume 44, No. 135, July 12, 1979; Amended 49 FR 880, January 6, 1984.

5. *Toward a National Strategy for Noise Control*, U.S. Environmental Protection Agency, April 1977.

6. *Wahiawa Galbraith Trust Lands Traffic Study*, Wilbur-Smith Associates, November 3, 1992, Received November 30, 1992.

7. *FHWA Highway Traffic Noise Prediction Model*, FHWA - RD - 77 - 108; U.S. Department of Transportation, December 1978.

8. *Chapter 42 - Vehicular Noise Control for Oahu*, Department of Health, State of Hawaii, Administrative Rules, Title 11, November 6, 1981.

9. *Air Installation Compatible Use Zone (AICUZ) Plan for Wheeler Air Force Base, Oahu, Hawaii*, Department of the Army, U.S. Army Support Command, Hawaii (USASCH), Fort Shafter, Oahu, Hawaii, February, 1986.

APPENDIX A

ACOUSTICAL TERMINOLOGY

Sound (Noise) Level

Sound or noise consists of minute fluctuations in atmospheric pressure capable of evoking the sense of hearing. It is measured using precision instruments known as sound level meters, in terms of decibels (dB). Sound Level or Sound Pressure Level is defined as:

$$SPL = 20 \log (P/Pref) \text{ dB}$$

where P is the sound pressure fluctuation (above or below atmospheric pressure) and Pref is 20 micropascals, which is approximately the lowest sound pressure that can be detected by the human ear. For example, if P is 20 micropascals, then SPL = 0 dB, or if P is 200 micropascals, then SPL = 20 dB. The relation between sound pressure in micropascals and sound pressure level in decibels (dB) is shown in Figure A-1.

The sound level that results from a combination of noise sources is not the sum of the individual sound levels, but rather the result is the logarithmic sum. For example, two sound levels of 50 dB produce a combined level of 53 dB, not 100 dB; two sound levels of 40 and 50 dB produce a combined level of 50.4 dB.

Human sensitivity to changes in sound level is highly individualized. Sensitivity to sound depends on frequency content, time of occurrence, duration, and psychological factors such as emotion and expectations. However, in general, a change of 1 or 2 dB in the level of a sound is difficult for most people to detect, a 3 to 5 dB change corresponds to a small but noticeable change in loudness, and a 10 dB change corresponds to an approximate doubling or halving in loudness.

A-Weighted Sound Level

The human ear is more sensitive to sound with frequencies above 1000 Hertz (Hz), than with frequencies below 125 Hz. Due to this type of frequency response, a weighting system, A-weight, was developed to approximate the frequency response of the human ear. A-weighted sound level (dBA) de-emphasizes the low frequency portion of the spectrum of a signal. The A-weighted (dBA) level of a sound is a good measure of the loudness of that sound, and so different sounds having the same A-weighted level sound about equally as loud. Typical values of the A-weighted sound level of various noise sources are listed in Figure A-1.

Statistical Sound (Noise) Levels

The sound levels of long-term noise producing activities, such as traffic movement, aircraft operations, etc., can vary considerably with time. In order to obtain a single number rating of such a noise source, several statistical noise levels have been developed and instrumentation are available to measure them. Common statistical sound levels include Equivalent Continuous Noise Level, Leq, and Percentile Exceedence Level, Lx.

The Equivalent Continuous Noise Level, Leq, represents a constant level with the same amount of total acoustic energy as that contained in the actual time-varying sound being measured over a specific time period. Leq is commonly used to describe community noise, traffic noise, and hearing damage potential.

A Percentile Exceedence Level, Lx, represents the sound level which is exceeded for x% of the measured time period. For example, L10 = 60 dBA describes that over the measured time period, the measured noise exceeded 60 dBA for 10% of the time. Common Percentile Exceedence Levels include L1, L10, L50, and L90, which are widely used to assess community and environmental noise. Figure A-2 illustrates the relationship between selected statistical noise levels.

Day Night Average Sound Level

The Day Night Average Sound Level, Ldn, is essentially the Equivalent Continuous Noise Level measured over a 24-hour period. However, in calculating the Ldn, 10 dBA is added to the noise levels recorded between 10 pm and 7 am to account for people's higher sensitivity to noise at night. The Ldn is a commonly used noise descriptor in assessing land use compatibility, and is used by federal and local agencies and standards organizations.

TABLE 1

NOISE MEASUREMENTS CONDUCTED ON AUGUST 18, 1992
WITHIN AND ADJACENT TO THE PROPOSED PROJECT SITE

Location	Measured Noise Levels (dBA)							Dominant Noise Source
	L_{eq}	L_{min}	L_{90}	L_{50}	L_{10}	L_{01}	L_{max}	
A1	47	43	45	46	49	54	57	Wind
								Distant Traffic
A2	50	44	47	49	53	55	58	Distant Traffic
								Wind
								Distant Aircraft
A3	53	44	48	50	55	62	73	Ventilation Equipment within Horizon Industries
								Operations within Horizon Industries
A4	50	41	44	46	53	60	63	Wind
								Residential Traffic
								Distant Aircraft
A5	55	39	43	51	59	65	69	Traffic-Kaukonahua Road
								Wind
A6	59	39	45	57	63	67	69	Traffic-Kamehameha Highway
								Wind

TABLE 2

EXISTING 1992 AND PROJECTED FUTURE 2010 TRAFFIC
NOISE LEVELS (dBA) DURING PEAK TRAFFIC HOURS

	Locations			
	T1	T2	T3	T4
Existing 1992				
AM	63.0	63.0	62.8	64.6
PM	62.9	64.0	64.0	65.2
Future Without Project				
AM	64.7	64.7	64.4	65.9
PM	64.7	65.7	65.2	66.4
Future With Project				
AM	65.0	65.1	64.7	68.8
PM	65.1	66.1	67.1	69.4

NOTE: Noise levels are equivalent continuous noise levels (L_{eq}) at an arbitrary 100 foot reference distance.

TABLE 3

PROJECTED FUTURE 2010 TRAFFIC NOISE LEVEL (dBA)
INCREASES DURING PEAK TRAFFIC HOURS

	Locations			
	T1	T2	T3	T4
Future Traffic Noise Level Increases Without Project				
AM	1.7	1.7	1.6	1.3
PM	1.8	1.7	1.2	1.2
Future Traffic Noise Level Increases With Project				
AM	2.0	2.1	1.9	4.2
PM	2.2	2.1	3.1	4.2
Future Traffic Noise Level Increased Due to Project Generated Traffic				
AM	0.3	0.4	0.3	2.9
PM	0.4	0.4	1.9	3.0

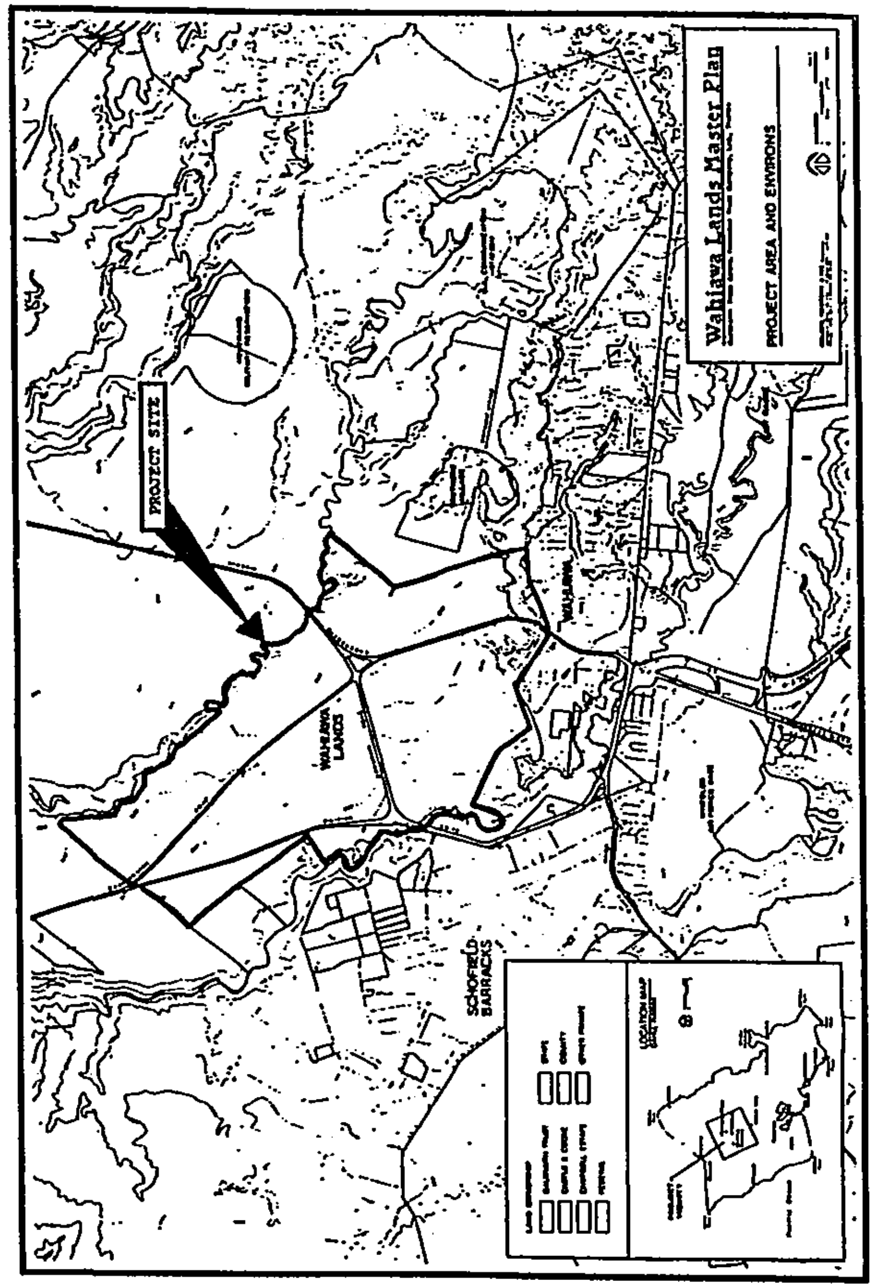

FIGURE 1 PROJECT SITE AND VICINITY

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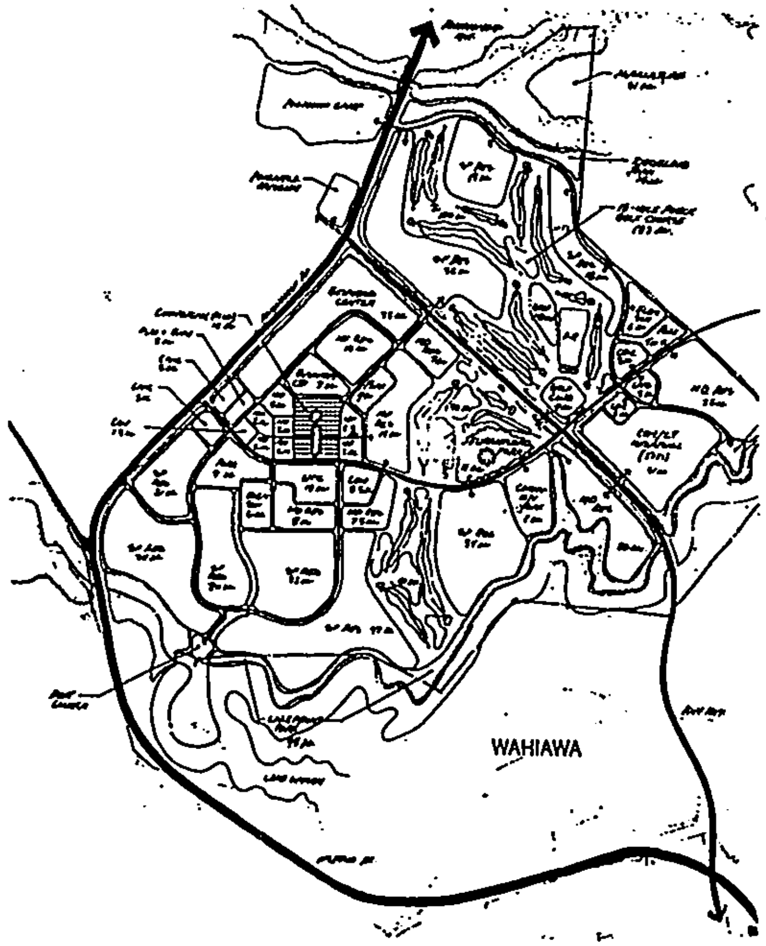

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FIGURE 2 WAHIAWA LANDS DEVELOPMENT PLAN

WAHIAWA LANDS MASTER PLAN
Development Concept Plan

Land Use	Area (Acres)	Density (Du/Ac)	Dwelling Units
Residential			
Single Family (S.F.)	247.0	6.0	1,482
Medium Density (M.D.)	66.0	10.0	660
Multi-Family (M.F.)	54.0	15.0	810
Subtotal	367.0	10.3 (Avc.)	2,952
Commercial			
Convenience	10.0		
Mixed Use (Com./Res.)	12.0	15.0	148
Commercial/Industrial			
Mixed Use (C/IMX)	33.0		
Business Center (CMX)	38.0		
Subtotal	93.0		148
Other			
Elementary Schools (2)	12.0		
Civic	17.0		
Park & Ride	2.0		
18-hole Public Golf Course	200.0		
Golf Clubhouse	4.0		
Parks	31.0		
Ridgeline Park	14.0		
Lakefront Park	45.0		
Poamoho Camp	32.0		
Pineapple Museum	6.0		
Kukaniloko Park	11.0		
Ope: ace/Circ.	58.0		
Subtotal	432.0		
TOTAL	892.0 ACRES*		3,100 UNITS

*Excludes re voir, some gulch lands, Wahiawa Parcels, and 1,200 acres north of Kamananui Road.

HELBER HASTERT & FEE, Planners
September 14, 1992
Rev. October 14, 1992

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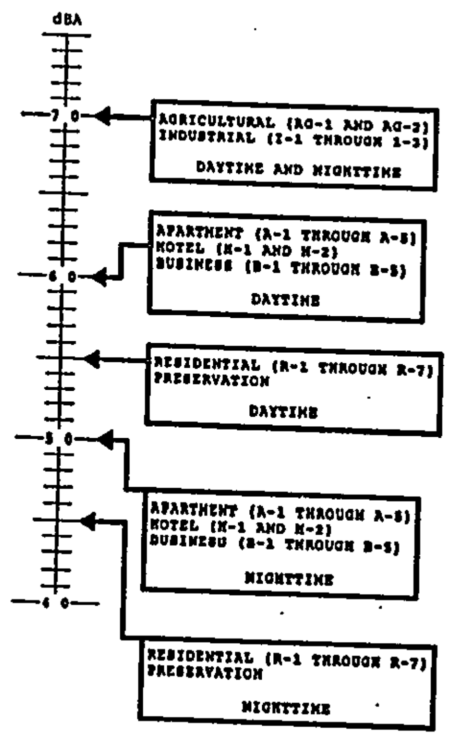
FIGURE 3 WAHIAWA LANDS MASTER PLAN SCHEDULE



NOTE: THE REGULATION STATES THAT THE ALLOWABLE LEVELS SHALL NOT BE EXCEEDED FOR TEN PERCENT OF THE TIME WITHIN ANY TWENTY MINUTE PERIOD

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FIGURE 4 ALLOWABLE NOISE LEVELS FOR VARIOUS ZONING DISTRICTS; COMMUNITY NOISE CONTROL FOR OAHU; STATE OF HAWAII, DEPARTMENT OF HEALTH

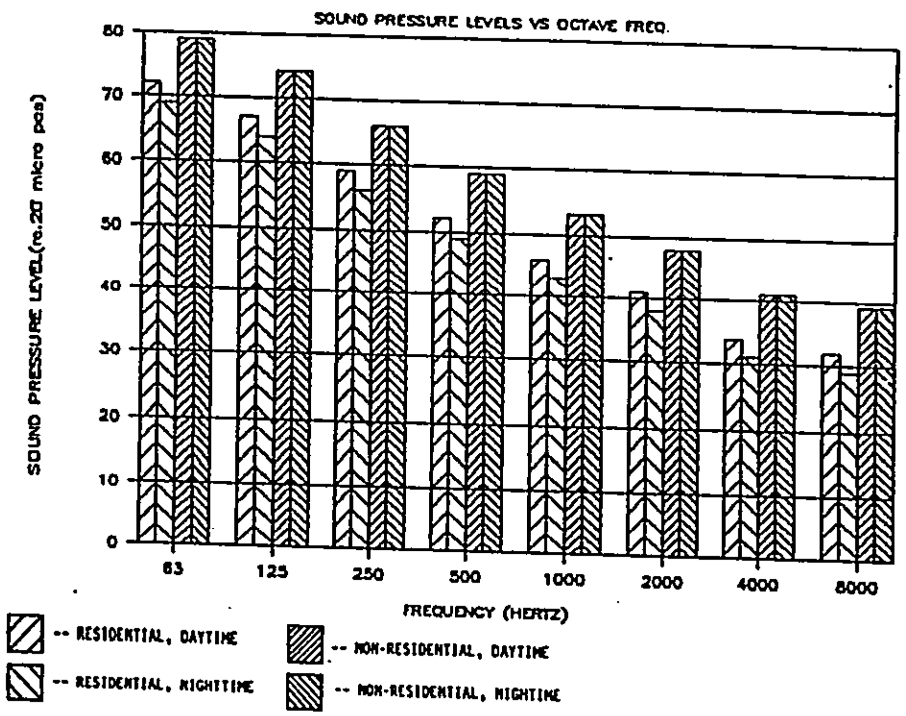

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FIGURE 5 MAXIMUM ALLOWABLE NOISE LEVELS VS OCTAVE BAND CENTER FREQUENCIES; CITY AND COUNTY OF HONOLULU LAND USE ORDINANCE

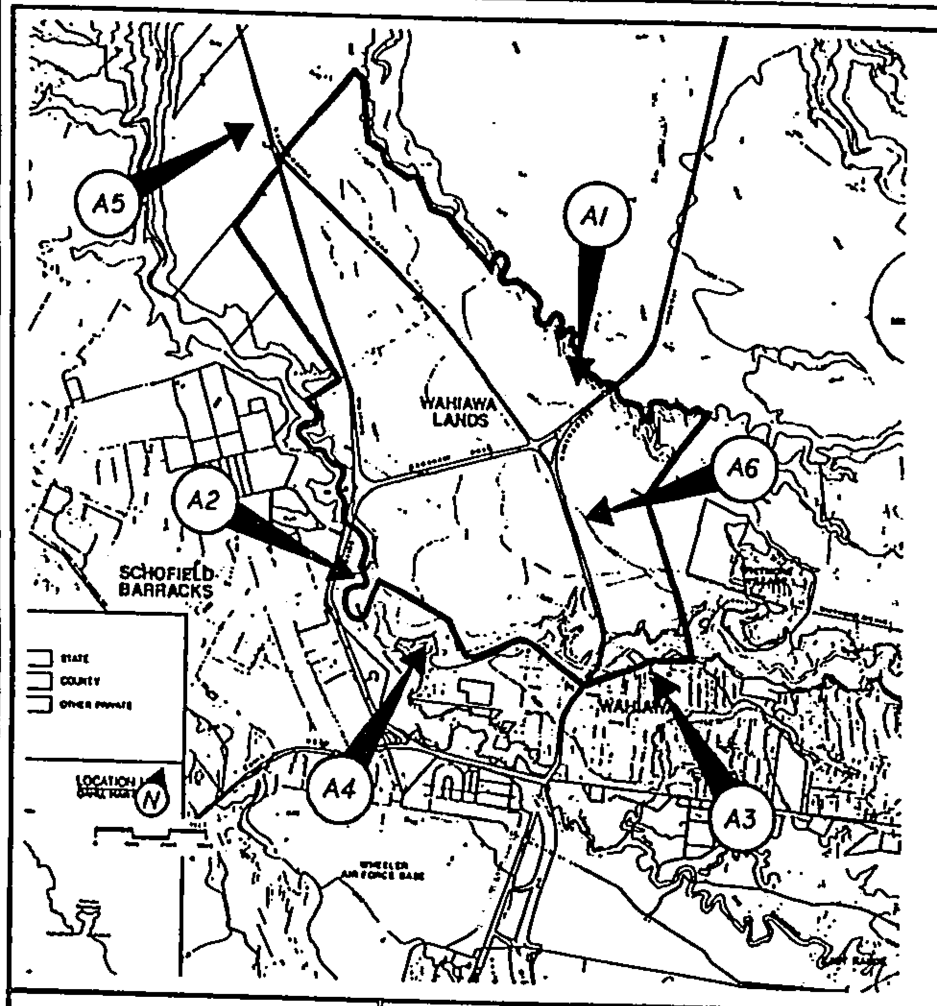

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FIGURE 6 AMBIENT NOISE MEASUREMENT LOCATIONS

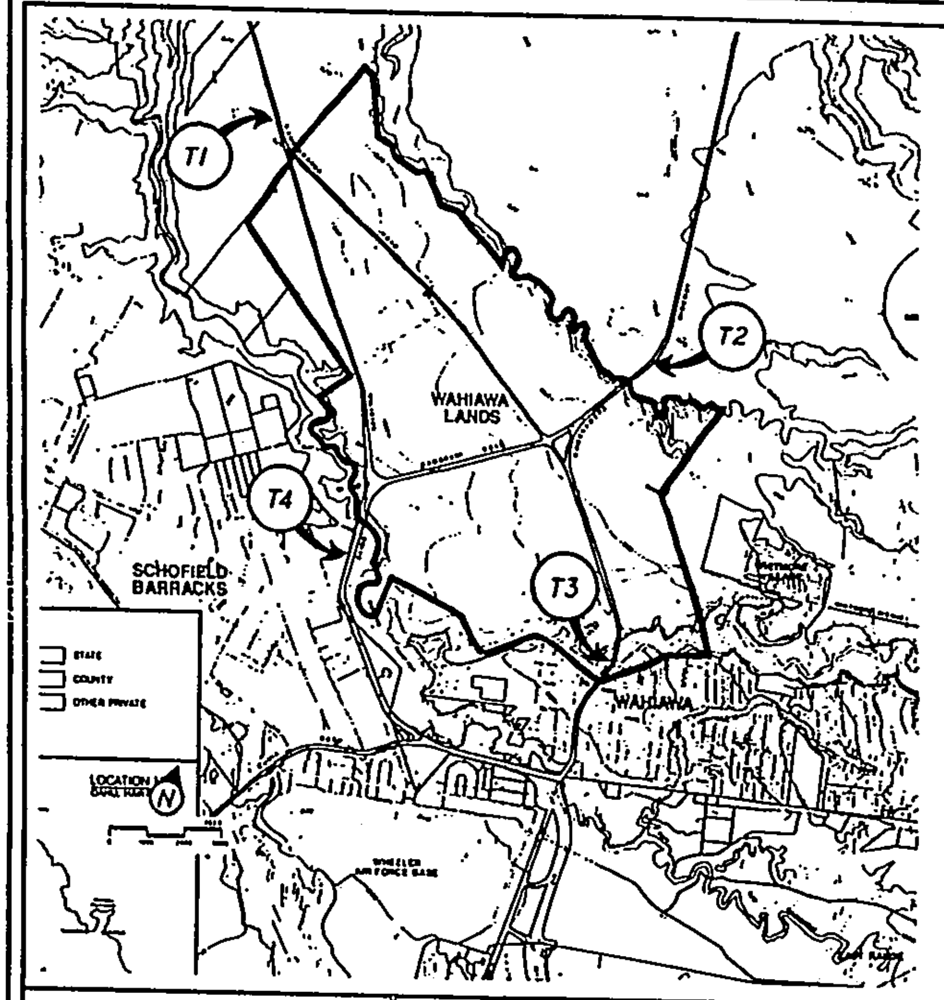

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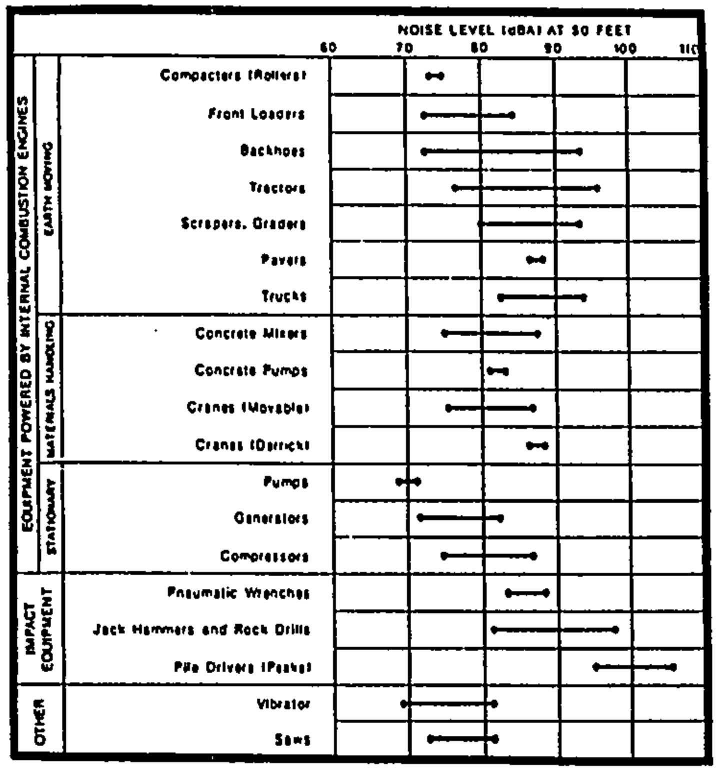
FIGURE 7 TRAFFIC NOISE LEVEL ASSESSMENT LOCATIONS



Note: Based on Limited Available Data Samples

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FIGURE 8 TYPICAL SOUND PRESSURE LEVELS FROM CONSTRUCTION EQUIPMENT

SOURCE: U.S. ENVIRONMENTAL PROTECTION AGENCY 1972

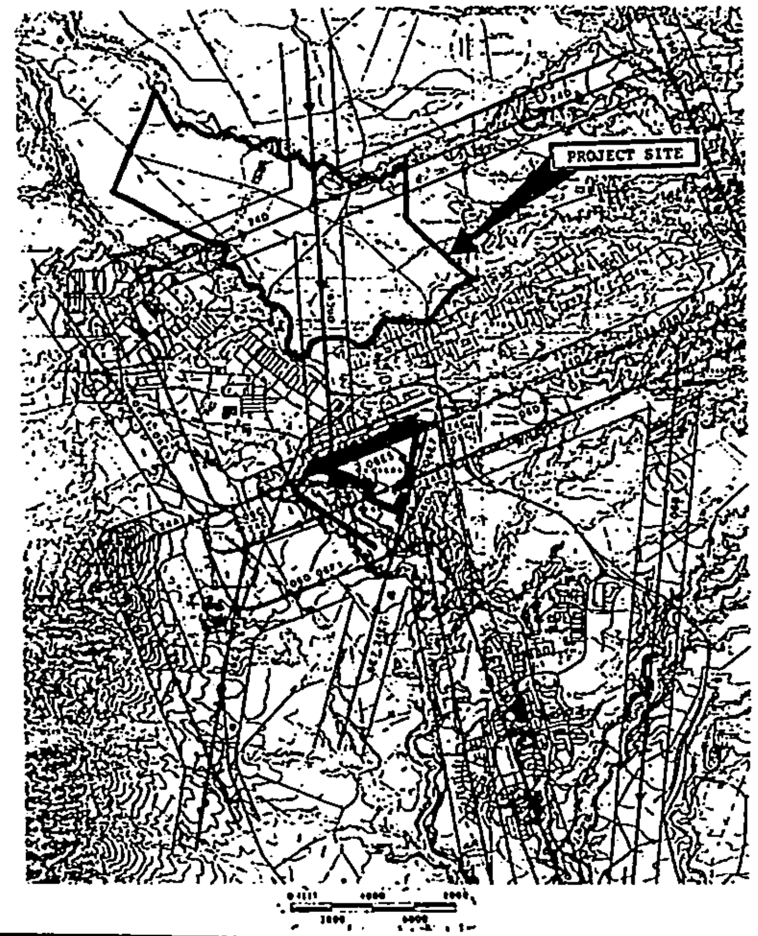

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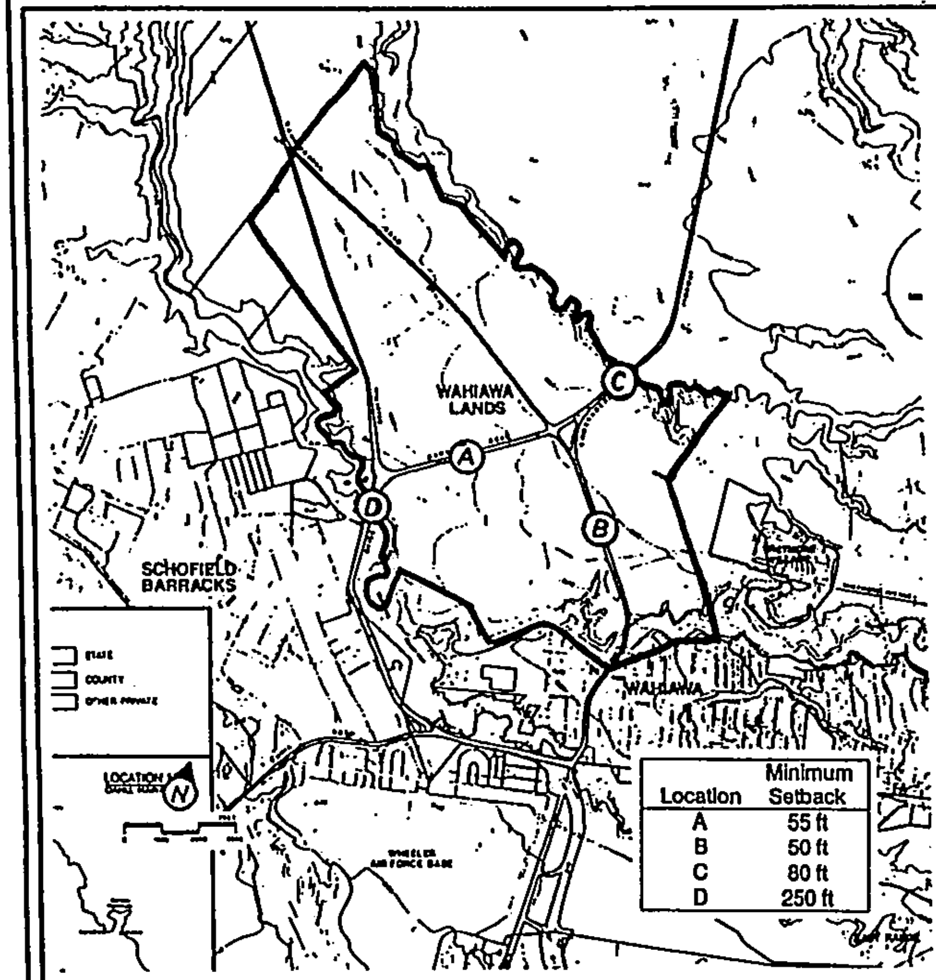
FIGURE 9 PROXIMITY OF PROJECT SITE TO WHEELER AIR FORCE BASE AIRFIELD AND ITS FLIGHT TRACKS



Location	Minimum Setback
A	55 ft
B	50 ft
C	80 ft
D	250 ft

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FIGURE 10 MINIMUM SETBACKS SUCH THAT TRAFFIC NOISE EXPOSURE IS BELOW FHWA RECOMMENDED Leq = 67 dBA

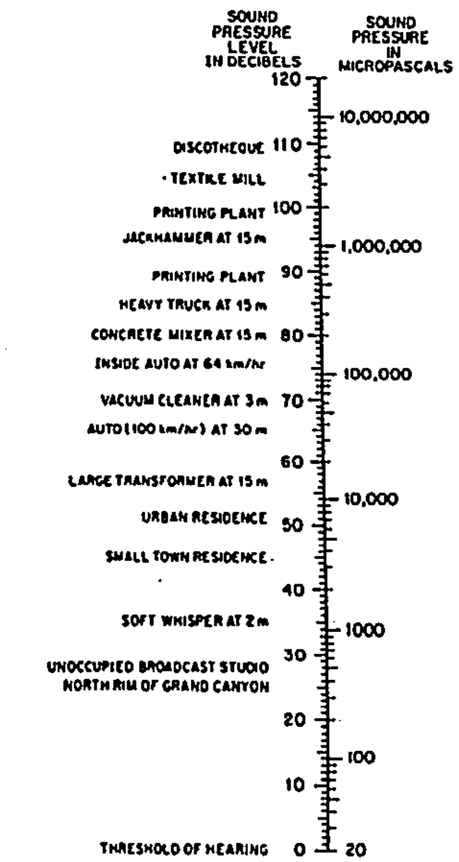

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FIGURE A-1 The relation between sound pressure, P, and sound pressure level, SPL. Also shown are typical values of A-weighted sound levels of various noise sources.

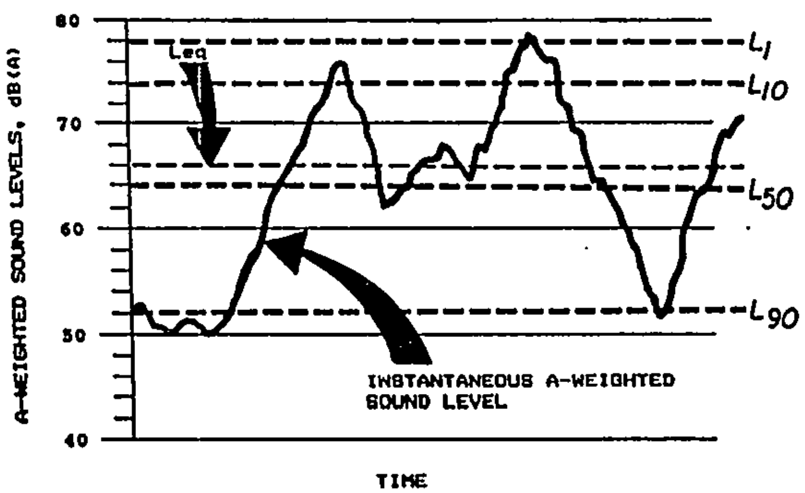

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FIGURE A-2 Sample of a comparison of an instantaneous A-weighted sound level and the corresponding statistical sound levels.

APPENDIX G

Archaeological Inventory Survey
Paul H. Rosendahl, Ph.D., Inc.

Archaeological Inventory Survey
Galbraith Trust Lands

Lands of Kamananui and Wahiawa
Waialua and Wahiawa Districts, Island of Oahu

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Report 1260-080192

Archaeological Inventory Survey
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Lands of Kamananui and Wahiawa
Waialua and Wahiawa Districts, Island of Oahu

by

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and

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SUMMARY

At the request of Mr. Thomas A. Fee of Helber, Hastert & Fee, Planners (HH&F), on behalf of their client, Hawaiian Trust Company, Paul H. Rosendahl, Ph.D., Inc. (PHRI) recently conducted an archaeological inventory survey of the approximately 2,000-acre Galbraith Trust Lands project area, located in the Lands of Kamananui and Wahiawa, Waialua and Wahiawa Districts, Island of Oahu. The overall objective of the survey was to provide information sufficient to satisfy all historic preservation requirements of the City and County of Honolulu (CCHONO) and the Department of Land and Natural Resources - State Historic Preservation Division (DLNR-SHPD). The information (this survey report) is for inclusion in an Environmental Impact Statement (EIS) to be submitted in support of a proposed Development Plan (DP) Amendment application.

The survey field work was conducted July 27-30, 1992 under the supervision of Project Supervisor Jack D. Henry, B.A. Hawaii Projects Director Alan T. Walker, B.A., and Principal Archaeologist Dr. Paul H. Rosendahl provided overall guidance for the project. The inventory survey consisted of (a) 100% low-elevation aerial reconnaissance (by helicopter), (b) a variable-intensity ground survey, and (c) limited subsurface testing.

The survey field work resulted in the relocation of Kukaniloko Birthstones (SIHP Site 50-80-04-218), and the identification of a stacked stone wall (SIHP Site 4571). As part of the survey field, work, 12 shovel tests were excavated in the project area in order to test areas for buried cultural deposits. No such deposits were identified.

Based on the findings of the current work, Site 4571 is assessed as significant solely for information content. Site 218 is assessed as significant for information content, cultural value, and as a representative example of a site type. No further work is recommended for Site 4571, and preservation "as is" is recommended for Site 218.

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ILLUSTRATIONS

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Table

INTRODUCTION

BACKGROUND

At the request of Mr. Thomas A. Fee of Helber, Hastert & Fee, Planners (HH&F), on behalf of their client, Hawaiian Trust Company, Paul H. Rosendahl, Ph.D., Inc. (PHRI) recently conducted an archaeological inventory survey of the approximately 2,000-acre Galbraith Trust Lands project area, located in the Lands of Kamananui and Wahiawa, Waialua and Wahiawa Districts, Island of Oahu. The overall objective of the survey was to provide information sufficient to satisfy all historic preservation requirements of the City and County of Honolulu (CCHONO) and the Department of Land and Natural Resources - State Historic Preservation Division (DLNR-SHPD). The information (this survey report) is for inclusion in an Environmental Impact Statement (EIS) to be submitted in support of a proposed Development Plan (DP) Amendment application.

The survey field work was conducted July 27-30, 1992 under the supervision of PHRI Project Supervisor Jack D. Henry, B.A. Hawaii Projects Director Alan T. Walker, B.A., and Principal Archaeologist Dr. Paul H. Rosendahl provided overall guidance for the project. The field work consisted of (a) 100% low-elevation aerial reconnaissance of the project area (by helicopter), (b) a variable-intensity ground survey, and (c) limited subsurface testing. Approximately 12 labor-days were required for the field work portion of the project.

SCOPE OF WORK

The basic purpose of the current inventory survey was to identify all sites and features of potential archaeological significance present in the project area. An inventory survey in general comprises an initial level of archaeological investigation. It basically determines the presence or absence of archaeological resources within an area, and indicates the general nature and variety of the resources, and their general distribution and density. It also permits a general significance assessment of the resources, and facilitates formulation of realistic recommendations and estimates for such further work as might be necessary or appropriate. Such work could involve further data collection involving detailed recording of sites and features, and selected limited excavations; and possibly subsequent mitigation—data recovery research excavations, construction monitoring, interpretative planning and development, and/or preservation of sites and features with significant scientific research, interpretive, and/or cultural value.

Based on a review of readily available background literature and on familiarity with the vicinity of the project area; and based on the current requirements of review authorities and on discussions with Mr. Scott Ezer of HH&F, and Mr. Tom Dye of the DLNR-SHPD, the following specific tasks were determined to constitute an adequate scope of work for the current project:

1. Review archaeological and historical literature relevant to the project area, and conduct historical documentary research (emphasis on readily available literature and documentary sources) and interviews with local informants;
2. Conduct 100%-coverage aerial reconnaissance (helicopter) of the entire project area;
3. Conduct 100%-coverage, variable-intensity ground survey of the project area, with (a) relatively higher intensity coverage of unmodified areas with natural (uncultivated) vegetation, and (b) relatively lower intensity coverage of historically cultivated and otherwise modified portions;
4. Conduct limited subsurface testing (manual excavations) (a) to determine the presence or absence and general distribution of potentially significant buried cultural features or deposits, and (b) to obtain suitable samples for age determination analysis; and
5. Analyze field and historical research data, and prepare appropriate reports.

The inventory survey was carried out in accordance with the standards for inventory-level survey recommended by the DLNR-SHPD. The significance of all archaeological remains identified in the project area was to be assessed in terms of (a) the National Register criteria contained in the Code of Federal Regulations (36 CFR Part 60), and (b) the criteria for evaluation of traditional cultural values prepared by the national Advisory Council on Historic Preservation. The DLNR-SHPD uses these criteria to evaluate eligibility for both the Hawaii State and National Registers of Historic Places.

To further help clients make decisions regarding the subsequent treatment of resources, the general significance of all archaeological remains identified during the survey was also evaluated in the terms of three PHRI Cultural Resource Management (CRM) value modes, which are derived from the previously mentioned federal evaluation criteria. These value modes are discussed in detail in the Conclusion section.

PROJECT AREA DESCRIPTION

The project area lies adjacent to the city of Wahiawa (Figure 1) and consists of TMK:7-1-1:5-8, 25, 26, 31, 32, por. 11, por. 29, por. 30. The area is bordered on the south by Wahiawa Reservoir and Tunnel Stream, on the north by Poamoho Stream Gulch, on the east by Whitmore Village, and on the west by pineapple fields. Several paved roads and unmarked dirt roads bisect the project area. The paved roads include Kamehameha Highway, Kamananui Road, Kaukonahua Road, Wilikina Drive, and Whitmore Avenue.

Most of the land in the project area is planted in pineapple (*hala-kahiki*, *Ananas comosus*). These planted areas are generally level, and soils in the areas include Wahiawa silty clay, Kolekole silty clay loam, and Manana silty clay loam. Wahiawa silty clay is the primary soil in the area. According to Foote et al. (1972), this soil type is present on smooth, broad interfluves, in areas 500 to 1,200 feet above sea level. The soils developed in residium and old alluvium derived from basic igneous rock. The soil's potential for erosion is minimal (Foote et al. 1972). Kolekole silty clay loam and Manana silty clay loam are present in the project area only in small pockets.

The uncultivated portions of the project area include narrow zones of vegetation along Wahiawa Reservoir and Tunnel Stream Gulch, and along Poamoho Stream Gulch. Vegetation in these areas include staghorn fern (*Dicranopteris linearis* [Burm.] Underw.), *uluhe* (earpod or elephant ear tree; *Enterolobium cyclocarpum* [Jacq. Griseb.]), ironwood (*Casuarina equisetifolia* L.), African tulip tree (*Spathodea campanulata* Beauv.), silk oak (*Grevillea robusta* A. Cunn., *oka kilika*), mango (*Mangifera indica* L., *manako*), passion flower (*Passiflora* spp., *liliko'i*), *kukui* (candlenut tree, *Aleurites moluccana* [L.] Willd.), banana (*Musa* spp., *mai'a*), coconut palm (*Cocos nucifera* L., *niu*), and assorted grasses and ferns.

Soils in the gulches and bordering Wahiawa Reservoir are composed of Helemano silty clay. According to Foote, Helemano silty clay is present on the sides of steep, V-shaped gulches, and is developed in alluvium and colluvium derived from basic igneous rock. Elevations for this soil type range from 500 to 1,200 feet above sea level; rainfall for this soil type is 30 to 75 inches annually. Permeability is moderately rapid, with runoff ranging from medium to very rapid. The potential for erosion for this soil type is severe to very severe (Foote et al. 1972).

HISTORICAL DOCUMENTARY RESEARCH
by Kepa Maly

The following summarizes several earlier publications, and includes a reference from a recently available PHRI Index of legendary accounts published in Hawaiian language newspapers.

The Galbraith Trust project area lies within the traditional *moku-o-loko* (district [literally: interior island]) of Waialua, one of the six major land divisions of the *moku puni* (island) of O'ahu. The *moku-o-loko* were further divided into *ahupua'a* (land divisions) which may be compared to pie-shaped wedges of land that stretch from the coast to the islands' interior. The project area lands are within the *ahupua'a* of *Kamananui* (the large division) of Waialua, and *Wai'anae-uka* (upland-mullet water) of Wai'anae District, in the area traditionally called *Wahi-a-wa* (place of rumbling).

Under the ancient land system Kamananui and Wahiawa Ahupua'a were sub-districts within the traditional Waialua District. Following a 1913 reapportionment of O'ahu lands, Wahiawa was designated a separate district by combining the *ahupua'a* of Wahiawa and Wai'anae-uka. It was in this way that the seventh district of Wahiawa was added to O'ahu Island (Coulter IN Sterling and Summers 1978:134). In 1925 the third edition of the Revised Laws was enacted and the Wahiawa District was expanded to include large irregular tracts of land from Waialua to the north, and 'Ewa to the south. In a special session of 1932, most of the newly-added lands were returned to their respective districts and the boundaries of the district of Wahiawa were restored to those established in 1913. Small tracts of 'Ewa and Waialua were acquired by the United States and were included within Schofield Barracks Military Reservation (ibid:134).

The Legendary Setting

Wahi-a-wa is translated as "place of rumbling, or roaring." At least two legends allude to the origins of naming this land. One traditional account is associated with the journey of *Hi'iaka-i-ka-poli-o-Pele* (*Hi'iaka*), the youngest sister of the volcano goddess *Pele*, and describes the nature of this region. This legend basically follows Nathaniel Emerson's 1915 rendition of the story of "*Pele and Hi'iaka*," but contains an added wealth of alternate island-wide place name accounts, site event narratives, and chants. The version of the legend ran in the Hawaiian newspaper, *Ka Hoku o Hawai'i* (September 18, 1924 to July 17, 1928), and has yet to be translated in its entirety. The following legend excerpts are taken from a draft PHRI manuscript, translated by the author of this section.

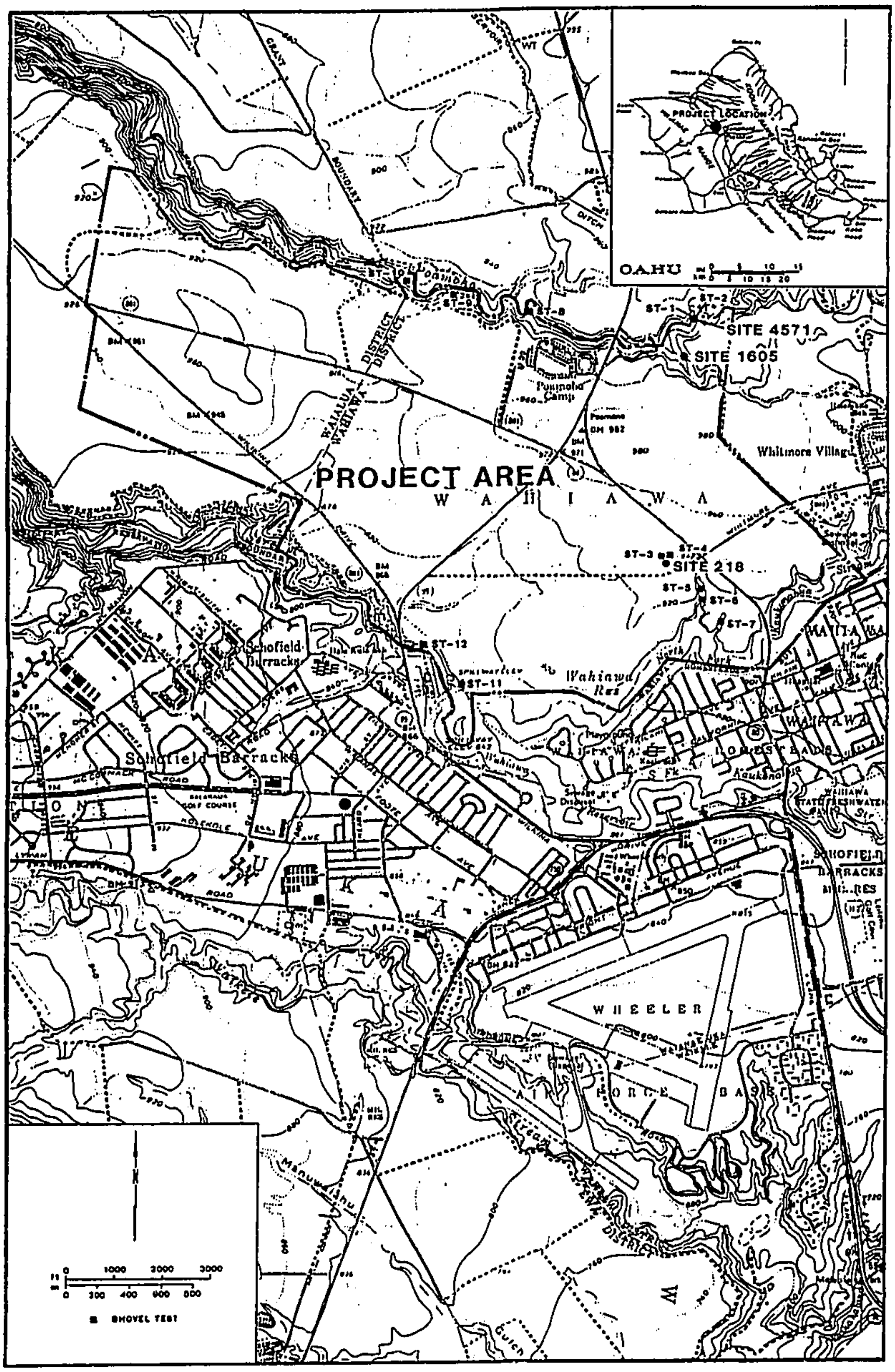

Figure 1. Project Area, Showing Site and Shovel Test Locations

The goddess Hi'iaka journeyed from Hawai'i Island to Kaua'i to fetch the chief *Lohiau-ipo* (Lohiau) from Ha'ena and return with him to Pele's domain at Kilauea, Hawai'i. While traveling on O'ahu, Hi'iaka passed along the Ko'olau (windward) side of the island.

Departing from the sands of Kalama'ula at Pupukea, Hi'iaka and her companions continued their journey. While on the Ko'olau loa side of Waimea River, Hi'iaka turned the dual-formed lizard being named Pili'a'ama into a stone which may be seen to this day. Upon crossing the Waimea River, *Hi'iaka ma** entered the district of Waialua and offered a chant in praise of this famous district of O'ahu:

O Waialua la'i 'eha,
'Eha ka malino lalo o Waialua e,
La'i mau o ke kakahiaka,
La'i a'e o ke 'awakea,
La'i mai ana ke ahiahi,
La'i Waialua i ka po e!

Behold Waialua of the four fold tranquility
There are four natures of calm at lower Waialua
The perpetual calm of the morning
Calm when the sun is overhead
Calm with the coming of evening
And the calm of Waialua in the night

As *Hi'iaka ma* traveled along the shore of Waialua towards Mokuleia, Hi'iaka chanted out, describing the nature of the sea which fronts Waialua District:

O Waialua kai leo nui,
Ia lono ka uka o Lihu'e,
Ke wa ala i Wahiawa e,
Kuli wale ka leo o ke kai,
Kuli wale ka leo,
He leo no ke kai e!

At Waialua is the great voiced ocean
Heard to the uplands of Lihu'e,
Rumbling atop Wahiawa,
Deafening is the voice of the sea,
It is a deafening voice,
Indeed the ocean has a voice

(February 9-16, 1924)

Note the reference to Wahiawa as a "place of rumbling, or roaring," for the rumbling voice of the ocean is carried up the valleys and heard on the plateau.

* ma - *A Hawaiian word meaning companion, or associates.*

Another legend deals more directly with the project area lands, and gives an account of the famous birth site of royalty —*Ku-kani-loko* (interpretive translation: The sound/resonance rises from within). Kukaniloko (SIHP Number 50-80-04-00218) is one of the most sacred places on the island of O'ahu. The functions of Kukaniloko will be further discussed later in this report.

Martha Beckwith's account of Kukaniloko mentions an interesting piece of information which can be used to interpret the meaning of Wahiawa: "The site chosen is one frequently visited by thunderstorms, whose manifestations were regarded as the voices of ancestral gods of the heavens welcoming an offspring of divine rank. The drums [of Ho'olooopahu] perhaps simulated the voices of deity." (Beckwith 1970:377)

To this day, Hawaiian *kupuna* (elders) remember stories from their childhood, in which they were told that thunder was either the voice of the gods, or the sounds made by their playing the game *'ulumaika*. Traditionally, it was *kapu* (forbidden) to call out or make any kind of noise while the gods were thundering. It is easy to make the inference that the rumbling of this plain might also have been that of the thundering god *Kanewawahilani ma*, and because of the regular occurrence of this phenomenon, Wahiawa was so named.

Of all the ancient Hawaiian sites in Wahiawa, Kukaniloko is the most famous. Although few physical features of the site remain, it is a place which to this day is given great reverence by Hawaiians familiar with the location. While leading a historical sites workshop on O'ahu in October of 1991, the author visited Kukaniloko, and found *lei* offerings on several of the boulders.

The following excerpts from Thomas Thrum and Abraham Fornander provide an overview of the history and use of Kukaniloko.

"Among the various Hawaiian traditions connecting with important early periods in their history, few, if any, have had a deeper hold among them than attaches to Kukaniloko, the famous birth-place of ali'is of the highest rank, at Helemanu, in the Waialua district of O'ahu, better known now as Wahiawa. The fact that a number of those who were born there became identified with events that affected the whole [island] group doubtless helped in this recognition of predominant virtue...

We look in vain today for the prominent boulder which in tradition, if not fact, held the magic power and marked the locality on the plains of Helemanu,

and against which chiefesses of the highest rank were alleged to lie during childbirth that virtue of a painless accouchment as well as recognized 'blue blood' of her offspring would be assured. Instead, the searcher will find a scattered lot of large stones, most of which are deeply imbedded in the earth, and several of which are flat surfaced, even with the ground. These are in an area of about one hundred square feet...

Amid a group of three or four of the more prominent of these stones is one standing, tongue-shaped, measuring a little over five feet in height by two and one-third feet in width, that has been supposed by many was the famous stone in question from its weather worn condition, but an aged native familiar with the locality and its traditions, says it was brought from elsewhere a number of years ago by the late George Galbraith and set up there... Facing this stone, westward, is one of the largest, deeply imbedded in the ground, the upper surface of which has rudely-shaped depressions fitting the human form that primitive mind in ages past coupled with the cause and purpose familiar to the savage idea, which subsequent generations, through superstition and tradition, have magnified.

While this origin may be lost to us, the tradition of its recognized eminent virtue has come down by various native authorities which traces it back to about the opening of the twelfth century.

One early writer gives the following descriptive account of its origin and purpose: 'There are two famous places for the birth of children of tabu chiefs, viz., Holoholoku at Wailua, Kaua'i, and Kukaniloko at Waialua, O'ahu. These birth places were thought to add some special divine gift to the sacred place already occupied by a high tabu chief'" (Thrum 1912:101-103).

Thrum continues his article by quoting Abraham Fornander's documentation on Kukaniloko. Fornander identifies the site as first belonging to the chief *Nanakaoko* and his wife *Kahihiokalani* (1969:Vol. II, p 20). It was at Kukaniloko that their son *Kapawa* was born.

"...A row of stones was laid down on the right hand and another on the left hand, and the face was to the right side. A hill or mound was made for the back. Kukaniloko was the stone to be trusted. If anyone came in confident trust and lay properly upon the supports the child would be born with honor. It would be called a chief divine; a burning fire."

Fornander's narratives continue by stating that when a child was born at Kukaniloko, it was quickly taken within the nearby *Waihau* (temple) of Ho'olonopahu where 48 chiefs were assembled. To these chiefs belonged the ceremonial duty of cutting the navel cord. The sacred drum of *Hawea* was beaten and the ringing of its voice signified that a chief was born. The voices of temple drums symbolized the thundering voices of the gods.

So great was the power of Kukaniloko that numerous informants have documented the fact that even commoners born nearby would become great chiefs. The idea of using this site remained in the minds of Hawaiians after the arrival of Captain Cook, as evidenced by Fornander, who relates an account from 1797. When Keopuolani, the sacred wife of Kamehameha I, drew near to the fulfillment of her pregnancy with Liholiho, Kamehameha tried to get his royal wife to Kukaniloko for the birth, but because of her illness, this was not accomplished (Fornander 1969:Vol. II: 21).

In another Fornander rendition of Kukaniloko, the site is associated with a chiefess who bore that name, and from her line were born powerful *ali'i*. Thus this site gained its prominence (ibid: Vol. II: 91).

Hawaiian historian John Papa I'i offers one other note of interest concerning use of Kukaniloko by identifying it as an important *pu'uhonua* (place of refuge) on O'ahu (1959:138). While listing sanctuaries of the various islands, I'i also identifies the other sacred birthing site, Holoholoku at Wailua, Kaua'i as a place of refuge.

The presence of sacred sites and their associated oral traditions are a sign that at one time there must have been a sizable community nearby. An ancient Hawaiian saying is that "A chief is only made chief, by the people who serve him," (Kekuhaupi'o 1921). In order to support the formal and structured community associated with *ali'i* and their *heiau*, a community had to be established.

In *Native Planters In Old Hawai'i* (1972), it is noted that a large population once lived in the Wahiawa area, judging from the various areas of *lo'i* (irrigated terraces) in the area. It is also noted that extensive sweet potato and yam plantations were developed. Wahiawa is one of the few places where sweet potatoes were known to have been irrigated, with water drawn from Helemano Stream to the northern *lo'i*. There were also extensive *lo'i* fed by Wahiawa Stream, and many small terrace areas along the sides of the valleys of all the streams of this general area. Handy and Handy note that the area is unusual in that it is the only extensively level area on the island at such a high altitude (Handy and Handy 1972:464-465). Handy also comments on the field pond system near Kukaniloko: "Kukaniloko was the name of an ancient high chief of O'ahu who is said to have made the first *lo'i* here" (ibid:465).

Sterling and Summers of Bishop Museum compiled an extensive review of both legendary and historical documentation for the island of O'ahu. Their work was published as "Sites of O'ahu," and it is the source of the following information.

Ka-mana-nui (The large branch or division) - Formerly there were large terrace areas along the flatlands between the junction of Helemano and Poamoho Streams and the flatland west of Poamoho. There were also small terrace areas up in the lower flats of Poamoho and Kaukonahua Valleys. There were small flats in the bottom of Kaukonahua Canyon for several miles above its junction with Manawai Stream. Poamoho is probably too narrow for taro terraces. It is likely that in these gulches, as at Waimea, sweet potatoes and bananas were planted around home sites along the ridge and near taro patches at the bottom of the gulch. Wild taro and bananas grow in Manawai Valley and presumably also in the other five valleys that run up toward Pu'u Kane. At Kamananui are the remains of what McAllister describes as "the longest irrigation ditch of which there is any memory" among modern Hawaiians (1978:103).

Wahiawa - According to Oscar Cox, there were terraces at Kanaku and at Kuaikua, both of which are somewhere in the vicinity of Kukaniloko. According to old Mahoe there were numerous terraces on the level uplands in the vicinity of Wahiawa town, irrigated by a ditch bringing water from Helemano Stream. However, this is impossible, since Poamoho Stream intervenes. The chiefess, Lanikaha built terraces inland in Helemano. There were small terraces in all the inner valleys (1978:138).

Kuaikua (Interpretive translation: In the presence of the god) Stream - Kuaikua is located in Halemano. It has a sacred spring and only those related to the supernatural ones who made and hid it are allowed to bathe in it (Ke Au Hou IN Sterling and Summers 1978:138).

Early Historical Accounts

In the early 19th century, the verdant forests of the Wai'anae and Ko'olau ranges were the source of sandalwood trees which were harvested to supply income and trade items for various chiefs.

Describing the general nature of sandalwood harvesting, Kamakau states:

> "The chiefs, old, and young went into the mountains with their retainers, accompanied by the king and his officials, to take charge of the cutting, and some of the commoners cut while others carried the wood to the ships at the various landings; none was allowed to remain behind. Many of them [commoners] suffered for food, because of the green herbs they were obliged to eat they were called 'Excreters-of-green-herbs' (Hilaulele), and many died and were buried there. The land was denuded of sandalwood by this means (1961:252).

Additional entries from Kamakau reference sandalwood collection in the Wahiawa region:

> "At the completion of the fort, Ka-lani-moku and all the chiefs went to work cutting sandalwood at Wahiawa, Halemano, Pu'ukapu, Kanewai, and the two Ko'olaus. The largest trees were at Wahiawa, and it was hard work dragging them to the beach. All the people were drawn into service, and the chiefs bought quantities of cloth, and some began to buy ships..." (1961:207).

> "While Boki was engaged on his cultivation up in Nu'uanu he heard that Kau-i-ke-aouli's favorites were gone to the mountains of Wahiawa, Hale'au'au, and Lihu'e to cut sandalwood and that Paki and 'Aikanaka had been placed in command. He and Kuini Liliha immediately returned to their Beretania place, and the chief prepared to go to Wahiawa to cut sandalwood..." (ibid:293).

Land Tenure and Settlement Patterns

From the 1790s through the 1840s, the Hawaiian Kingdom was undergoing radical changes as Western ways gained ever-growing influence over the *ali'i* (rulers) of Hawai'i. In 1848, during the reign of Kauikeaouli (Kamehameha III), the traditional Hawaiian land distribution system was replaced with a Western-style ownership system. This radical restructuring was called The Great Mahele (The Great Division). The Great Mahele defined the land interests of the King, the high-ranking chiefs, and the *konohiki*, who were originally those in charge of tracts of land on behalf of the king or a chief (Chinen 1958:vii and Chinen 1961:13).

More than 240 of the highest-ranking chiefs and *konohiki* in the kingdom joined Kamehameha III in this division. The first *mahele* was signed on January 27, 1848 by Kamehameha III and Princess Victoria Kamamalu, and by her guardians Mataio Kekuanao'a and Ione I'i. The last *mahele* was signed by the King and E. Enoka on March 7, 1848 (Chinen 1958:16).

The *mahele* did not convey title to any land. The chiefs and *konohiki* were required to present their claims to The Land Commission to receive awards for lands quiet claimed to them by Kamehameha III. They were also required to pay commutations to the government in order to receive royal patents on their awards. Until an award was issued, title remained with the government. The lands awarded to the chiefs and *konohiki* became known as Konohiki Lands. Because there were few surveyors in Hawai'i at the time of the *mahele*, the lands were identified by name only, with the understanding that the ancient boundaries would prevail until the land could be surveyed. This expedited the work of the Land Commission and speeded the transfers (Chinen 1961:13).

During this process all land was placed in one of three categories: Crown Lands (for the occupant of the throne), Government Lands, and Konohiki Lands. These were all "subject to the rights of native tenants," (Laws of Hawaii 1848:22). Native tenants were the common Hawaiian people who lived on the land and worked it for their subsistence.

Questions concerning the nature of these rights began to arise as the King, the government, and *konohiki* began selling parcels of land. On December 21, 1849 the Privy Council attempted to clarify the situation by adopting four resolutions intended to protect the rights of native tenants referred to in the 1848 law (Chinen 1958:29).

These resolutions authorized the Land Commission to award fee simple title to all native tenants who occupied and improved any portion of Crown, Government, or Konohiki lands. These awards were to be free of commutation except for house lots located in the districts of Honolulu, Lahaina, and Hilo (ibid.).

Before receiving their awards from the Land Commission, the native tenants were required to prove that they cultivated the land for a living. They were not permitted to acquire wastelands or lands which they cultivated "with the seeming intention of enlarging their lots." Once a claim was confirmed, a survey was required before the Land Commission was authorized to issue any award. These lands became known as "Kuleana Lands" (ibid:30).

Until its dissolution on March 31, 1855, the Land Commission issued thousands of awards to the native tenants for their *kuleana*; even so, less than 30,000 acres of land were awarded to the native tenants as Kuleana Lands.

While the commoners were required to provide documentation substantiating their use of, and/or residence on lands which they claimed, the *ali'i* simply claimed their rights. For the commoners, this requirement of proof produced volumes of registry and testimony which help us understand land use practices, crop production, resource harvesting, and architectural sites of the time. In the instances of royal claims, there is generally little documentation, particularly when the claims encompassed entire *ahupua'a* or large tracts of land.

In conducting historical documentary research for the project area lands, PHRI Historical Researcher Lehua Kalima made the following observations:

> At the time of the Great Mahele in 1848 the district of Wahiawa was not yet formed. The project area would have been made up of land in Wai'anae Ahupua'a in the Wai'anae District and Kamananui Ahupua'a in the Waialua District, as no reference to the *ahupua'a* of Wahiawa could be found in any of the records dealing with the *Mahele* (Board of Commissioners 1929). When the *Mahele* took place Kamananui Ahupua'a was designated as government lands and Wai'anae Ahupua'a was designated as Crown Lands. This explains the absence of Land Commission Awards (LCA) within the project area, as no private citizens were awarded land within the project area, thus no record exists for the use of the land in this area at this time. Previous documentary sources refer to the area as containing numerous *lo'i*, so it could be expected that these existed up to the time of the *Mahele*, until such time as the land was sold off by the government or the Crown lands were utilized by the ruling *ali'i* in some way."

Kalima also cited documents from the State Historic Preservation Department; these documents report the presence of one previously unidentified site within the project area, and two previously unidentified sites just outside of the project area. State Site 50-80-04-01605, which is supposed to be located within the project area, was pointed out to SHPD staff by Mr. James Saifuku from his memories of the area in the 1940s. Mr. Saifuku referred to this site as a *helau*; however, no other sources, including well-known archaeologist McAllister (1933) make any reference to a *helau* in this area.

> There is now little to see at Kukaniloko. It is an inclosed[sic] area about one-half acre in size, with many large stones, some just visible, others protruding to a height of 3 to 4 feet, scattered about on a well-kept lawn. Tall trees border the site. To the old Hawaiians these stones were all named and represented *ali'i*, but now the only name remembered is *Kahamaluihi*, a flat stone near the center of the group. The old Hawaiians of today remember in their childhood they were never allowed by their parents to approach even near the sacred birthplace, an indication of the great respect in which Kukaniloko was held, even a century after contact with Europeans and more than a half-century after the coming of missionaries (McAllister 1933:136).

Presently the project area is planted in pineapple. The Kukaniloko site, surrounded by Galbraith Estate land, is in the possession of the State of Hawaii and is protected as a historical site (Site Number 50-80-04-00218).

PREVIOUS ARCHAEOLOGICAL WORK - PROJECT AREA VICINITY

During previous archaeological investigations by McAllister and Saifuku several archaeological sites were identified in the vicinity of the project area (Figures 1 and 2). A summary of previously recorded sites is presented in Table 1. The McAllister sites include three *heiau* (Sites 50-80-04-215, -217, and -219), a house site (Site 216), and Kukaniloko Birthstones (Site 218) (McAllister 1933). Due to the extensive military and agricultural disturbance in the vicinity, most of the sites have been destroyed.

McAllister identified Site 215, Haleauau Heiau, in Pumaialau Gulch, about 150 above the gulch stream. According to McAllister, the site was adjacent to an artillery range, and thus most of its features had been obliterated. Artifact hunters had also disturbed the site. McAllister describes the site below:

> The walls of the pit, which is on the southeast corner, are evenly faced, with a fill of small rocks as a flooring. Beneath the few inches of flooring is the natural earth. Two kukui trees are now growing in the pit. The three sides of the small terrace below the pit are evenly faced with 1 foot stones to a height averaging 5 feet. The low 1 foot terrace on the east half of the *heiau* is hardly perceptible, but an occasional low facing suggests the low elevation depicted. The whole structure was stone paved, but the greater part of the flooring has been disturbed. The north side presents a steep face, portions of which could not be scaled. The other three sides are neither so steep nor as deep. There is about a 150-foot drop to a small stream. The other three sides are neither so steep nor so deep. Large natural stones have been utilized in building, notably one 8 feet in size on the northeast corner. Unusually large stones are found in several instances in the wall. A few pieces of coral were noticed (1933:134).

McAllister's Site 216 was a house site on a ridge east of Haleauau Heiau. The site consisted of large stones three feet in diameter. The stones formed an enclosure 15 by 20 feet. No additional information on this site is available.

Site 217 was a *heiau* in Kalena Gulch in the Land of Mohiakea. No information concerning the site's size and construction is available. According to McAllister, "...the heiau is said to have had a tunnel artificially dug underneath the platform, containing burials. It is not known if this was of recent or ancient construction..." (1933:137). Site 217 was in an area used as an artillery range and was destroyed by bombing.

Site 218, Kukaniloko, is said to represent one of the two famous birthplaces of *alii*. Due to the efforts of W.W. Goodale of Waialua Plantation, and the Daughters of Hawaii, Kukaniloko has been preserved. Site 218 is in Galbraith Trust Lands, and has been discussed in detail in the Historic Documentary Research section. The site was extensively recorded during the current project (see Findings).

Site 219 was a *heiau*, adjacent to the Kukaniloko Birthstones site. The *heiau* was called "Hoolonopahu", and is said to have been associated with Kukaniloko. According to documentary research, the drums of Opuku and Hawea were kept here and beaten to signal the birth of an *alii*. The site has been destroyed by pineapple cultivation, and no information concerning the *heiau's* size and construction are available. For a comprehensive discussion of Hoolonopahu Heiau, refer to the Historic Documentary Research section.

Mr. James Saifuku visited the Poamoho Stream Gulch area in the 1940s. His examination of the area resulted in the identification of three archaeological sites—a *heiau*, a stacked stone wall, and a stone alignment. In September of 1987, Mr.

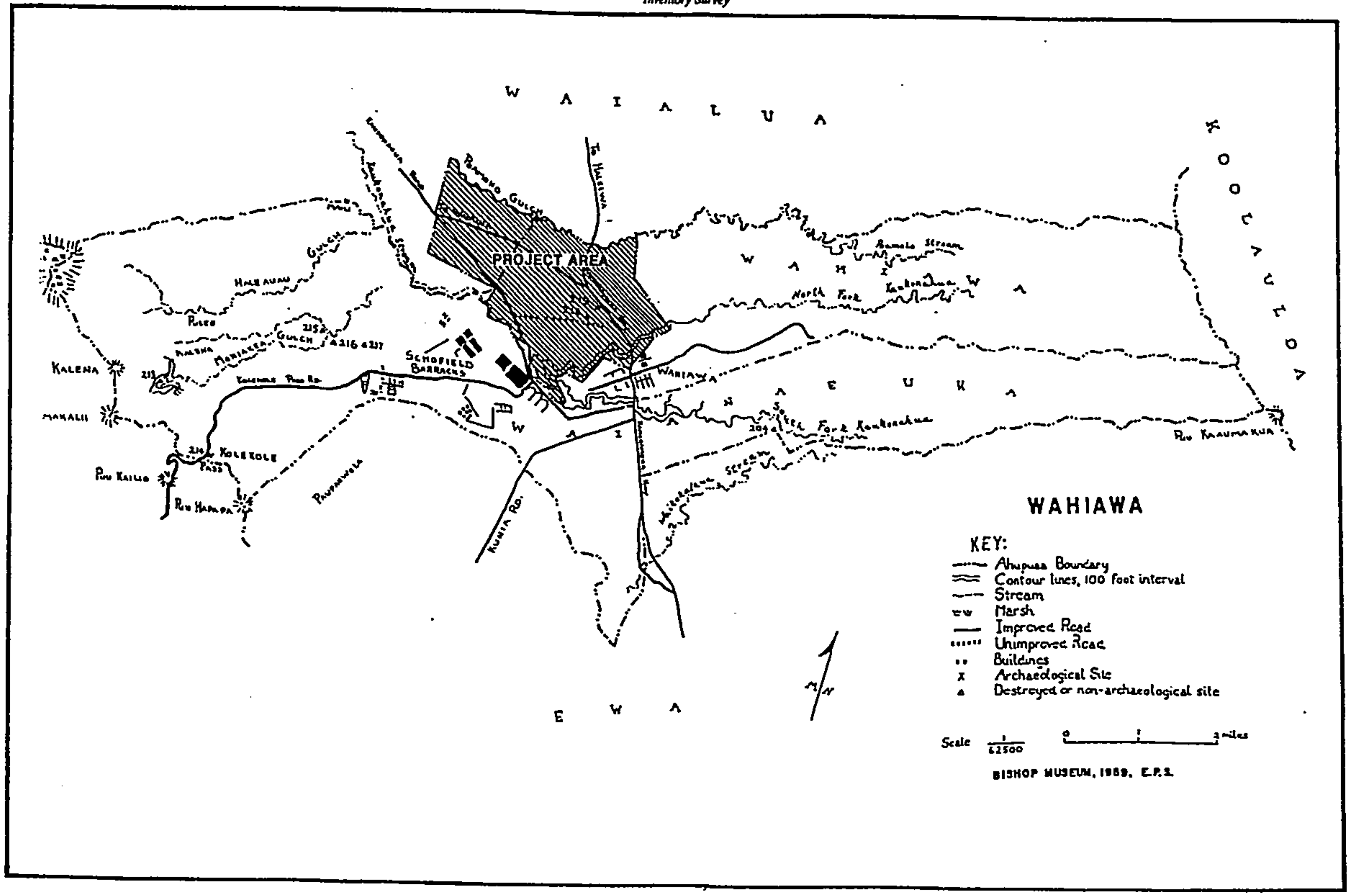

Figure 2. Wahiawa District Showing Ahupua'a Boundaries and Site Locations

Table 1.

SUMMARY OF PREVIOUSLY IDENTIFIED SITES IN THE VICINITY OF THE PROJECT AREA

SIHP Site No.	Formal Type	Function Interpretation	Comments
215	Heiau	Ceremonial	Located in Pumaialau Gulch. Destroyed by practice artillery and artifact hunters (McAllister 1933).
216	House Site	Habitation	Located on ridge east of Pumaialau Gulch. 15 by 20 foot enclosure composed of large stones (McAllister 1933).
217	Heiau	Ceremonial	Located in Kalena Gulch. Destroyed by practice artillery (McAllister 1933).
218	Birthstones	Ceremonial	Kukaniloko Birthstones. Located within current project area. Preserved by State (McAllister 1933).
219	Heiau	Ceremonial	Hoolonopahu Heiau. Served in conjunction with Kukaniloko. Was located in current project area. Destroyed by pineapple cultivation (McAllister 1933).
1605	Heiau	Ceremonial	Was located in current project area, in Poamoho Gulch, east of Poamoho Camp (Saifuku 1987).
1606	Wall	Indeterminate	"L" shaped wall located at bottom of Poamoho Gulch. Located outside current project area boundaries (Saifuku 1987).
1607	Alignment	Indeterminate	Stone alignment with artifacts located at bottom of Poamoho Gulch. Located outside current project area boundaries (Saifuku 1987).

Note: SIHP site numbers are preceded by 50-80-04.

Saifuku reported his findings to the DLNR. Mr. Saifuku generated locational maps and brief descriptions of the three sites from memory. Based on this information, the sites were subsequently assigned State Site numbers 50-80-04-1605, -1606, and -1607.

Site 1605 is a *heiau* in Poamoho Stream Gulch, east of Poamoho Camp. Saifuku's field maps provide no information on the *heiau's* size, exact location, or the presence or absence of portable remains or subsurface deposits (Saifuku 1987, unpublished field maps). According to the field maps, Site 1605 is within the boundaries of the current project area; however, it was not located during the inventory survey.

Site 1606 is an L-shaped stone wall at the bottom of Poamoho Stream Gulch. According to Saifuku's field map, one portion of the wall is approximately 150 feet long, with the other portion measuring approximately 100 feet long. Both portions of the wall are about 3 to 4 feet wide and 3 to 4 feet high. The site is about 150 to 200 feet below the pineapple fields, on a small, level area. Field maps indicate that Site 1606 is outside the current project area, to the west.

Site 1607 is a stone alignment located at the bottom of Poamoho Stream Gulch. According to Saifuku's field map, "This area had an interesting stone layout - nearly flat, and 6 to 8 feet above the river". Saifuku noted several artifacts at the site, including a broken chisel, game stones, and a *pohaku kui*. It is unclear if these artifacts were collected. Field maps also indicate that the site is outside the current project, to the west, about 1/4 mile from the old Kemdo Camp site, in an area with considerable bamboo (Saifuku 1987, unpublished field maps).

IMPLICATIONS OF PREVIOUS ARCHAEOLOGICAL WORK - PROJECT AREA VICINITY

Information from the previous archaeological work conducted in the general vicinity of the project area and the historic documentary research for this project was used to formulate a proposed cultural settlement and land utilization pattern for the vicinity of the project area (in the interior uplands of Oahu). This pattern considers the divergent geographic regions in the area and the distribution of cultural occupations within these regions. It should be noted that the following is merely speculative; it is based on information from an extensively disturbed area and is not supported by evidence from prehistoric archaeological deposits.

The vicinity of the project area consists of a relatively level, interior upland plateau, and numerous adjacent stream gulches. The area is discussed here in terms to five periods of Hawaiian cultural evolution proposed by Kirch (1985)—the Colonization Period (AD 300-600), the Developmental Period (AD 600-1100), the Expansion Period (AD 1100-1650), the Proto-Historic Period (AD 1650-1795) and the Historic Period (Contact to 1850).

Colonization Period

Although a Colonization Period (AD 300-600) component has been documented on Oahu, information concerning this earliest phase of Hawaiian pre-history is exiguous at best. To date, only a few sites in the Hawaiian archipelago have yielded dates prior to AD 600. Kirch comments on two of such sites—Bellows Dune Site (O18)(Layer III) on Oahu, and Pu'u Alii Dune Site (Layer III) at South Point on Hawaii (Kirch 1985). In addition, PHRI investigations at the Hyatt Regency Kauai Hotel project area resulted in the recovery of a radiocarbon sample which dated to AD 220-690 (Layer II, Block 1) (Walker, Rosendahl and Goodfellow 1992).

According to Kirch:

> The first settlers of Hawaii probably numbered in the tens, and by the close of the Colonization Period the population may have grown to several hundred or a thousand persons. Thus, we should not expect sites of this period to be frequent, and it is not surprising that only two archaeological deposits have been discovered (1985:298).

The current project area is a considerable distance inland, away from the easily exploitable coastal resources, making it even less likely that any Colonization Period sites are in the area.

Developmental Period

Developmental Period occupation and utilization of the interior of Oahu is currently poorly documented. This is no doubt due in part to the small populations that frequented Oahu during this early period. Although Kirch notes a probable population increase during the Developmental Period, he also states that it is unlikely that there were more than 20,000 individuals in all of the Hawaiian chain by AD 1100 (1985:302). The occupants of these small settlement clusters focused their subsistence activities on the readily accessible, coastal marine environment, making occasional forays to the interior for limited resource procurement. No evidence of a Developmental Period occupation has been noted in the vicinity of the project area, either on the plateau or in the stream gulches. It is possible that Developmental Period sites once existed in this area and that they have been destroyed by the extensive historic agricultural and military activities in the vicinity.

Expansion Period

The Expansion Period (AD 1100-1650) is characterized by numerous developments, including a rapid increase in population and intensified agriculture (large-scale irrigation, dryland agriculture, and aquacultural systems) which resulted in the creation of new social, political and religious forms (Kirch 1985:303-306). The *ahupua'a* system, a system of land division and related social organization unique to Hawaii, developed during this period and led to a more complex level of social and political integration (Hommon 1976, Green 1980).

During the Expansion Period people moved inland, away from the coast, primarily as a means of providing food for a steadily increasing population. Large-scale agriculture and aquaculture were initiated. The level, interior plateau in the current project area contains large areas of fertile alluvial and colluvial soils, perfectly suited to large-scale agricultural. The historic documentary research for this project suggests that numerous areas of *lo'i* once existed in the area. Based on this, Handy and Handy postulates that a relatively large population once occupied the Wahiawa area.

The flat plateau region and stream gulches in the project area apparently supported a population of chiefly importance from almost the beginning of the Expansion Period. Sites which reflect the utilization of this area by the *ali'i* are Kukaniloko Birthstones (Site 218), Hoolonopahu Heiau (Site 219), and several smaller *heiau* (Sites 215, 217, and 1605). According to Fornander, Kukaniloko was initially used close to the 12th century, which means the site has existed for hundreds of years (Fornander IN Sterling and Summers 1978:139).

Proto-Historic Period

The Proto-Historic Period (AD 1650-1795) is characterized by a full utilization of available lands in order to support a population that had grown enormously during the Expansion Period. Due to the extensive agricultural and military disturbance in the vicinity of the project area, most of the Proto-Historic Period sites that once existed have probably been destroyed. Historic documentary research, however, suggests that the lands in the vicinity of Wahiawa once supported a large population, typical of the Proto-Historic Period. According to Fornander:

> The south side of Kukaniloko was a furlong and a half, and on the western side two furlongs. There the tabu drum of Hawea was sounded, signifying that a chief was born. On such occasions the common people assembled on the east side of the stream—a thousand of them (a mano), on that side of Kualkua (Fornander IN Sterling and Summers 1978:103).

The project area lacks analyzable, Proto-Historic Period sites, but the fertile soils and accessible water in the area suggest this area was probably substantially utilized during this period of Hawaiian cultural history.

Historic Period

During the Historic Period the traditional Hawaiian lifestyle was altered considerably. According to Kirch:

> "...the death of Kamehameha in 1819 marked the passing of an era. The *kapu* system was abolished when Ka'ahumanu induced the young Liloliho to partake of a meal with a number of the chiefly women, and in the following year, 1820, the first company of American Protestant missionaries arrived on the brig Thaddeus. A Hawaiian orthography was prepared, the Bible translated, laws passed and printed. By mid-century, the fledgling Kingdom undertook the single most significant inducement to cultural change, the Great Mahele or division of lands between the king, chiefs and government, establishing land ownership on a Western-style, fee-simple basis. From this single act, an entire restructuring of the ancient social, economic, and political order followed (1985:309).

There was increased trade with the outside world during this period. Numerous cash crops, including sandalwood, *wauke*, and later, sugar cane and pineapple were cultivated. Within the vicinity of the current project area, sandalwood was cultivated. According to Alvarez:

> The plain at neighboring Waianae-Uka Ahupua'a was thickly forested, however, in the early part of the nineteenth century, the sale of Hawaiian sandalwood to the Chinese market increased from what had formerly been modest amounts to substantial quantities. In order to participate in the trade, some of the chiefs ordered their people to go out with them to cut it. The natives would set fire to the native forest in search of the fragrant wood, which revealed its location more quickly. The trade diminished when the supply of sandalwood was exhausted.

Historical documentary research indicates there was a considerable Historic Period occupation in the vicinity of the project area. However, there is little archaeological evidence to support this.

Summary

Despite the disturbance in the vicinity of the project area, it is still possible to estimate where sites might have been, and at what period of time they may have existed. Previous archaeological investigations in the Hawaiian Islands indicate it is unlikely that Colonization or Development Period sites will be identified in this interior portion of Oahu. Early occupations generally centered around rich coastal strands and fertile windward valleys, and inland areas were only occasional visited primarily to procure resources. The lack of easily exploitable resources in the vicinity of the project area makes it an unlikely area for early settlement.

The historic documentary research on the current project indicates that the occupations during the Expansion, Proto-Historic and Historic Periods were extensive and complex. The flat, easily irrigated alluvial plains and terraced gulches, suitable for wetland taro cultivation, would be expected to yield remnants of these agricultural complexes. The presence of Kukaniloko and several *heiau* in this area all indicate a complex, stratified society typical of the middle and latter periods of Hawaiian cultural history.

The disturbance in the interior uplands plateau makes the recovery of significant prehistoric cultural deposits in the area unlikely. Several prehistoric sites have been recorded in the vicinity, but most have apparently been destroyed by agriculture and military activities. The plateau areas currently planted in pineapple are unlikely to have significant prehistoric cultural remains. The only areas which may have such remains are those minimally disturbed—namely, the sides and bottoms of the numerous stream gulches.

FIELD METHODS AND PROCEDURES

Field work for the current project was conducted July 28-31, 1992. Twelve labor-days were expended on the field work portion of the project. The field work was conducted under the supervision of PHRI Project Supervisor Jack D. Henry, B.S. The field personnel included Project Supervisor Martin Boudreau, B.A., and Field Archaeologist Dwayne Pickett, B.A.

The methods employed during the field work included 100% low-elevation aerial reconnaissance survey by helicopter, variable-density pedestrian survey, shovel testing, and site recordation.

The aerial reconnaissance survey was used to rapidly examine the areas that had a low potential to yield archaeological materials (the pineapple fields). The survey involved flying E-W transects over the pineapple fields, as close to the ground as possible. The entire perimeter of the project area was also surveyed from the air, focusing on unmodified areas and areas with natural vegetation.

The pedestrian survey covered unmodified areas and areas with natural vegetation. As most of the project area is planted in pineapple, the ground survey was restricted to the banks of the Wahiawa Reservoir and the Kaukonahua Stream Gulch in the south, and Poamoho Stream Gulch in the north. The intensity in which the ground survey was conducted was based primarily on the terrain and on an area's potential to contain cultural materials of archaeological interest.

Ground survey of the area bordering Wahiawa Reservoir and Kaukonahua Stream consisted primarily of walking a single transect along the banks. Areas of natural vegetation and unmodified areas in the vicinity of the banks were relatively narrow, ranging in width from 10 to 40 meters. The banks were generally steep and vegetation in the vicinity was moderately thick (Figures 3 and 4). Several areas required more extensive examination. One such area was a small gulch east of Kamehameha Highway; this gulch extended north from Wahiawa Reservoir; other such areas included several terraced areas west of Kaukonahua Stream. Both areas were relatively level and had thick vegetation. These areas were thoroughly examined with surveyors conducting east-west transects spaced at 10 m intervals. The beginning and end of each transect was flagged and labeled.

Pedestrian survey of the area bordering Poamoho Stream Gulch was conducted in two phases. The first phase concentrated on the western portion of the northern project area boundary, which originates at the division of Waialua and Wahiawa Districts and extends to the northwest corner of the project area. The boundary in this area is the edge of the pineapple fields and does not extend down into the gulch. Ground survey in this area consisted of walking a single transect along the upper edge of the gulch. The sides of the gulch were very steep and had moderately thick vegetation (Figure 5).

The second phase was conducted east of the division between Waialua and Wahiawa Districts. The project area boundary in this area extends to the bottom of the Poamoho

Figure 3. Banks of Wahiawa Reservoir (Neg. 4207:1:33a)

Figure 4. Walls of Tunnel Stream Gulch (Neg. 4207:1:28a)

Figure 5. Walls of Poamoho Stream Gulch (Neg. 4208:2:29)

Stream Gulch, and extends east to the northeast corner of the project area. Ground survey in this area consisted of east-west transects running parallel to the stream. The beginning and end of each transect was flagged and labeled.

All sites and surface features encountered in the project area were photographed and recorded using standard PHRI forms. Scaled plan and cross-section maps were prepared when appropriate. The approximate locations of identified sites were plotted on available topographic maps.

Twelve shovel tests (ST) were excavated throughout the project area to determine the presence or absence and general distribution of buried cultural deposits (Figure 1). The STs averaged 0.3 m in diameter and were 0.3 to 0.6 m deep. All STs were recorded using standardized PHRI forms. Soils encountered in the STs were described using standard procedures and terminology as set forth in the *Soil Survey Manual* (Soil Survey Staff 1962). All STs were excavated 0.2 m into culturally sterile soil before termination.

Site 218 (Kukaniloko Birthstones) was initially located through background research, and was subsequently identified during the aerial survey. During the ground surface survey, Site 218 was extensively recorded. A detailed plan map of all associated stones was prepared, extensive photographs were taken, and a PHRI Site form was completed. Petroglyphs encountered at the site were drawn and photographed. Due to Site 218's preserve status, no subsurface testing was conducted.

FINDINGS

AERIAL RECONNAISSANCE FINDINGS

The aerial reconnaissance survey resulted in relocating one site—Kukaniloko Birthstones (Site 218). The site is in a cluster of trees about 200 m west of the intersection of Kamehameha Highway and Whitmore Road (Figure 1). Background research indicated that the small parcel of land containing the birthstones is owned by the state and is protected. The site is discussed further below.

SURFACE FINDINGS

Two archaeological sites were identified during the inventory survey. One is a stacked stone wall (Site 4571) and the other is Kukaniloko Birthstones (Site 218) (Figure 6). Site 219, Hoolonopahu Heiau, was originally adjacent to Kukaniloko, but the site was destroyed during modification of the land for pineapple cultivation. Site 1605, a *heiau* previously identified at the bottom of Poamoho Gulch, was not located during the current project. No portable remains of any kind were recovered during the surface survey.

Site 218

Site 218 (Figure 6) is about 200 m west of the intersection of Kamehameha Highway and Whitmore Road (Figure 1). The site is on a state-owned parcel surrounded by Galbraith Trust Lands (McAllister 1933). The parcel is about 1,500 m^2 and is encircled with coconut and eucalyptus trees (Figure 7).

Site 218 consists of about 180 waterworn basalt rocks, 0.4 to over 2.0 m in diameter (Figure 7). The primary "birthing stone" is a large basalt rock measuring 1.01 m long, 0.65 m wide, and 0.41 m high (Figure 8). In the center of this rock is a smooth, bowl-shaped depression about 0.5 m in diameter by 0.2 m in deep. Adjacent to this depression, to the west, is a smaller "bowl" measuring approximately 0.2 m in diameter and 0.1 m deep.

At the time of the survey there were recent offerings on several of the rocks in this area, including leis, grass skirts, banana leaves wrapped around stones, coins, fruit, candy, and even children's toys. Photos of the birthing stone showing some of the offerings were taken. Then, prior to completing written descriptions of the stone, the offerings were removed, and the stone was sketched and again photographed. Once the recording was completed, the offerings were replaced.

Several rocks containing petroglyphs were noted at Site 218. Approximately 4 m northwest of the "birthing stone" is a large flat basalt rock measuring 1.5 m long by 0.8 m wide (Rock "A"). Etched into the surface of this rock were several images. One is a series of four concentric circles, with a dot in the center (Figure 9). The outer circle is about 0.38 m in diameter. About 0.08 m to the west is a second image—what appears to be a Japanese written character (Figure 9). This character is approximately 0.10 m long. About four meters northeast of the "birthing stone" is another rock with petroglyphs. Ten petroglyphs were on the rock, seven on the north face and three on the east. The petroglyphs on the north face included four human figures, two of which were wielding spears. Each of the other two figures had a circle with a dot in the center located just below the right foot. Located at the top of the rock was a series of half circles or arches, with the outer arch measuring approximately 0.20 m across. There were four arches overlying one another, with a dot at the base (Figure 10). All three petroglyphs on the east side of the rock were human figures, with a large male figure in the center, a smaller figure to the right and a larger, partially obscured figure to the left (Figure 11).

Site 4571

Site 4571 is a retaining wall just outside the northeast boundary of the project area (Figure 1). The wall, on the north bank of Poamoho Stream, consists of a single course of basalt stones stacked against the stream bank. The stones are 0.1-1.25 m in diameter. Most of the wall has collapsed into the stream bed (Figure 12); the intact portion of the wall is about 3.0 m wide. The height of the intact portion (measured from the stream bed, up the bank, to the highest portion of the wall) is about 2.0 meters. Including the collapsed portion, the wall is about 10.5 m long.

Two shovel tests were placed in a relatively level area directly above the wall. No cultural remains were identified. No portable remains were found in the site vicinity. The structure may have functioned as a retaining wall for agriculture, as it is in the area of a flood plain, but this is not supported by the subsurface findings.

Other Findings

The current study documented much modern utilization of the project area. In addition to pineapple cultivation, two small currently operating farms were identified in the area.

Figure 6. Aerial View of Kukaniloko (Site 218) (Neg. 4207:1:11a)

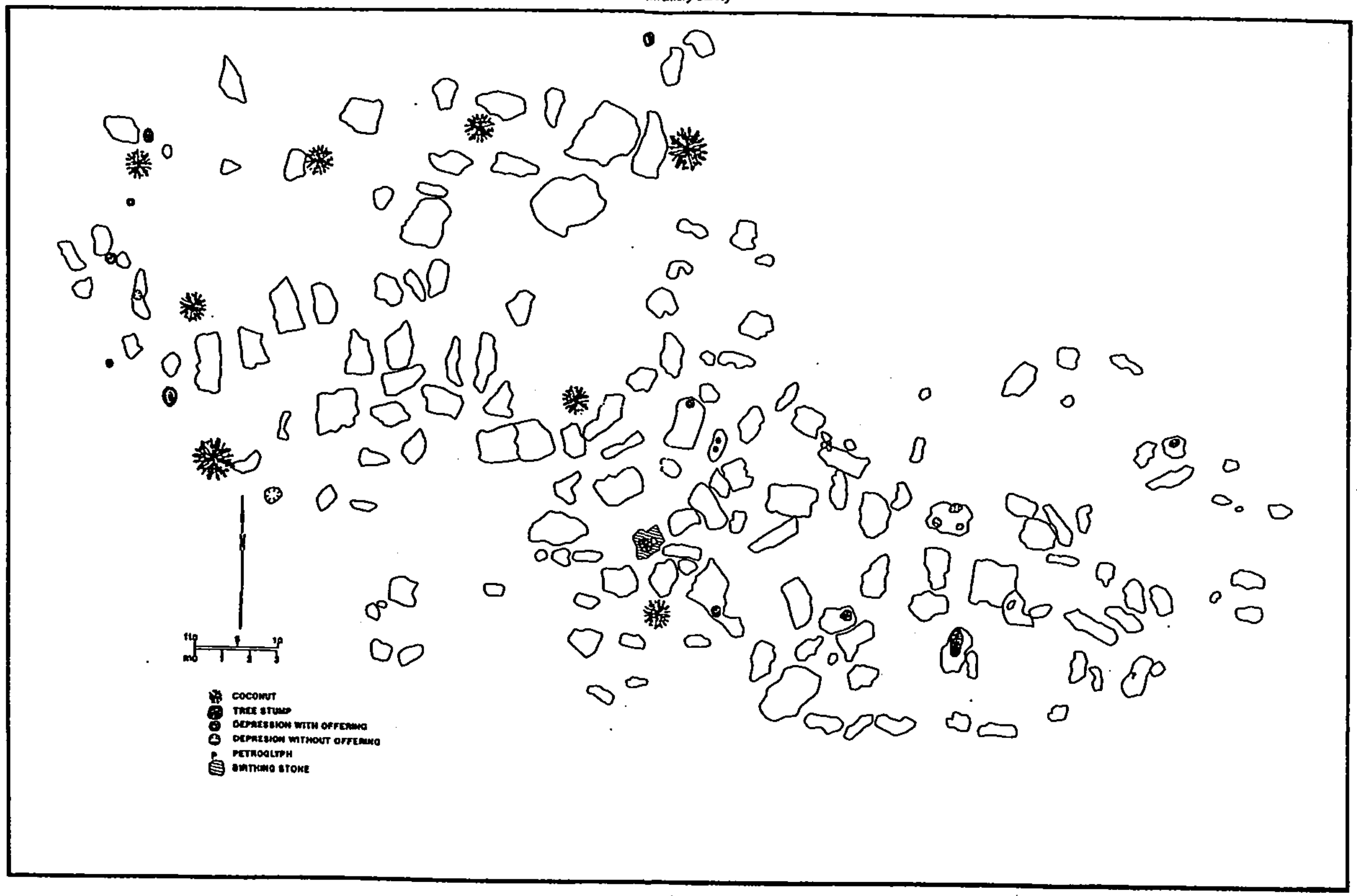

Figure 7.
Plan Map of Kukaniloko (Site 218)

Figure 8. Primary Birthing Stone (Site 218) (Neg. 4208:2:11)

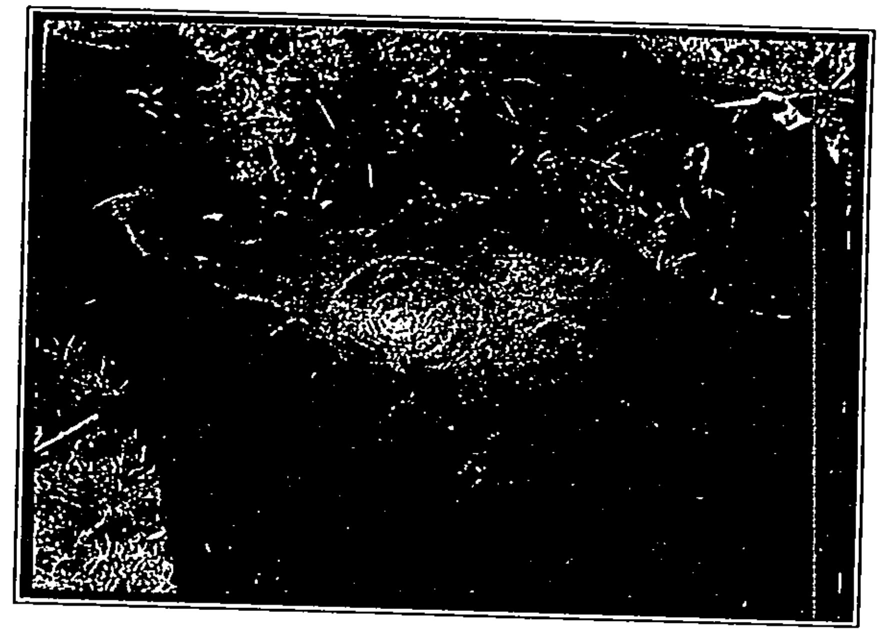

Figure 9. Rock "A" Petroglyphs (Neg. 4208:2:27)

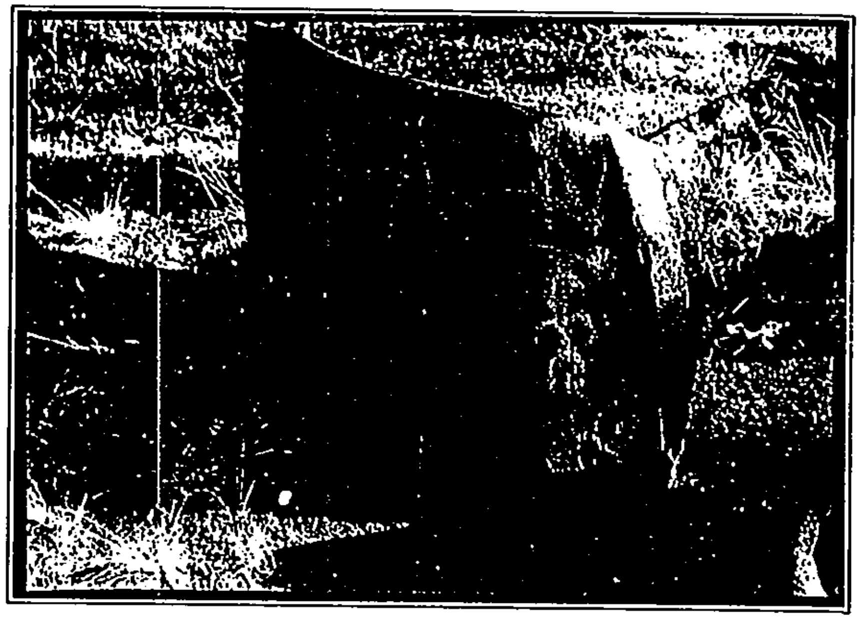

Figure 10. North View of Rock "B" Petroglyphs (Neg. 4208:2:26)

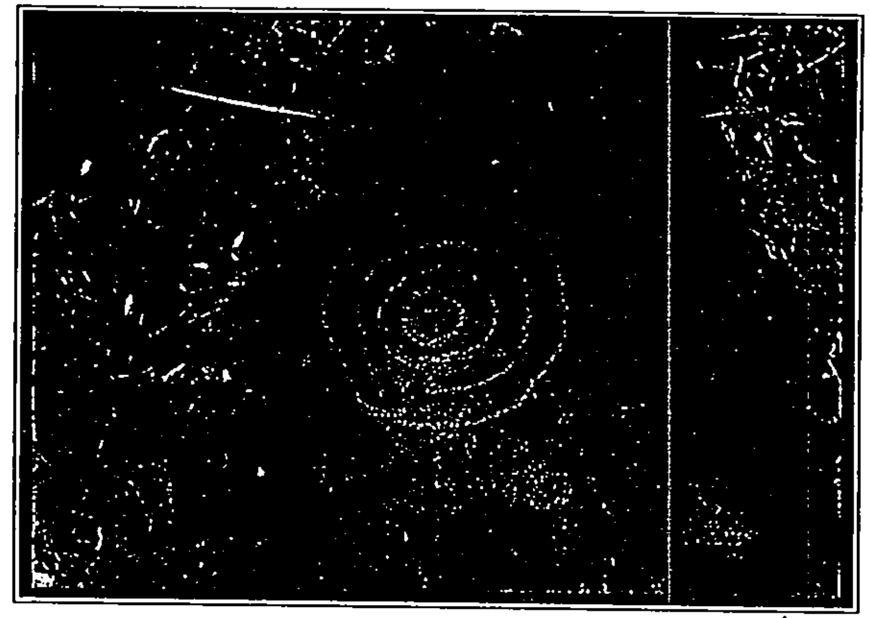

Figure 11. East View of Rock "B" Petroglyphs (Neg. 4208:2:21)

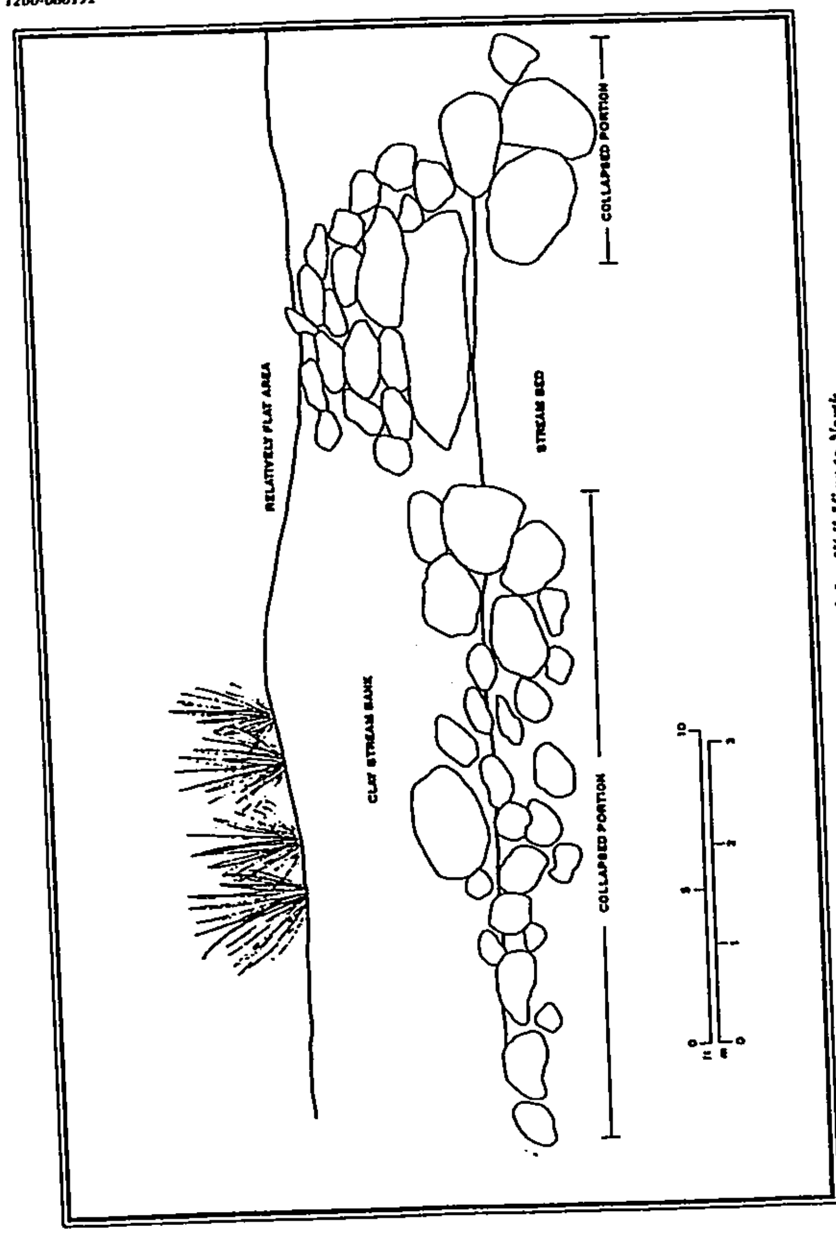

Figure 12. Site 4571, Retaining Wall, View to North

One is situated at the bottom of Poamoho Gulch, adjacent to the Kamehameha Highway Bridge (Figure 1). Another is in Kaukonahua Stream Gulch, approximately 600 m northwest of the intersection of Wilikina Drive and Kamananui Road (Figure 1).

The Wahiawa Refuse Convenience Center, a trash drop-off point for local residents, is in the current project area, 50 m west of the intersection of Kamananui Road and Wilikina Drive. Adjacent to the Refuse Center are the remains of an abandoned cement mixing operation (Figure 13).

A water diversion system was located at the western end of Wahiawa Reservoir, on the eastern side of Wilikina Drive (Figure 1). This system consists of a large concrete spillway, four water diversion gates, and a diversion canal. The concrete spillway is at the western end of Wahiawa Reservoir and apparently served to channel water into Kaukonahua Stream during periods of overflow (Figure 14). Two of the diversion gates are about 10 m southwest of the spillway. Both are small, are made of concrete, and have associated concrete channels which lead to a large pond below the spillway. One of the gates is imprinted with "1921" (Figure 15). The other two diversion gates and an associated canal are located about 100 m northwest of the spillway. One of the gates is imprinted with "1959", while the other one appears much older and currently not in use (Figure 16). A canal is present below the "1959" gate, and carries water from Wahiawa Reservoir to the northwest; in other words, the canal runs parallel to Kaukonahia Stream (Figure 17). On the west side of Wilikina Drive, the canal disappears underground. It reemerges north of the Wahiawa Refuse Convenience Center, where it joins with Kaukonahua Stream.

During the current study large amounts of historic trash were documented along the project area boundaries. Most of the trash is on the banks of Wahiawa Reservoir, Kaukonahua Stream Gulch and Poamoho Stream Gulch. The trash includes at least 30 abandoned automobiles, a wooden boat, stoves, refrigerators, beds, couches, 50-gallon drums, and assorted aluminum cans, glass bottles, plastic, tires, and corrugated metal roofing. Numerous former campsites were also documented along the banks of Wahiawa Reservoir and Poamoho Stream Gulch.

SUBSURFACE FINDINGS

Twelve shovel tests (ST) were excavated throughout the project area. Two STs were excavated in the vicinity of Site 4571 to determine the presence or absence and general distribution of buried cultural materials in this area. In addition, STs were excavated in areas deemed likely to yield intact cultural deposits. No cultural materials were documented in any of the STs. Site 218 was not shovel tested due to its preserve status. The locations of the shovel tests are illustrated in Figure 1. A summary of shovel test results is presented in Table 2.

Table 2.

SUMMARY OF SHOVEL TEST RESULTS

ST No.	Area	Depth (mbs)	Soil Color	Soil Texture	Cultural Material
1	Site 4571	0.41	Dark brown	Silty clay	None
2	Site 4571	0.46	Dark brown	Silty clay	None
3	Wahiawa Res.	0.35	Brown	Silty clay	None
4	Wahiawa Res.	0.40	Brown	Silty clay	None
5	Wahiawa Res.	0.35	Brown	Silty clay	None
6	Poamoho Gulch	0.30	Dark brown	Silty clay	None
7	Poamoho Gulch	0.30	Dark brown	Silty clay	None
8	Poamoho Gulch	0.35	Dark brown	Silty clay	None
9	Wahiawa Res.	0.35	Brown	Silty clay	None
10	Wahiawa Res.	0.35	Brown	Silty clay	None
11	Kaukonahua Stream	0.30	Strong brown	Silty clay	None
12	Kaukonahua Stream	0.35	Strong brown	Silty clay	None

Figure 13. Cement Plant (Neg. 4207:1:31a)

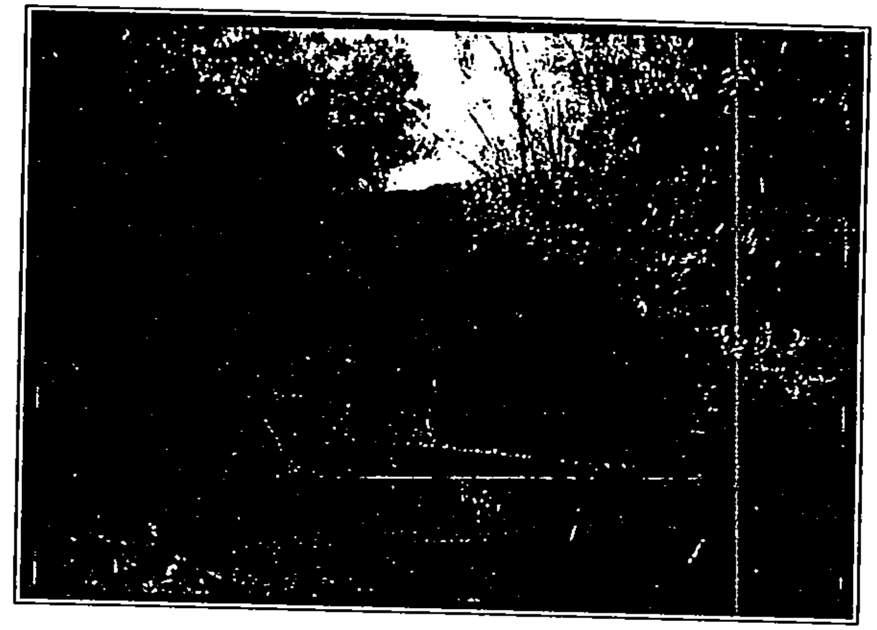

Figure 14. Spillway from Wahiawa Reservoir (Neg. 4207:1:23a)

Figure 15. "1921" Diversion Gate (Neg. 4207:1:19a)

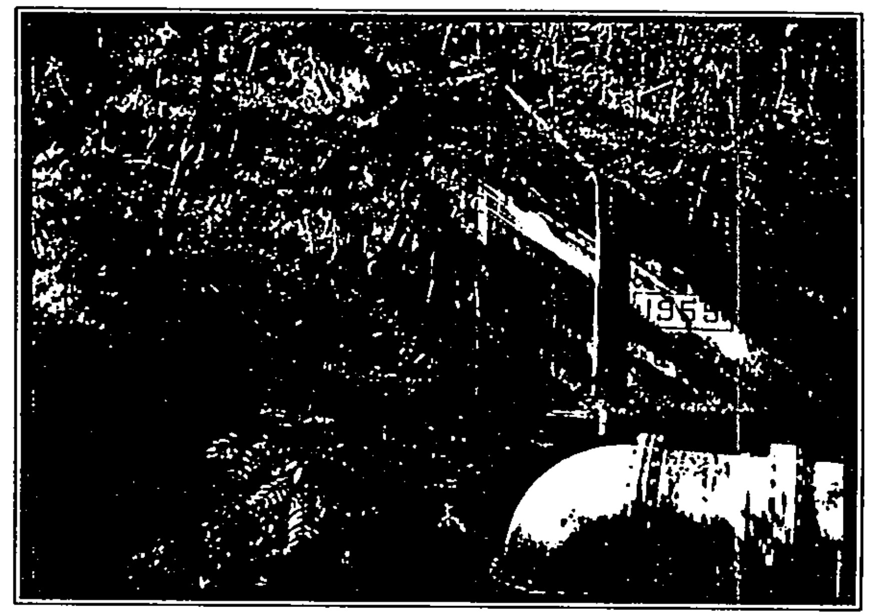

Figure 16. "1959" Diversion Gate (Neg. 4207:1:25a)

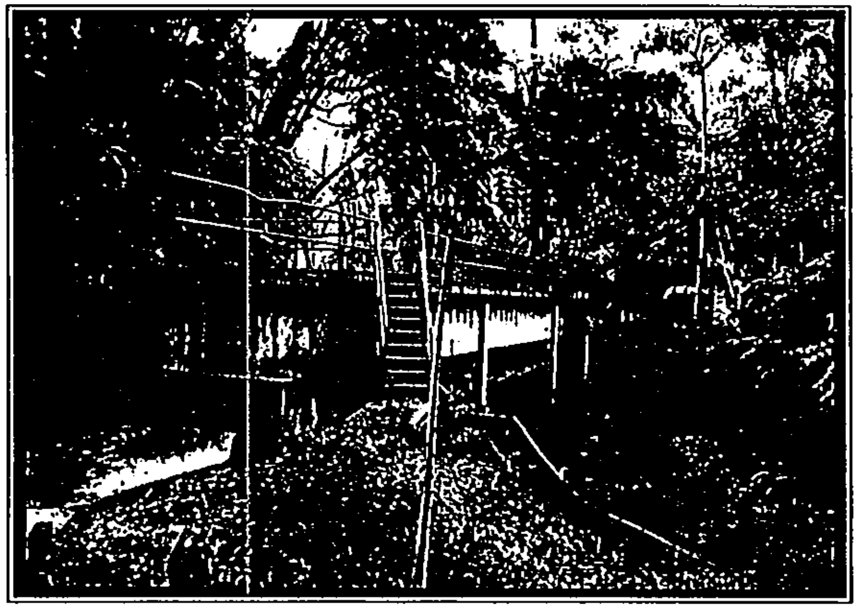

Figure 17. Diversion Canal (Neg. 4207:1:27a)

CONCLUSION

SUMMARY AND DISCUSSION

The current surface survey resulted in the identification of two archaeological sites—Site 4571, a stone wall at the bottom of Poamaho Gulch, and Kukaniloko Birthstones (Site 218), the previously identified "Birthplace of the Alii." The subsurface survey, consisting of placing two shovel tests at Site 4571 and excavating ten other shovel tests throughout the project area, yielded no significant cultural material of any kind.

The project area has been greatly disturbed and this disturbance has undoubtedly destroyed numerous sites once in the area. According to historical documentary research, a substantial prehistoric agricultural complex once existed in the vicinity, as evidenced by numerous former *lo'i* areas present on both the level plateau and on the sides of the adjacent stream gulches (McAllister 1933, Sterling and Summers 1978). The presence of Kukaniloko Birthstones (Site 218), and the former presence of several *heiau* in the area indicate this area was once associated with the *alii*.

No age determination samples were found during the current project. However, based on documentary research and previous archaeological research, occupation in the vicinity of the project area may have occurred as early as the 12th century AD. This is based on Hawaiian legends and the belief that Kukaniloko was first utilized during the early years of the Expansion Period (Fornander IN Sterling and Summers 1978:139). Whatever the chronology is for the Wahiawa area, it is clear that the area once supported a substantial, complex society.

The settlement patterns for the current project area during the Expansion, Proto-Historic and Historic Periods can only be theorized, as there is a lack of supporting evidence. As previously mentioned, it is thought that numerous *lo'i* once existed in the area. If they did indeed exist, this means the area was used for large-scale prehistoric agriculture. Such agriculture took place during the Expansion and Proto-Historic Periods in response to the rapidly expanding population. Related to this large-scale agriculture would be numerous habitation structures. It is possible that further examination of unmodified gulch areas outside the current project area would yield the remains of such structures.

Historic documentary research indicates that a substantial historic period occupation occurred in the vicinity of the project area. According to Alvarez, in the early 1800s, the neighboring *ahupua'a* of Waianae-Uka was heavily forested with sandalwood, and large-scale harvesting of these trees was undertaken (1982:6). At least part of the occupation in the vicinity, therefore, must have been related to this sandalwood harvesting. Historic sites that may have once existed in the project would include trails used to transport the sandalwood to the coast, and temporary habitations, both in the forests and along the trails, to house workers.

Due to the efforts of W.W Goodale of the Waialua Plantation, and the Daughters of Hawaii, the project area still contains one of the most culturally significant sites on Oahu. Kukaniloko Birthstones, considered to be one of two famous places in the islands for the birth of children of the *ali'i* is permanently preserved in a state-owned parcel that is within the bounds of the current project area. In addition to being a birthplace of the *ali'i*, Kukaniloko was thought to have also been a *pu'uhonua*, where a person who killed another person or committed another serious offense could take refuge (I'i 1959:138).

Kukaniloko consists of a primary birthstone, and other stones associated with it. A large flat rock (Rock "A") is adjacent to the primary birthing stone. On this rock is a series four concentric circles each with a dot in the center (Figure 10). According to Beckwith, one possible interpretation of this type of figure—according to two elderly Hawaiian informants—is that it represents the first born of an *ali'i* (Beckwith IN Cox 1989). Rock "B", east of the primary birthing stone also contains forms which may represent the birth of a child (Figure 10). Two of the four human figures present on the north face of the rock have an associated circle with a dot in the center, located slightly below them and to the left. Beckwith's informants postulated that these features may represent the hole where the *piko* for the firstborn child was placed (Beckwith IN Cox 1989). Rock "B" also includes petroglyphs of human figures wielding spears (on the north face) (Figure 11).

Site 1605 was a *heiau* in the project area, identified during the 1940s by Mr. James Saifuku, a visitor to the Poamoho Gulch area. Saifuku located it just south of Poamobo Stream, at the intersection of a small tributary east of Kamehameha Highway bridge. Site 1605 was not relocated during the current survey despite an extensive search for it. If future development plans include ground disturbance in Poamobo Stream Gulch, further efforts to locate Site 1605 may be necessary.

GENERAL SIGNIFICANCE ASSESSMENTS AND RECOMMENDED GENERAL TREATMENTS

To facilitate outside review, general significance assessments and recommended general treatments for all identified sites are summarized in Table 3. Significance categories used in the site evaluation process are based on the National Register criteria for evaluation, as outlined in the Code of Federal Regulations (36 CFR Part 60). The DLNR-SHPD uses these criteria for evaluating cultural resources. Sites determined to be potentially significant for information content (Category A) fall under Criterion D, which defines significant resources as ones which "...have yielded, or may be likely to yield, information important in prehistory or history." Sites potentially significant as representative examples of site types (Category B) are evaluated under Criterion C, which defines significant resources as those which "...embody the distinctive characteristics of a type, period, or method of construction...or that represent a significant and distinguishable entity whose components may lack individual distinction."

Sites with potential cultural significance (Category C) are evaluated under guidelines prepared by the Advisory Council on Historic Preservation (ACHP) entitled "Guidelines for Consideration of Traditional Cultural Values in Historic Preservation Review" (Draft Report, August 1985). The guidelines define cultural value as "...the contribution made by an historic property to an ongoing society or cultural system. A traditional cultural value is a cultural value that has historical depth." The guidelines further specify that "[a] property need not have been in consistent use since antiquity by a cultural system in order to have traditional cultural value."

Based on the above federal criteria, Sites 218 and 4571 are both assessed as significant for information content. In addition, Site 218 is assessed as significant for cultural value, and as a representative example of a site type. Preservation "as is" is recommended for Site 218. Due to the lack of subsurface deposits at the site, no further work is recommended for Site 4571.

To further facilitate client management decisions regarding the subsequent treatment of sites, the general significance of sites was also evaluated in terms of three PHRI Cultural Resource Management (CRM) value modes—scientific research, interpretive, and/or cultural values. *Research value* refers to the potential of archaeological resources for producing information useful in the understanding of cultural history, past lifeways, and cultural processes at the local, regional, and interregional levels of organization. *Interpretive value* refers to the potential of archaeological resources for public education and recreation. *Cultural value*, within the framework for significance evaluation used here, refers to the potential of archaeological resources for the preservation and promotion of cultural and ethnic identity and values. Based on the CRM value modes, Site 218 is assessed as highly significant for cultural value, research value, and interpretive value. Site 4571 is assessed as having low cultural value, research value, and interpretive value. The sites are summarized in terms of site number, site type and function, CRM value mode assessments, and recommended field work tasks in Table 4.

It should be noted that the above evaluations and recommendations are based on the findings of an inventory-level surface survey and limited subsurface testing. There is always the possibility, however remote, that potentially significant unidentified cultural remains might be encountered in the course of future development activities involving the modification of the ground surface. In such a situation, archaeological consultation should be sought immediately.

Table 3.

SUMMARY OF GENERAL SIGNIFICANCE ASSESSMENTS AND RECOMMENDED GENERAL TREATMENTS

Site Number	Significance Category A	X	B	C	Recommended Treatment FDC	NFW	PID	PAI
218	-	+	+	+	-	+	-	+
Subtotal:	0	1	1	1	0	1	0	1
4571	-	+	-	-	-	+	-	-
Subtotal:	0	1	0	0	0	1	0	0
Total:	0	2	1	1	0	2	0	1

General Significance Categories:
A=Important for information content, further data collection necessary (CRM value mode assessment = scientific research value)
X=Important for information content, no further data collection necessary (CRM value mode assessment = scientific research value)
B=Excellent example of site type at local, regional, island, state, or national level (CRM value mode assessment = interpretive value)
C=Culturally significant (CRM value mode assessment = cultural value)

Recommended General Treatments:
FDC=Further data collection necessary (further survey and testing, and possibly subsequent data recovery/mitigation excavations)
NFW=No further work of any kind necessary; sufficient data collected; no preservation potential (possible inclusion into landscaping suggested for consideration)
PID=Preservation with some level of interpretive development recommended (including appropriate related data recovery work) and
PAI=Preservation "as is," with no further work (and possible inclusion into landscaping), or minimal further data collection necessary

Table 4.

SUMMARY OF IDENTIFIED SITES

Site Number Type	Formal Site/Feature	Tentative Functional Interpretations	*CRM Value Mode Assess. R	I	C	+Field work Tasks DR	SC	EX
4571	Stone Wall	Retaining Wall	L	L	L	-	-	-
218	Birthstones	Ceremonial	H	H	H	-	-	-

**Value Mode Assessment*
Nature: R = scientific research, I = interpretive, C = cultural;
Degree: H = high, M = moderate, L = low

+Recommended Field Work Tasks: DR = detailed recording (scaled drawings, photographs, and written descriptions), SC = surface collections, EX = test excavations.

REFERENCES CITED

ACHP (Advisory Council on Historic Preservation)

1980 Treatment of Archaeological Properties. A Handbook. Advisory Council on Historic Preservation. Washington, D.C.

1985 Guidelines for Consideration of Traditional Cultural Values in Historic Preservation Review. Advisory Council on Historic Preservation, Washington, D.C. (Draft report, August)

Alvarez, P.M.

1982 A History of Schofield Barracks Military Reservation (Doc. 16). Prepared for Department of the Army, U.S. Army Engineer Division, Fort Shafter, Hawaii.

Beckwith, M.

1970 *Hawaiian Mythology.* Honolulu: University of Hawaii Press.

Board of Commissioners

1929 Indices of Awards made by the Board of Commissioners to Quiet Land Titles in the Hawaiian Islands. Star-Bulletin Publishing, Honolulu.

CFR (Code of Federal Regulations)

36 CFR Part 60: National Register of Historic Places. Washington, D.C.: Dept. Interior, National Park Service. Historic Sites Section, Division of State Parks Department of Land and Natural Resources.

Chinen, J.J.

1958 *The Great Mahele: Hawaii's Land Division of 1848.* Honolulu: University of Hawaii Press.

1961 *Original Land Titles in Hawaii.* Honolulu: privately published.

Cox, J.H.

1989 *Hawaiian Petroglyphs.* Honolulu: Bishop Museum Press. (With E. Stasack).

Foote, D.E., E.L. Hill, S. Nakamura, and F. Stephens

1972 Soil Survey of the Islands Kauai, Oahu, Maui, Molokai, and Lanai, State of Hawaii. U.S. Dept. Agriculture - Soil Conservation Service and University of Hawaii Agriculture Experiment Station. Government Printing Office, Washington, D.C.

Fornander, A.

1969 *An Account of the Polynesian Race: Its Origin and Migrations.* Japan: Charles E. Tuttle Company.

Green, R.C. (ed.)

1980 Makaha Before 1880 A.D. *Makaha Valley Historical Project - Summary Report* No. 5. *Pacific Anthropological Records* 31. Dept. Anthro., B.P. Bishop Museum.

Handy, E.S.C.

1940 The Hawaiian Planter: His Plants, Methods and Areas of Cultivation. *B.P. Bishop Museum Bulletin* 161. Bishop Museum Press, Honolulu.

Handy, E.S.C., E.G. Handy, with M.K. Pukui

1972 Native Planters in Old Hawaii: Their Life, Lore and Environment. *B.P. Bishop Museum Bulletin* 223. B.P. Bishop Museum Press, Honolulu.

Hommon, R.J.

1976 The Formation of Primitive States in Pre-Contact Hawaii. Ph.D. Dissertation (Anthropology), University of Arizona, Tucson. University Microfilms, Inc., Ann Arbor, Michigan.

I'i, J.P.

1959 Fragments of Hawaiian History. *Bishop Museum Special Publication* 70. Bishop Museum Press, Honolulu.

Kamakau, S.M.

1961 *Ruling Chiefs of Hawaii.* Honolulu: The Kamehameha Schools Press.

Kirch, P.V.

1985 *Feathered Gods and Fishhooks: An Introduction to Hawaiian Archaeology and Prehistory.* Honolulu: University of Hawaii Press.

Maly, K.

In prep He Mo'olelo Ka'ao no Hi'iaka-i-ka-poli-o-Pele... Translation excerpts from a legendary account of Hi'iaka's journey to Kaua'i from Hawai'i. Published in the Hawaiian newspaper *Ka Hoku o Hawai'i*; September 18, 1924 to July 17, 1928. PHRI manuscript.

In prep Kekuhaupi'o. Translation of a legendary account of Kekuhaupi'o and the History of Kamehameha I. Published in the Hawaiian newspaper *Ka Hoku o Hawai'i*; December 16, 1920 - September 11, 1924. PHRI manuscript.

McAllister, J.G.

1933 Archaeology of Oahu. *B.P. Bishop Museum Bulletin* 104. Bishop Museum Press, Honolulu. (Reprinted 1971. New York: Kraus Reprint Co.)

Soil Survey Staff

1962 Soil Survey Manual. U.S. Dept. Agriculture-Soil Conservation Service. Handbook No. 18. Government Printing Office, Washington, D.C.

Sterling, E.P., and C.C. Summers

1978 Sites of Oahu. Dept. Anthro., B.P. Bishop Museum, Honolulu.

Thrum, T.G.

1912 Kukaniloko: Birth Place of Aliis. *Hawaiian Annual and Almanac for 1912.* Honolulu: T.G. Thrum.

Walker, A.T, P.H. Rosendahl, and S. Goodfellow

1992 Archaeological Data Recovery - Phase II, Hyatt Regency Kauai Mitigation Program, Land of Paa, Koloa District, Island of Kauai. PHRI Report 472-123191. Prepared for Grove Farm Properties.

JOHN WAIHEE
GOVERNOR OF HAWAII

STATE OF HAWAII
DEPARTMENT OF LAND AND NATURAL RESOURCES
P O BOX 621
HONOLULU, HAWAII 96809

WILLIAM W. PATY, CHAIRPERSON
BOARD OF LAND AND NATURAL RESOURCES

DEPUTIES
JOHN P. KEPPELER, II
DONA L. HANAIKE

AQUACULTURE DEVELOPMENT PROGRAM
AQUATIC RESOURCES
CONSERVATION AND ENVIRONMENTAL AFFAIRS
CONSERVATION AND RESOURCES ENFORCEMENT
CONVEYANCES
FORESTRY AND WILDLIFE
HISTORIC PRESERVATION PROGRAM
LAND MANAGEMENT
STATE PARKS
WATER AND LAND DEVELOPMENT

REF:OCEA:KCK

DEC 18 1992

File No.: 93-262
DOC. ID.: 1917

RECEIVED
DEC 22 1992
HELBERT HASTERT & FEE

Ms. Gail Uyetake, Project Planner
Helbert Hastert and Fee, Planners
733 Bishop Street, Suite 2590
Honolulu, Hawaii 96813

Dear Ms. Uyetake:

Subject: Additional Comments - Environmental Impact Statement Preparation Notice (EISPN) for Wahiawa Lands Development, Wahiawa District, Oahu

Thank you for giving our Department the opportunity to review this matter. As promised in our earlier correspondence, dated December 9, 1992, the following comments are provided.

HISTORIC PRESERVATION DIVISION COMMENTS:

These lands are adjacent to State Site 50-80-04-218, Kukaniloko, which was placed on the National Register of Historic Places in 1973 and has been actively preserved for over 60 years. The State has recently acquired title to about 5 acres of land at this site and long-term preservation and interpretive display will fall to the Department of Land and Natural Resources, Division of State Parks. We note that the master plan includes an 11 acre Kukaniloko Park, and we interpret this to mean that an additional six acres of Galbraith Trust Lands will be used as a buffer between development and the 5 acre parcel managed by State Parks. We further note that development plans for the lands adjacent to the 11 acres call for a golf course and, across the road, a community park and single family residences. We believe that low-rise, low-density development is appropriate for the area surrounding this important historic site, and that there is an opportunity to make considerable improvements to the present preservation and interpretive display of the site.

We have also received an Archaeological Inventory Survey (Henry, Walker, and Rosendahl) for this project. We have responded directly to the archaeologists with some minor suggestions. We anticipate that these can be adequately addressed with small effort and that an acceptable inventory survey will result.

DIVISION OF STATE PARKS COMMENTS:

As indicated in the Preparation Notice, the project area surrounds Kukaniloko Birthstones State Park. The 5-acre park includes the site, a buffer of 100-200 feet around the stones, and an access road from Kamehameha Highway. In our previous review of the proposed Development Plan Amendment (File No. 93-149), we stated that this is an inadequate buffer and expressed several concerns regarding the development around this significant historic and cultural site:

- Adequate buffers and development setbacks to maintain the historical and cultural setting of the site.
- Low-rise development to maintain the visual corridors around the historic site.
- Access route to the park site that will provide an adequate setback for the roadway and parking lot at the park site.
- Insure public access to the site while considering potential security measures to assist in site management and preservation.

We believe that the applicant is making an concerted effort to address these concerns by setting aside an additional 6 acres for the historic park and by proposing a golf course, park, and low-rise housing in the area surrounding the historic site. Galbraith Trust has not discussed the details regarding the additional 6 acres for the park with State Parks and therefore, we are uncertain if this will be a donation, a management agreement, or if the State is expected to purchase the additional acreage. As we initiate our research and planning for Kukaniloko Birthstones State Park, we encourage the applicant to continue discussions and consultation regarding the site as indicated in Section II-3 of the document.

Thank you for your cooperation in this matter. Please feel free to contact Sam Lemmo at our Office of Conservation and Environmental Affairs, at 587-0377, should you have any questions.

Very truly yours,

John P. Keppeler II

WILLIAM W. PATY

JOHN WAIHEE
GOVERNOR OF HAWAII

STATE OF HAWAII
DEPARTMENT OF LAND AND NATURAL RESOURCES
STATE HISTORIC PRESERVATION DIVISION
33 SOUTH KING STREET, 6TH FLOOR
HONOLULU, HAWAII 96813

\# 1260

LOG NO: 7002
DOC NO: 9212TD07

December 7, 1992

Dr. Paul H. Rosendahl
Paul H. Rosendahl, Ph.D., Inc.
305 Mohouli Street
Hilo, Hawaii 96720

Dear Dr. Rosendahl:

SUBJECT: Review of Archaeological Inventory Survey,
Galbraith Trust Lands (Henry, Walker, Rosendahl)
Wahiawa, O'ahu
TMK: 7-1-1: 5-8, 25, 26, 31, 32, por. 11, por. 29, por. 30

Thank you for the opportunity to review this draft report. Most of the project area has been used for pineapple cultivation; small uncultivated areas are found along Wahiawa Reservoir and Tunnel Stream Gulch and along Poamoho Stream Gulch. The cultivated areas were inventoried with the aid of a helicopter; no previously unrecorded historic sites were found. The uncultivated areas were subjected to pedestrian survey; a single historic site, variously identified in this report as site 4571 and 1260-1 was found at Poamoho Stream Gulch. Site 50-80-04-1605, whose rudimentary description, tentative functional interpretation, and approximate location were reported to our office in 1987, was not reidentified within the project area. We believe that this site is either no longer extant or is not located within the project boundaries. Therefore, we believe that survey techniques were sufficient to identify all historic sites within the project boundaries, totalling one historic site.

Before we evaluate the significance of the site found, there are some minor errors and inconsistencies that need to be corrected to clarify the description of the site. The site number for 50-80-04(?)-4571 needs to be consistent throughout the report. The description of this site is confusing as it stands. The wall is said to extend from the stream bed to the top of the bank--a distance of 2.5 meters. But the intact portion of the wall is 3.0 meters long, and its original length is said to be 10.5 meters. Is the wall not straight? Also, the wall is described as located on the north bank of Poamoho Stream, but the Figure 1 map clearly shows the site on the south bank of the stream. The wall orientation is described as E-W, which would seem to indicate that it parallels the stream. Please review this descriptive section carefully for consistency. Also, a bit of discussion about site function would be helpful.

We recognize that the functional associations of isolated wall segments are difficult to determine; some discussion would convince us that the various alternatives have been considered.

There is an error in the transcription of the second extended quote from McAllister on page 8, which is found on page 134, not 136. Also, Saifuku did not report his findings to Tom Dye, since Dye did not work at this office in 1987. We would also appreciate a list of the tax map parcels in the description of the survey area.

If you have any questions please call Tom Dye at 587-0014.

Sincerely,

DON HIBBARD, Administrator
State Historic Preservation Division

TD:amk

PHRI
Paul H. Rosendahl, Ph.D., Inc.
Archaeological • Historical • Cultural Resource Management Studies & Services
305 Mohouli Street • Hilo, Hawaii 96720 • (808) 969-1763 • FAX (808) 961-6998
P.O. Box 23305 • G.M.F., Guam 96921 • (671) 472-3117 • FAX (671) 472-3131

Letter 1260-010893

January 8, 1993

Ms. Gail Uyetake
Helber, Hastert & Fee
Grosvenor Center, PRI Tower
733 Bishop Street, Suite 2590
Honolulu, Hawaii 96813

Subject: Archaeological Inventory Survey
Galbraith Trust Lands
Lands of Kamananui and Wahiawa
Waialua and Wahiawa Districts, Island of Oahu

Dear Ms. Uyetake:

The purpose of this letter is to address potential adverse impacts to State Site 50-80-04-218 (Kukaniloko) and appropriate treatment for lands surrounding the site. As we understand it, the State of Hawaii has acquired the five acres of land at this site and thus long-term preservation and interpretive display for the site will be the responsibility of the Department of Land and Natural Resources, Division of State Parks (DLNR-DSP). It is also our understanding that Galbraith Trust will set aside an additional six acres surrounding the Kukaniloko site which would act as an additional preservation buffer and would also provide an opportunity to improve the interpretation of the site.

In our opinion, the six-acre additional preservation buffer is appropriate treatment of the area immediately surrounding the Kukaniloko site. Because the State-owned five-acre Kukaniloko site will be surrounded by an additional six-acre buffer, no direct adverse impact to the site is anticipated. With regard to recommended treatment of the land surrounding the site and buffer area, a development concept proposing the six-acre buffer for open space and the surrounding area for other open-space uses (park, golf course) or low-rise, low-density residential housing, would be appropriate.

If you have any questions, please call me at our Hilo office (808-969-1763).

Sincerely yours,

Paul H. Rosendahl, Ph.D.
President and Principal
Archaeologist

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January 12, 1993
92-1260

Dr. Tom Dye
Department of Land & Natural Resources
State Historic Preservation Division
33 South King St., 6th Floor
Honolulu, Hawaii 96813

Subject: Revised Pages for PHRI
Final Report (Pending DLNR-SHPD Approval)
Galbraith Trust Lands
Lands of Kamananui and Wahiawa
Waialua and Wahiawa Districts
Island of Oahu

Dear Dr. Dye:

Enclosed are six revised pages (pages 2,8,18,25,26 & 34) for PHRI Final Report No. 1260-080192, for the above project. The revisions are in response to a DLNR review letter dated December 7, 1992.

If you have any questions or comments please contact me at our main office in Hilo (808) 969-1763.

Sincerely yours,

Paul H. Rosendahl Ph.D.
President and Principal
Archaeologist

/pno

Encls.: Revised pages 2,8,18,25,26 & 34 of PHRI Final Report #1260-080192

cc: Mr. Thomas Fee, Helber Hastert & Fee (w/encl.- three copies)

JOHN WAIHEE
GOVERNOR OF HAWAII

STATE OF HAWAII

DEPARTMENT OF LAND AND NATURAL RESOURCES

STATE HISTORIC PRESERVATION DIVISION
33 SOUTH KING STREET, 6TH FLOOR
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HISTORIC PRESERVATION DIVISION
LAND MANAGEMENT
STATE PARKS
WATER AND LAND DEVELOPMENT

February 5, 1993

LOG NO: 7439
DOC NO: 9302TD09

Paul H. Rosendahl
Paul H. Rosendahl, Ph.D., Inc.
305 Mohouli Street
Hilo, Hawaii 96720

Dear Dr. Rosendahl:

SUBJECT: Review of Revisions to Archaeological Inventory Survey, Galbraith Trust Lands (Henry, Walker, Rosendahl)
Wahiawa, O'ahu
TMK: 7-1-1: 5-8, 25, 26, 31, 32, por. 11, por. 29, por. 30

Thank you for the opportunity to review the revisions to this report. The description of site 4571 still needs some clarification. Is this a free-standing wall, or does it face the stream bank? If the latter, the term retaining wall might be appropriate. Does the statement "the intact portion of the wall extends from the stream bed up to the top of the bank" refer to the base and top of a retaining wall, rather than describing two ends of a free-standing wall? If the former, then the parenthetical "north-south" is confusing. If the latter, then the statement that "the wall is about 3.0 m long (E-W)" appears to be contradictory. Figure 12 is also confusing. Does the drop-off in the ground surface at the right hand side of the page indicate that the stream runs there, or does the stream run across the page? If the latter, then what does the drop-off represent? If the former, then the wall is more than a single course wide. The meaning of the lower bold line that runs above the label "STREAM BED" is unclear Also, if the wall is on the south bank of the stream, to what does the label "NORTH FACE" at the top of the figure refer. Please review this descriptive section carefully once again for consistency.

Also, please note on page 11 that Saifuku did not report his findings to Tom Dye, since Dye did not work at this office in 1987.

If you have any questions please call Tom Dye at 587-0014.

Sincerely,

DON HIBBARD, Administrator
State Historic Preservation Division

TD:amk

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February 16, 1993
92-1260

Mr. Tom Dye
Department of Land & Natural Resources
State Historic Preservation Division
33 South King St., 6th Floor
Honolulu, Hawaii 96813

Subject: Final Report (pending DLNR-SHPD approval)
Archaeological Inventory Survey
Galbraith Trust Lands
Waialua and Wahiawa Districts
Island of Oahu

Dear Mr. Dye:

Enclosed are six revised pages (pages iv, 3, 18, 11, 25, & 34) for PHRI Final Report No. 1260-080192, for the above project. These revisions are in response to a DLNR review letter dated 5 February 1993; specifically the description for Site 4571 has been revised and given a definite function.

If you have any questions or comments, please contact me at our main office in Hilo (808) 969-1763.

Sincerely yours,

Paul H. Rosendahl, Ph.D.
President and Principal
Archaeologist

/bjm

Encls.: Revised pages iv, 3, 11, 18, 25, & 34 for
PHRI Report No. 1260-080192

cc: Mr. Thomas Fee, HH&F (w/encls.- three copies)

PHRI
Paul H. Rosendahl, Ph.D., Inc.
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February 22, 1993
92-1260

Mr. Thomas Fee
Helber Hastert & Fee
Grosvenor Center, PRI Tower
733 Bishop St., Suite 2590
Honolulu, Hawaii 96813

Subject: Final Report (pending DLNR-SHPD approval)
Archaeological Inventory Survey
Galbraith Trust Lands
Lands of Kaamanui and Wahiawa
Waialua and Wahiawa Districts, Island of Oahu

Dear Mr. Fee:

Enclosed are three copies, two bound and one camera ready of page 18, for PHRI Report No. 1260-080192 for the above project.

If you have any questions or comments please contact me at our main office in Hilo (808) 969-1763.

Sincerely yours,

Paul H. Rosendahl, Ph.D.
President and Principal
Archaeologist

/bjm

Encls.: Revised page 18 for PHRI Report No. 1260-080192 (three copies)

cc: Mr. Tom Dye, DLNR-SHPD (one copy)

PHRI
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March 11, 1993
92-1260

RECEIVED
13
HELBER HASTERT & FEE
PLANNERS

Dr. Tom Dye
Department of Land & Natural Resources
State Historic Preservation Division
P.O. Box 621
Honolulu, Hawaii 96809

Subject: Final Report (pending DLNR-SHPD approval)
Archaeological Inventory Survey
Galbraith Trust Lands
Waialua and Wahiawa Districts
Island of Oahu

Dear Dr. Dye:

Enclosed is revised page 3 of PHRI Final Report No. 1260-080192, for the above project.

If you have any questions or comments, please contact me at our main office in Hilo (808) 969-1763.

Sincerely yours,

Paul H. Rosendahl, Ph.D.
President and Principal
Archaeologist

/bjm

Encls.: Revised page 3 of PHRI Final Report No. 1260-080192 (one copy)

✓cc: Mr. Tom Fee, HH&F (w/encls. three copies)

APPENDIX H

Socio-Economic Impact Assesssment
Community Resources, Inc.

SOCIO-ECONOMIC IMPACT ASSESSMENT OF WAHIAWA LANDS, GALBRAITH TRUST ESTATE

December 1992

FINAL REPORT

Prepared for:
Hawaiian Trust Company
Helber, Hastert & Fee, Planners

Prepared by:
Community Resources, Inc.

EXECUTIVE SUMMARY

The Galbraith Trust is requesting a Development Plan Amendment for about 900 acres of its land bordering Wahiawa. If permits are granted, most of the acreage would be used for a mixed-use project. At build-out, the project would include some 3,100 housing units, sites for a business center and light industrial park, other commercial uses, civic uses (including schools), a golf course, and other recreation areas. The project would take 15 to 20 years to build out.

This report deals with social and economic impacts of the proposed development. Attention focuses mainly on the surrounding communities (Wahiawa, Whitmore Village, Poamoho Camp, Schofield Barracks, and Wheeler Field). When appropriate, the entire Central Oahu Development Plan area and nearby North Shore towns are considered.

EXISTING AND LIKELY FUTURE CONDITIONS. The nearby communities have seen relatively little change in recent years. In contrast, residential and commercial developments have transformed the leeward side of Central Oahu. Pressure for further urban development is strong in the DP area. With job growth slower than residential development, residents are increasingly likely to commute long distances.

The economic bases of study area communities -- plantation agriculture and military operations -- seem stable, but their future depends on national and international factors outside local control.

IMPACT ANALYSIS: GENERAL CONSIDERATIONS. The Wahiawa Lands project would provide sites for residential and commercial expansion likely to occur on Oahu with or without the project. It would not attract new capital from outside Hawaii. Hence the project is, in relation to the State and County economies, a consequence of other developments generating jobs (e.g., statewide tourism growth), rather than a source of new economic impacts. Its impacts have above all to do with the location of new homes and operations on the site, and inclusion of project components in a single planned development.

Impacts of locating growth on the project site could be more significant for nearby communities, and far smaller for the region, island, and State. (This assumes that agricultural impacts of the project are minimal, and that demand for housing and commercial space will exceed the supply now planned and permitted, as shown in other technical studies for the project.)

ECONOMIC AND DEMOGRAPHIC ASPECTS OF THE PROJECT. Employment, income, population, housing, and fiscal implications of the project are estimated in the report.

Project construction is projected as beginning in 1996. Construction activities would continue steadily, and then taper off after 2005. On average, project construction would support about 250 full-time direct jobs annually from 1996 to 2010. Of these, about 200 would be on site. Construction spending would support an annual average of about 530 indirect and induced jobs in Hawaii as well between 1996 and 2010.

Operations located on the project site could employ over 1,200 persons by 2000, and 3,400 by 2010. Anticipated operations would employ people in a wide range of permanent white- and blue-collar jobs. Indirect and induced jobs Statewide associated with those operations would total over 3,000 jobs by 2010.

Direct construction workers would earn over $10 million annually between 1996 and 2010 (in 1992 dollars). Incomes of direct operations workers would climb from about $8 million in 1998, to reach $76 million by 2010. The total wages of direct, indirect, and induced workers associated with both construction and operations would amount to $155 million in 2010.

A mix of single-family, medium density, and multi-family units is planned for the project. Some 60% would be affordable. Housing for the elderly would be included. The project could house nearly 2,000 persons by 2000. The resident population would climb to over 8,000 by 2010.

The project's mix of elements minimizes the chance that new jobs would affect existing residential areas. Over time, much of the workforce associated with operations at the project site -- including many induced and indirect workers -- would likely live or seek housing in the Central Oahu/North Shore region. This regional workforce is estimated as supporting a population of nearly 7,700 persons (including workers) by 2010 in some 2,500 households. New demand from that workforce for additional housing in the region would depend on housing prices and availability. Workers could come to occupy some 400 to 750 additional units.

The regional demand for housing from the project-related workforce matches the new housing development included in the project. The on-site occupied housing stock would exceed the number of regional workforce households by some 350 units as of 2005. If workforce households and new demand are combined -- counting both workers' family homes and new households they form -- total regional demand would reach 2,900 to 3,300 units. Project workers are likely to live in many communities in the region, not just on the site. The balance between workforce demand and on-site housing stock means that workers moving into the area would not appreciably affect demand for existing housing (and hence crowding and prices).

De facto population -- the population on the site at any given time, including residents, workers, and customers -- is estimated as reaching high points of 7,900 to 8,500 persons on different days of the week.

Fiscal impacts involve the costs and revenues associated with meeting demand for housing and commercial space in a new planned community, rather than through accelerated buildout of other communities and through infill in older areas. Costs associated with those impacts are expected to occur during the construction phase, but not afterwards.

Over the period 1996-2010, the balance of revenues over costs associated with the project is positive for both the City and County of Honolulu and the State. The cumulative balance is estimated as about $13 million for the City and County and $7 million for the State, in 1992 dollars.

COMPATIBILITY WITH NEARBY COMMUNITIES. The project has been conceptualized by its planners as complementing the adjacent civilian community of Wahiawa (including Whitmore Village). Analysis of community responses suggests that both opportunities for "fit" with the Wahiawa community and also potential problems of "fit" exist.

Opportunities for "fit" include nearby jobs for Wahiawa residents, both a larger and a more diverse housing stock, a wider range of retail outlets, and enhanced recreation resources. These would enable the community to grow. Businesses at the project site would diversify the local economy. The existing trend for residents to commute outside the region for work would be countered. The project could help Wahiawa, rather than Mililani, be seen as the regional center.

From one perspective, all these changes amount to an opportunity to revitalize an aging, vulnerable community. However, many Wahiawa residents see these changes as unneeded or risky. They are concerned that the project could jeopardize the local pineapple industry.

Problems of fit could follow from (a) the size of the project, in relation to Wahiawa residents' sense of their community as a small town; and (b) the possibility that new areas would overshadow existing sections of Wahiawa and compete with existing businesses. Also, many residents are concerned that the project would result in a loss of agricultural or rural identity for Wahiawa, by displacing pineapple cultivation from the project site. Project design decisions will clearly be crucial if the project is to have a "country" atmosphere compatible with Wahiawa, not a "suburban" one.

The project's potential compatibility with Poamoho Camp and Schofield Barracks is overshadowed by other issues. Major land use decisions of concern to people in those communities are outside the scope of the present project and depend largely on other parties, not the Galbraith Trust.

SOCIAL IMPACTS. Many of the most important concerns of residents -- notably the impact of the project on agriculture, traffic impacts, water supply and means of waste disposal -- are addressed in other reports. This report focuses on the social consequences of development:

- As previously noted, the project's combination of job sites and housing offers a chance for Wahiawa to be a regional center, reducing commuting distances for the workforce;
- Additional affordable housing stock and shorter commutes tend to help reduce personal stress and family problems for residents and workers;
- The project's impact on existing commercial areas of Wahiawa is not certain, but could be limited through continuing consultation and planning of project commercial areas;
- The project would integrate Whitmore Village into a greater Wahiawa;
- Recreation and public facilities sites within the project could lower crowding in nearby areas, at least until the project is built out;
- However, during the construction period (until 2010), construction noise, dust, and traffic will be irritants for some nearby residents.

MITIGATIONS. The project plans sketch out a community that would avoid adding Central Oahu's problems of traffic congestion and suburban sprawl. Further planning and consultation can help to make the project respond to local needs and concerns, notably:

- Continuing community consultation, (1) with the general aim of gaining local input, to insure that project design helps Wahiawa residents judge the project as part of their community, and (2) to meet specific goals, above all to ensure that competition from project businesses does not endanger existing commercial areas;
- Development of design concepts and standards that underline the provision of open space in the project and help the project function and be perceived as part of a country town, not a bedroom community; and

- Further development of plans to encourage residents not to drive their cars on short trips, such as development of a community transport system (using small vans or busses).

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1.0 INTRODUCTION

1.1 PROPOSED DEVELOPMENT ON GALBRAITH ESTATE WAHIAWA LANDS

The Galbraith Trust is proposing a Development Plan (DP) Amendment on about 900 acres of its land in Central Oahu, north of Wahiawa. (See Exhibit 1-A for location of the project site. Exhibit 1-B shows the site in relation to the other lands held by the Trust.)

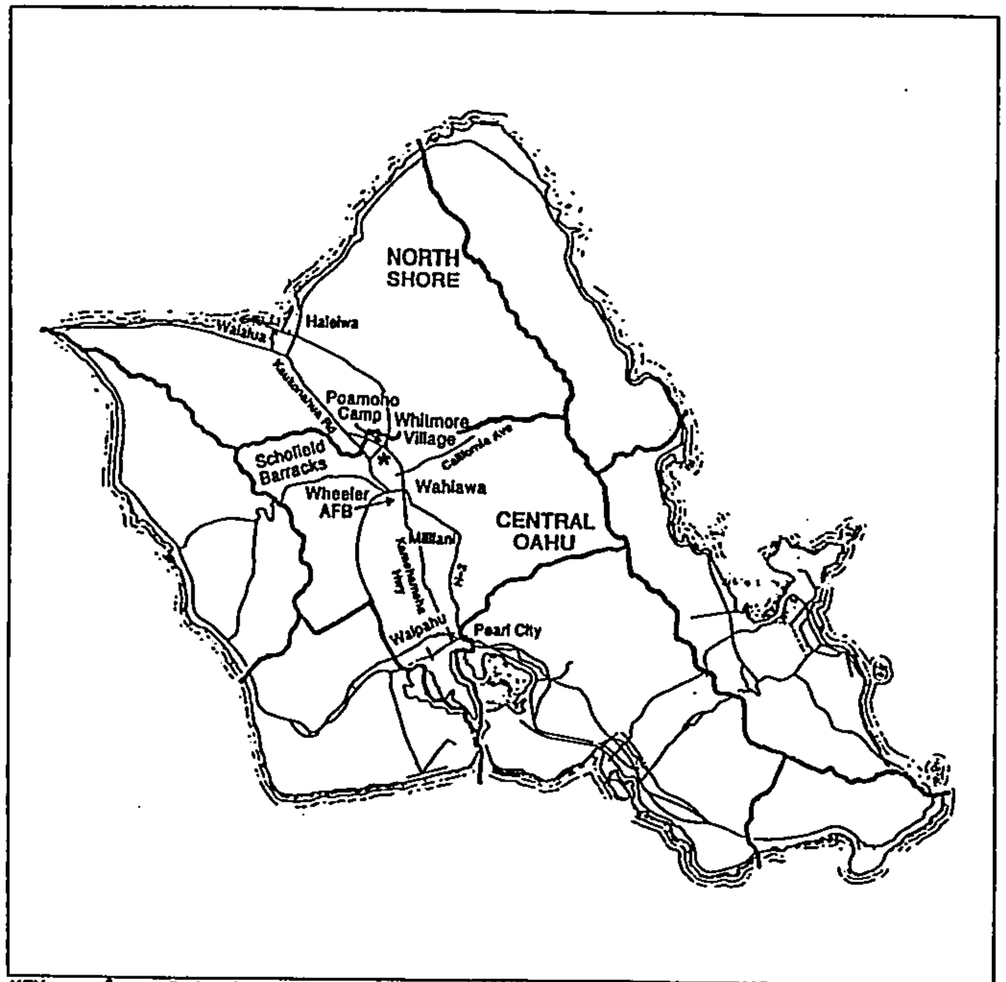
The Galbraith Trust consists of the estate of George Galbraith, who farmed and ranched in Central Oahu in the late nineteenth century. The estate is organized as a trust under the administration of Hawaiian Trust Company. Under terms of the will, the Galbraith Trust will be dissolved in 2007. Officials of the trust (like the trustees of the better known Campbell Estate) are empowered under Hawaii State law to enter into development agreements on behalf of the Trust that run beyond 2007.

The Galbraith Trust owns about 2,200 acres in Central Oahu that are now largely used for pineapple cultivation. Leases on the Trust's agricultural land -- held by Del Monte Fresh Produce (Hawaii) Inc. -- end in 1994. Current plans call for renewal of pineapple leases on most of the Trust's land. The Trust also owns part of Wahiawa itself, including the Wahiawa Industrial Center.

The current draft plan was developed on the basis of studies and discussions with members of the community. The proposed development could be built over some 15 to 20 years. It would included:

- Single family residential areas covering about 250 acres. Nearly 1,500 homes would eventually be built. Both affordable and market units would be included. Some of these, near Schofield Barracks, might be developed as military family housing under a lease arrangement.
- Other residential areas, with duplexes, multifamily housing, and some housing for the elderly. About 1,500 units would be in these areas. Nearly all would be affordable housing units.
- A community "core" of about 12 acres dedicated to a mix of uses. Elderly housing and health care facilities could be located in this area, as well as commercial uses. Both business and civic areas would be nearby, along with some of the housing listed above.

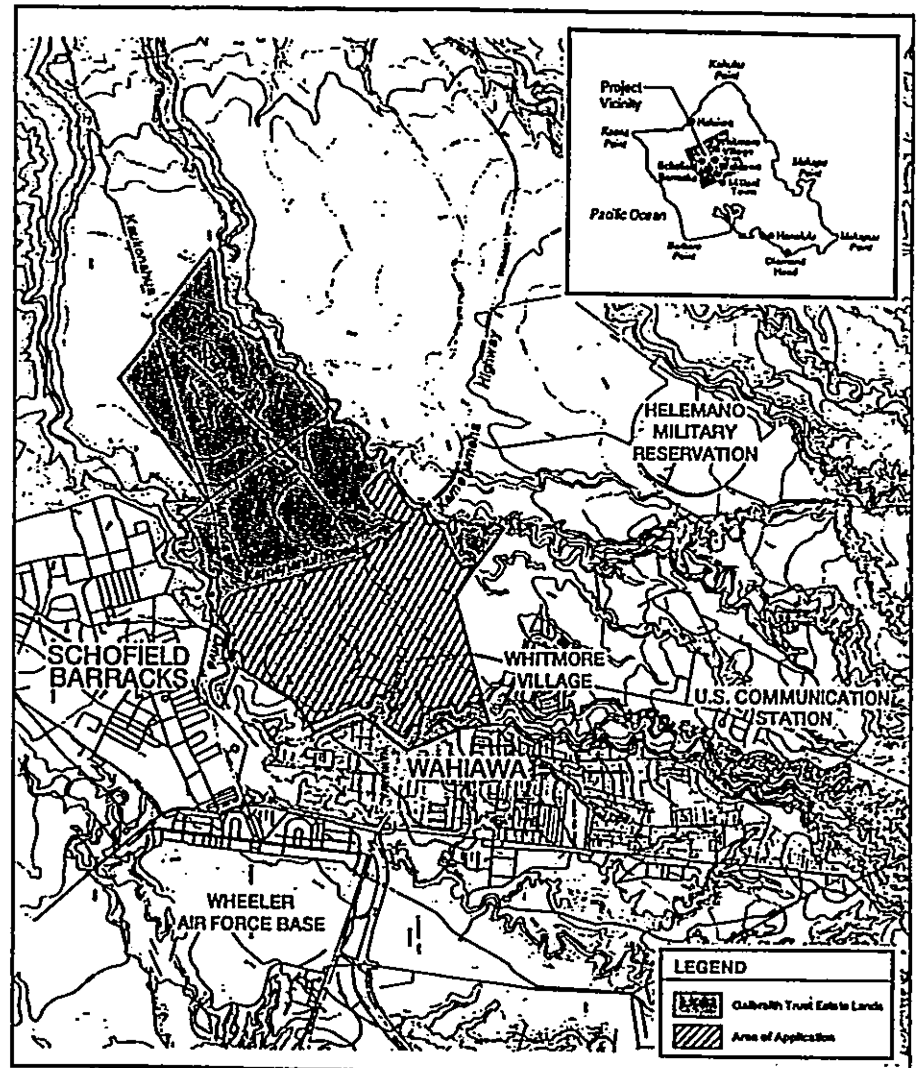
EXHIBIT 1-A: LOCATION MAP



KEY:
- * Project Site
- Wahiawa Study area community
- Mililani Major nearby community
- H-2 Major road

SOURCE: Adapted from Honolulu City & County Department of General Planning, 1990.

EXHIBIT 1-B: PROJECT AREA



SOURCE: Helber, Hastert & Fee, 1992.

- A mix of commercial areas, including both retail sites and areas where back office and health care employment are expected to develop.
- A light commercial/industrial area, across the reservoir from the existing Wahiawa Industrial Center.
- Parks, including a community park with ball fields, neighborhood parks, and a lakefront park along Lake Wilson.
- Park land buffering the State's land at the Wahiawa Birthing Stones (Kukaniloko) site. (Hawaiian alii women gave birth there, with the aim of ensuring high rank for their children. The State recently acquired a five-acre parcel including the Birthing Stones.)
- A public golf course. This could be a municipal course or a privately owned course open to the public for rates tied to municipal rates.

Exhibit 1-C is a conceptual project plan. A preliminary development schedule is shown in Exhibit 1-D.

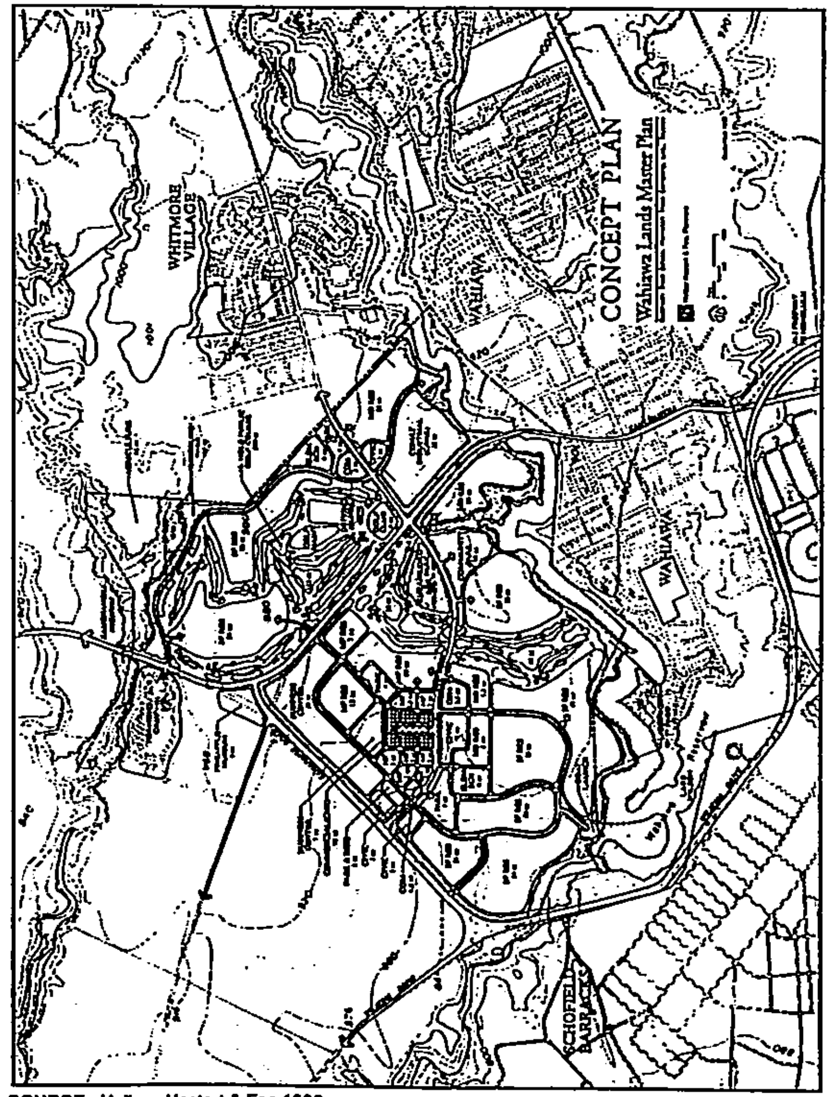
The planned development includes broad design features worth noting:

- It combines housing and sites for various sorts of employment, so that many residents could, in time, live near their place of work;
- The "core" would be designed to encourage people to walk from their homes to nearby facilities, lowering dependence on automobiles; and
- In the planning process, the development has been viewed as a means of expanding and improving the existing town of Wahiawa, rather than as a separate project unrelated to the surrounding context.

In order to support pineapple operations and workers, the Trust would assist Del Monte in locating alternate fields to use in place of the project site, and provide a site for a Pineapple Museum near the existing "Pineapple Triangle."

The DP application covers about 32 acres under Poamoho Camp, in addition to the project site for the proposed mixed-use community. No development is proposed for Poamoho Camp. The Amendment (from Agricultural to Residential) would only make the DP designation of land under the Camp conform with its actual use.

EXHIBIT 1-C: CONCEPT PLAN



SOURCE: Helber, Hastert & Fee 1992.

EXHIBIT 1-D: PROJECT COMPONENTS AND PROVISIONAL TIMETABLE

	Units	Acreage	Possible Timing of Development (1) BEGIN	END
RESIDENTIAL				
Market Single Family	1,236	217	1997	2009
Affordable Single Family	246	30	1998	2003
Medium Density	660	66	1998	2003
Multifamily (2)	958	54	1996	2006
COMMERCIAL				
Convenience Store Areas		10	1998	2006
Mixed Use "Core" (2)		12	1998	2008
Business Center		38	1999	2010
Light Industrial		33	1999	2009
OTHER				
Public Schools		12	1997	2004
Civic Areas, Park & Ride		19	2000	2010
Pineapple Museum		6	2000	2000
Public Golf Course		200	1998	1999
Clubhouse		4	1999	1999
Community Park		31	2000	2000
Lakefront and Ridge Parks		59	1997	2000
Kukaniloko Reserve (3)		11	N/A	N/A
Poamoho Camp (3)		32	N/A	N/A
MAJOR INFRASTRUCTURAL IMPROVEMENTS			1996	2005

NOTES: (1) Timetable developed by Community Resources, Inc., based on consultation with project planners and market consultants. These assumptions were used in developing the estimates shown in Chapter 4 of this report. These are provisional; actual timetables will depend on detailed planning and engineering analyses now under way.
(2) The "core" will contain multifamily housing as well as commercial uses. The housing units in the core area are counted under "Multifamily" in the residential category. However, the "core" acreage is only listed under "commercial" to avoid double-counting.
(3) No development is planned for these areas.

1.2 PURPOSE AND SCOPE OF THIS REPORT

This report deals with socio-economic impacts of the proposed development of the Galbraith Estate's Wahiawa Lands. It assesses such impacts in the context of existing conditions and likely future trends in the area surrounding the project.

This report is intended to serve as an appendix to an Environmental Impact Statement (EIS) for the project. It has been prepared for Helber, Hastert & Fee, the project planners, and for Hawaiian Trust, acting on behalf of the Galbraith Trust.

The report is written to identify and disclose information of use to members of the general public and to decision makers as they evaluate the implications of the project. Discussions of the likely points of compatibility of the project with surrounding land uses, of potential impacts, and of steps that might mitigate unwanted impacts are intended to help in community planning both in the EIS process and afterwards.

Chapters of the report deal with:

- Introductory topics;
- Existing conditions in the area surrounding the project;
- Forces for change shaping the future of the region and nearby communities;
- Quantifiable socio-economic impacts (employment, income, population, housing, and fiscal impacts);
- Questions of "fit" between the project and surrounding communities;
- Qualitative social impacts on surrounding communities and the Central Oahu region; and
- Mitigation measures that could be taken to minimize unwanted impacts.

1.3 DEFINITION OF STUDY AREA

The project is located in the Central Oahu Development Plan (DP) Area. Its social impacts are expected to be largely concentrated in the nearby communities of Wahiawa, Whitmore Village, Schofield Barracks, and Poamoho Camp. These communities, along with Wheeler Army Airfield, are treated as the study area for the purposes of this report. (All of these, except Poamoho Camp, are identified by the U.S. Census as Census Designated Places [CDPs]. The Census identifies Wheeler Field as an Air Force Base.

(Since 1990, Wheeler Field, including the Navy's Camp Stover housing area, has been turned over to the Army for administrative purposes.)

The study area communities include about 33% of the population of the Central Oahu DP Area.

The study area is the zone most immediately affected by the project, but project impacts extend beyond it. Population impacts affect both nearby communities and the prospects for other developments in the Development Plan area. Employment impacts extend throughout the island. The project affects both County and State revenues.

Potential employees of project businesses and customers in project stores would likely come from communities in Central Oahu (such as Mililani) and the North Shore (notably the Army's Helemano Housing Area, Waialua, and Haleiwa) as well as the study area. Residents of the entire North Shore and even Kahuku, in the Koolauloa DP Area, travel often through the project site and would likely be affected by changes in roadways and traffic.

2.0 EXISTING CONDITIONS

The study area is located in the center of Oahu, on the high-elevation Leilehua plateau that stretches north to south between the Waianae and Koolau mountains. The topography is characterized by deep ravines and gulches which drain both mountain ranges. Rainfall is frequent -- about half the days in any given month experience rain -- but temperatures cooler than the coastal flats help compensate for the rain-induced humidity (Koebig & Koebig, 1975).

Lake Wilson (colloquially known as Wahiawa Reservoir) is the most important water feature in the area. As the largest body of freshwater in the State, Lake Wilson is heavily fished by local anglers (Koebig & Koebig, 1975).

2.1 HISTORICAL BACKGROUND

In pre-contact times, the study area's importance derived mainly from the Kukaniloko birthing stones (see Exhibit 1-C). High-ranking alii women and their entourages would journey from locations throughout Hawaii to give birth at this spiritually significant site.

Tradition has it that two sacred drums, transported with the original Polynesian migrations to Hawaii, were housed in a heiau in the general vicinity. While neither the heiau nor other structures survive today, a number of stones surrounded by a grove of eucalyptus trees mark the Kukaniloko site.

The region was also important due to an ancient school located within the lands now occupied by Schofield Barracks. This school trained young Hawaiian men in the arts of warfare (Nedbalek, 1984).

During the late nineteenth century, Waianae Uka (on the western side of what is now known as Lake Wilson) included King Kalakaua's hunting reserve, Leilehua Ranch. The 20,000-acre ranch was bought by James Dowsett in an 1887 auction of royal lands. However, the entire property was declared a military reservation shortly after Hawaii's annexation by the United States. The area was eventually renamed Schofield Barracks.

The first contingent of troops to arrive at Schofield came in 1909. World War One increased the number of units garrisoned at the base. By 1921, the base's commands were consolidated under the taro leaf insignia of the Hawaiian Division.

After the 1941 Japanese attack on Pearl Harbor (in which the airfield at Wheeler suffered attack), Schofield became the focal point for Pacific-deployed American troops. The Schofield base population sometimes swelled above 100,000 during the war. This rapid population boom helped local businesses to develop and flourish.

Wahiawa Town itself was settled at the end of the nineteenth century by a group of Californians led by the homesteader Byron Clark. The settlers formed the Hawaiian Fruit and Plant Company. Transportation of supplies and produce to and from the railway junction at Pearl City posed a major hurdle for the pioneers. The lack of irrigation for the various crops they grew was equally problematic.

Pineapple was destined to become the major crop in the region as the problems of transportation and irrigation were resolved. The year 1902 saw the Wahiawa Water Company's first irrigation project to the Wahiawa fields, followed a year later by the completion of James Dole's cannery on California Avenue. Business expanded to the point that Dole decided to build a cannery at Iwilei, near the Honolulu port. This new structure's opening coincided with the 1907 opening of the railroad's Wahiawa branch.

After having grown pineapple for Dole's cannery, Alfred Eames began operation of his Cane Street cannery in 1906 under the name Hawaiian Islands Packing Company. This marked the beginning of the Del Monte pineapple operations.

As pineapple prospered during the early part of the century, a number of isolated outlying camps sprung up to house field workers. Of these, only Whitmore, Poamoho, Kunia, and Waipio have survived as settlements. When the Depression caused a slump in the pineapple market, Dole was forced to sell shares in his business. By 1932, Castle and Cooke owned 50% of the Dole Hawaiian Pineapple Company. Dole himself was sworn in as the revamped company's chairman.

2.2 REGIONAL TRENDS

Post-World War Two population growth in Central Oahu has outpaced the island as a whole (see Exhibit 2-A). In fact, Central Oahu is one of the fastest expanding regions on island. Most of the growth is attributable to suburban development of lands from Mililani to Waipahu. As plantation agriculture in these areas declined (pineapple in Mililani and sugar in Waipahu), more land opened up for residential development. Similarly, the Ewa plain has seen a considerable amount of plantation converted to housing. Most workers in these towns commute.

On the other side of the study area, the North Shore is one of the fasting growing region on Oahu, even though it is designated as a low-growth, rural area. Sunset Beach and, more recently, Helemano have been rapid developing North Shore communities.

EXHIBIT 2-A: POPULATION TRENDS, 1940–1990

AREA POPULATION	1940	1950	1960	1970	1980	1990
HONOLULU COUNTY	258,256	353,020	500,409	630,528	762,565	836,231
CENTRAL OAHU DP AREA (1)	31,912	29,629	47,969	66,228	100,953	130,698
Wahiawa	N/A	8,369	15,512	17,598	16,911	17,386
Whitmore Village	N/A	N/A	1,820	2,015	2,318	3,373
Poamoho Camp (2)	N/A	N/A	N/A	N/A	368	282
Schofield Barracks	N/A	N/A	14,873	13,516	16,851	19,597
Wheeler Field (3)	N/A	N/A	N/A	N/A	N/A	2,600
NORTH SHORE DP AREA (4)	N/A	N/A	N/A	N/A	13,061	15,660

AVERAGE ANNUAL GROWTH	1940–50	1950–60	1960–70	1970–80	1980–90
HONOLULU COUNTY	3.2%	3.6%	2.3%	1.9%	0.9%
CENTRAL OAHU DP AREA (1)	-0.7%	4.9%	3.3%	4.3%	2.6%
Wahiawa	N/A	6.4%	1.3%	-0.4%	0.3%
Whitmore Village	N/A	N/A	1.0%	1.4%	3.6%
Poamoho Camp (2)	N/A	N/A	N/A	N/A	-2.6%
Schofield Barracks	N/A	N/A	-1.0%	3.4%	0.4%
Wheeler Field (3)	N/A	N/A	N/A	N/A	N/A
NORTH SHORE DP AREA (4)	N/A	N/A	N/A	N/A	1.8%

NOTES: N/A Data not available.

(1) Actual DP (Development Plan) area population stood at 130,500 in 1990. To trace historical patterns, the DP area is approximated here in terms of the following component 1990 census tracts: 82, 87.01, 87.02, 87.98, 88, 89.01, 89.04, 89.05, 89.06, 89.07, 89.08, 89.09, 89.10, 89.11, 89.12, 90, 91, 92, 93, 94, 95.01, 95.02, 95.03, 95.04, and 95.05. Census tract designations often change radically each census year -- for example, this same area is coterminous with 1940 Census Tracts 36, 37, and 40.

(2) Coterminous with Block Group 2 of Census Tract 91.

(3) Previously known as Wheeler Air Force Base (AFB).

(4) In 1990, approximately equivalent to the North Shore Census Division plus Pupukea CDP (Census Designated Place).

SOURCES: U.S. Bureau of the Census, 1991a, 1983a, 1983b, 1981a, 1962, 1952a, 1952b, 1943; Hawaii State DPED, 1973; Honolulu City & County, 1992, 1989.

2.3 STUDY AREA COMMUNITIES

The communities in the study area can be divided into civilian communities (Wahiawa, Whitmore Village, and Poamoho Camp) and military bases (Schofield Barracks and Wheeler Field). The study area as a whole has experienced much slower growth than the rest of Central Oahu/North Shore region, and often has sometimes seen negative growth rates. As the major community in the study area, Wahiawa's population has been in decline for a number of decades and has only recently shown an increase (as graphed in Exhibit 2-B).

Study area settlements remain fairly distinct, despite their proximity to each other. Near the end of the H-2 freeway, Wahiawa lies on the fringe of the Oahu urban zone; Whitmore Village is a mix of well-maintained plantation homes and new high density single-family units; and Poamoho remains a self-contained but viable plantation community. All of these communities, along with Schofield Barracks, border the project site.

Schofield and Wheeler together form a sizable hub of shops, houses, barracks, and administrative buildings along Wilikina Drive. Schofield's training grounds (primarily the East Range) are extensive and stretch towards both the Waianae and Koolau mountains.

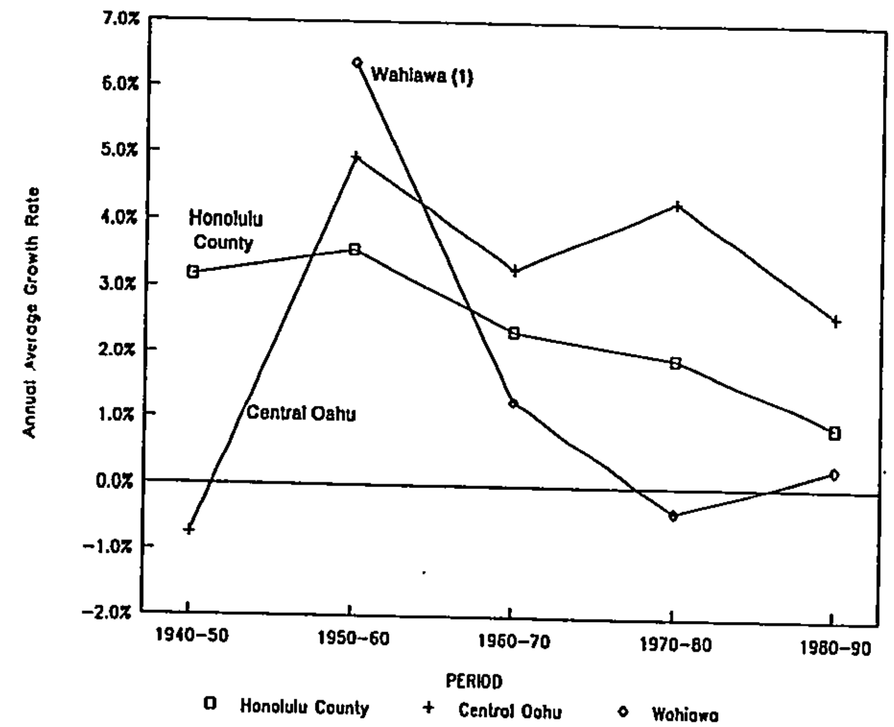
2.3.1 Wahiawa

Situated roughly in the middle of Oahu, Wahiawa is the principal settlement in the study area, serving as the regional commercial and educational center. The town is bordered by the north and south forks of Kaukonahua Stream, which combine at Wahiawa's western end to form a reservoir known as Lake Wilson. Residential development has spread laterally along California Avenue from Lake Wilson up toward the foothills of the Koolau Mountains.

Wahiawa's proximity to both Schofield Barracks and Wheeler Field has led to a sprawling mid-town development more typical of Mainland military base communities than other Hawaii towns. Many small retail establishments and light industrial operations crowd Kamehameha Highway and its feeder roads. The town's retail outlets rely heavily on soldiers from nearby Schofield and traffic traveling between the North Shore and Honolulu.

Despite the town's importance to the region, Wahiawa's residential areas retain something of a rural or "country" atmosphere. Few high-rise structures exist and many residential lots are large by Oahu standards. Furthermore, many of the town's retired folk

EXHIBIT 2-B: POPULATION GROWTH RATES, 1940-1990



NOTE: (1) Although Wahiawa was existant throughout this century, it was not defined in Census terms (that is, as a Census Designated Place) until 1950.

formerly worked on one of the area's surrounding pineapple plantations. Indeed, a number of Wahiawa homes were built by Dole to house employees.

POPULATION. As shown in Exhibit 2-C, Wahiawa's 1990 population of more than 17,000 makes it the largest civilian community in the study area. Unlike other study area towns, Wahiawa has ethnic and age breakdowns closely resembling the County's. Notably, Wahiawa has the only significant Native Hawaiian population in the study area.

The Wahiawa population is the most geographically stable of the study area communities, with around two-thirds born in Hawaii and close to 60% having lived in the same house since 1985. (See Exhibit 2-D.)

While Wahiawa residents have about the same share of high school graduates as islandwide, a considerably smaller proportion holds college degrees in Wahiawa than the island as a whole.

HOUSING. As shown in Exhibit 2-E, the town has over 5,700 units. Available housing is scarce. The town has a vacancy rate half that of the County. Close to 70% of the houses are single-family -- a far higher rate than the Oahu average of 55%.

Wahiawa has some of the oldest houses in the study area. (In general, study area units are older than units throughout the County.) Residences range from a few dilapidated tenements near the town's core to modest but well-maintained single-family units.

The 1990 median value for homes is almost $100,000 lower than the islandwide median, making Wahiawa inexpensive by Oahu standards. In other respects, Wahiawa homes and household characteristics are very similar to County averages.

INCOME. The town's median household income of just over $33,100 is substantially below the County median (Exhibit 2-F). Furthermore, Wahiawa has proportionally more households in the lowest income range and fewer households in the highest income range than County levels. Another indication of Wahiawa's relative lack of prosperity is the high incidence of households relying on public assistance as a source of income (double the County level).

In dollar values, homeowner costs are a little below the County average, and renter costs are well below the average. However, in relation to what people can pay, rents are high in Wahiawa. Over 40% of renting households spend a third or more of their income on housing.

Over a tenth of Wahiawa residents live below the poverty level. In particular, the poverty rate for Wahiawa children under 18 in families is about twice the County level.

EXHIBIT 2-C: DEMOGRAPHIC CHARACTERISTICS, 1980–1990

	HONOLULU COUNTY 1980	HONOLULU COUNTY 1990	Wahiawa 1980	Wahiawa 1990	Whitmore Village 1980	Whitmore Village 1990	Poamoho Camp (1) 1980	Poamoho Camp (1) 1990	Schofield Barracks 1980	Schofield Barracks 1990	Wheeler Field (2) 1980	Wheeler Field (2) 1990
POPULATION	762,565	836,231	16,911	17,386	2,318	3,373	368	282	18,851	19,597	N/A	2,600
ETHNICITY												
Caucasian	33%	32%	23%	23%	6%	10%	N/A	2%	64%	61%	N/A	74%
Japanese	25%	23%	32%	28%	12%	10%	N/A	4%	1%	0%	N/A	1%
Filipino	13%	14%	18%	21%	69%	66%	N/A	79%	1%	1%	N/A	3%
Hawaiian	11%	11%	9%	12%	6%	6%	N/A	6%	1%	1%	N/A	1%
Black	2%	3%	4%	4%	1%	1%	N/A	0%	22%	25%	N/A	12%
Other	16%	17%	14%	12%	6%	7%	N/A	9%	11%	11%	N/A	8%
AGE												
Less than 5 years	8%	7%	9%	9%	10%	10%	N/A	5%	13%	13%	N/A	16%
5 to 17 years	20%	17%	19%	17%	24%	21%	N/A	28%	19%	19%	N/A	20%
18 to 34 years	35%	31%	35%	30%	28%	30%	N/A	20%	60%	57%	N/A	50%
35 to 64 years	30%	34%	29%	30%	27%	28%	N/A	35%	8%	11%	N/A	14%
65 or more years	7%	11%	8%	13%	10%	12%	10%	13%	0%	0%	N/A	0%
Median age (years)	28.1	32.2	26.3	31.4	26.6	29.6	N/A	33.2	21.5	22.2	N/A	24.1
EDUCATION OF PERSONS AGED 25 & OVER (3)												
High School Diploma	N/C	28%	N/C	39%	N/C	31%	N/A	45%	N/C	35%	N/A	25%
College Degree (4)	N/C	33%	N/C	19%	N/C	11%	N/A	6%	N/C	23%	N/A	31%
PERSONS AGED 5 & OVER WHO SPEAK A LANGUAGE OTHER THAN ENGLISH AT HOME (3)	26%	26%	31%	26%	51%	51%	N/A	74%	13%	15%	N/A	12%
PERSONS WITH MOBILITY OR SELF-CARE LIMITATIONS (3)												
% of persons aged 16 to 64	N/A	9%	N/A	10%	N/A	11%	N/A	5%	N/A	5%	N/A	3%
% of persons aged 65 or more	N/A	29%	N/A	31%	N/A	21%	N/A	19%	N/A	0%	N/A	0%

NOTES: N/A Data not available.
N/C 1980 and 1990 categories are not comparable.
(1) Coterminous with Block Group 2 of Census Tract 91.
(2) Previously known as Wheeler AFB. There was no Wheeler AFB CDP prior to 1990.
(3) Based on 15% sample; hence, figures represent estimates only.
(4) Includes Associate, Bachelor's, and graduate degrees.

SOURCES: U.S. Bureau of the Census, 1992, 1991a, 1981a, 1981b, 1981c.

EXHIBIT 2-D: GEOGRAPHIC MOBILITY, 1980–1990 (1)

	HONOLULU COUNTY		Wahiawa		Whitmore Village		Poamoho Camp (2)		Schofield Barracks		Wheeler Field (3)	
	1980	1990	1980	1990	1980	1990	1980	1990	1980	1990	1980	1990
PERSONS (4)												
PLACE OF BIRTH												
Born in Hawaii	55%	54%	65%	66%	59%	51%	N/A	28%	6%	6%	N/A	12%
Other U.S.-born (5)	30%	30%	22%	22%	5%	10%	N/A	9%	87%	89%	N/A	82%
Foreign-born	15%	16%	13%	12%	37%	39%	N/A	63%	7%	5%	N/A	6%
RESIDENCE 5 YEARS PREVIOUS FOR PERSONS AGED 5 & OVER												
Same house	49%	50%	55%	58%	64%	52%	N/A	73%	2%	6%	N/A	6%
Same county, different house	26%	26%	25%	26%	26%	32%	N/A	14%	2%	2%	N/A	5%
Same state, different county	1%	1%	1%	1%	0%	1%	N/A	0%	0%	0%	N/A	0%
Different state	18%	17%	12%	12%	7%	4%	N/A	0%	83%	78%	N/A	69%
Lived abroad	7%	5%	7%	3%	3%	10%	N/A	13%	13%	13%	N/A	21%
HOUSEHOLDERS												
WHEN HOUSEHOLDER MOVED INTO UNIT												
In the last 5 years	58%	53%	54%	47%	47%	50%	N/A	31%	100%	100%	N/A	98%
6 to 20 years ago	31%	29%	26%	24%	27%	29%	N/A	43%	0%	0%	N/A	2%
21 to 30 years ago	7%	10%	14%	12%	20%	7%	N/A	11%	0%	0%	N/A	0%
31 years ago or more	3%	8%	6%	16%	7%	14%	N/A	14%	0%	0%	N/A	0%

NOTES: N/A Data not available.
(1) Based on 15% sample; hence, figures represent estimates only.
(2) Coterminous with Block Group 2 of Census Tract 91.
(3) Previously known as Wheeler AFB. There was no Wheeler AFB CDP prior to 1990.
(4) Base figures used in calculating these data may be different than in 100% count.
(5) Includes persons born in U.S. territories, and persons born abroad or at sea to American parents.

SOURCES: U.S. Bureau of the Census, 1992, 1981b.

EXHIBIT 2-E: HOUSING CHARACTERISTICS, 1980–1990

	HONOLULU COUNTY		Wahiawa		Whitmore Village		Poamoho Camp (1)		Schofield Barracks		Wheeler Field (2)	
	1980	1990	1980	1990	1980	1990	1980	1990	1980	1990	1980	1990
HOUSING UNITS	252,038	281,683	5,546	5,765	588	630	87	67	3,583	3,556	N/A	704
TOTAL VACANT UNITS	8%	6%	3%	3%	2%	3%	10%	8%	5%	1%	N/A	0%
Seasonal/recreational	1%	2%	0%	0%	0%	0%	N/A	0%	0%	0%	N/A	0%
Homeowner vacancy rate	1%	1%	1%	0%	1%	1%	N/A	0%	0%	5%	N/A	0%
Rental vacancy rate	7%	4%	2%	2%	2%	4%	N/A	8%	0%	0%	N/A	0%
AGE OF STRUCTURE (3)												
1 year	3%	2%	1%	1%	1%	12%	N/A	0%	0%	0%	N/A	1%
2 to 10 to years	32%	14%	13%	12%	30%	24%	N/A	14%	29%	6%	N/A	3%
11 to 20 years	30%	30%	29%	11%	12%	18%	N/A	17%	16%	22%	N/A	27%
21 years or more	35%	54%	58%	76%	57%	46%	N/A	69%	54%	72%	N/A	69%
UNITS IN STRUCTURE												
1 unit	47%	55%	63%	69%	58%	85%	91%	88%	18%	41%	N/A	74%
2 to 4 units	11%	7%	10%	8%	12%	2%	N/A	0%	42%	33%	N/A	13%
5 or more units	42%	38%	27%	22%	30%	11%	N/A	0%	40%	25%	N/A	13%
Trailer, other	0%	1%	0%	1%	0%	2%	N/A	12%	0%	1%	N/A	0%
NOT COMPLETE PLUMBING (4)	1%	1%	2%	1%	6%	0%	0%	0%	1%	1%	N/A	0%
HOUSEHOLDS	230,214	265,304	5,367	5,618	677	616	78	63	3,416	3,504	N/A	702
HOUSEHOLD TYPE												
1 or more non-relatives	10%	12%	9%	9%	9%	15%	N/A	8%	2%	2%	N/A	2%
No non-relatives	90%	88%	91%	91%	91%	85%	N/A	92%	98%	98%	N/A	98%
TENURE												
Owner-occupied	50%	52%	44%	47%	66%	71%	0%	3%	0%	1%	N/A	1%
Renter-occupied	50%	48%	56%	53%	34%	29%	100%	97%	100%	99%	N/A	99%
PERSONS PER HOUSEHOLD	3.15	3.02	3.13	3.09	3.98	4.12	4.72	4.48	3.74	3.58	N/A	3.38
CROWDED HOUSEHOLDS												
Mildly crowded (5)	5%	6%	9%	10%	22%	10%	N/A	11%	5%	7%	N/A	6%
Very crowded (6)	7%	8%	7%	9%	7%	23%	N/A	37%	2%	1%	N/A	1%
MEDIAN VALUE (7)	$130,400	$283,600	$99,800	$189,000	$71,600	$175,700	N/A	$275,000	$125,000	$175,000	N/A	$80,000

NOTES: N/A Data not available.
(1) Coterminous with Block Group 2 of Census Tract 91.
(2) Previously known as Wheeler AFB. There was no Wheeler AFB CDP prior to 1990.
(3) Based on 15% sample; hence, figures represent estimates only.
(4) Based on 100% sample in 1980, but 15% sample in 1990.
(5) Indicated by households with 1.00 to 1.50 persons per room.
(6) Indicated by households with 1.51 or more persons per room.
(7) For owner-occupied, non-condominium housing units.

SOURCES: U.S. Bureau of the Census, 1992, 1991a, 1981a, 1981b, 1981c.

EXHIBIT 2-F: INCOME CHARACTERISTICS AND HOUSING COSTS, 1980–1990 (1)

	HONOLULU COUNTY		Wahiawa		Whitmore Village		Poamoho Camp (2)		Schofield Barracks		Wheeler Field (3)	
	1980	1990	1980	1990	1980	1990	1980	1990	1980	1990	1980	1990
HOUSEHOLDS (4)												
INCOME LEVELS												
Lowest (5)	21%	13%	31%	16%	23%	12%	N/A	0%	39%	16%	N/A	9%
Highest (6)	·31%	39%	24%	29%	21%	33%	N/A	43%	3%	11%	N/A	8%
Median Income	$21,077	$40,581	$16,321	$33,173	$16,023	$42,962	N/A	$47,813	$11,376	$25,553	N/A	$25,821
WITH SELECTED INCOME SOURCES												
Social Security Income	19%	24%	21%	30%	31%	32%	N/A	63%	2%	1%	N/A	2%
Retirement Income	N/A	20%	N/A	27%	N/A	30%	N/A	20%	N/A	4%	N/A	2%
Public Assistance Income	8%	6%	12%	12%	6%	10%	N/A	18%	5%	5%	N/A	2%
OWNER HOUSING COSTS												
35% or more of Household Income (7)	12%	15%	7%	11%	10%	18%	N/A	0%	N/A	N/A	N/A	N/A
Median Monthly Costs (7)	$494	$1,121	$430	$976	$383	$1,029	N/A	0%	N/A	N/A	N/A	N/A
RENTER HOUSING COSTS												
35% or more of Household Income (8)	32%	34%	41%	41%	20%	36%	N/A	0%	18%	13%	N/A	32%
Median Gross Rent (8)	$315	$663	$280	$560	$225	$606	N/A	$239	$248	$403	N/A	$673
Median Contract Rent (9)	$279	$815	$236	$494	$202	$554	$35	$137	$246	$402	N/A	$614
POPULATION (4)												
PERSONS BELOW POVERTY LEVEL	11%	7%	13%	12%	8%	4%	N/A	0%	13%	9%	N/A	4%
% of persons aged 18 to 64	N/A	6%	N/A	9%	N/A	4%	N/A	0%	N/A	7%	N/A	3%
% of persons aged 65 or more	11%	8%	14%	9%	20%	3%	N/A	0%	0%	0%	N/A	0%
% of related children aged less than 18	15%	10%	23%	21%	7%	6%	N/A	0%	16%	11%	N/A	5%
% of unrelated individuals	27%	19%	34%	24%	57%	20%	N/A	0%	19%	17%	N/A	0%

NOTES: N/A Data not available.
N/C 1980 and 1990 categories are not comparable.
(1) Based on 15% sample (except "Median Contract Rent"); hence, figures represent estimates only.
(2) Coterminous with Block Group 2 of Census Tract 91.
(3) Previously known as Wheeler AFB. There was no Wheeler AFB CDP prior to 1990.
(4) Base figures used in calculating these data may be different than in 100% count.
(5) For 1990, incomes of less than $15,000; for 1980, incomes of less than $10,000. (Based on a CPI increase of 57.53% from 1979 to 1989, $15,000 in 1989 was worth $8,660 in 1979.)
(6) For 1990, incomes of $50,000 or more; for 1980, incomes of $30,000 or more. (Based on a CPI increase of 57.73% from 1979 to 1989, $50,000 in 1989 was worth $28,866 in 1979.)
(7) Owner costs include (but are not limited to) mortgage, real property tax, property insurance, utilities, and fuels.
(8) Renter costs include (but are not limited to) rent, utilities, and fuels.
(9) Monthly cash rent only. Does not include other costs.

SOURCES: U.S. Bureau of the Census, 1992, 1991a, 1981a, 1981b, 1981c.

LABOR. As shown in Exhibit 2-G, unemployment is somewhat higher than elsewhere in the County, especially for women. (The latest 1992 Department of Labor and Industrial Relations unemployment estimates were not cited because they (1) are based on census tract boundaries not comparable to the CDPs used in this report; and (2) reflect the changes from 1980 to 1990 rather than showing more recent trends.) Wahiawa's employed civilian workforce numbers over 7,700, with a far lower proportion of Wahiawa workers holding managerial or professional occupations than Oahu residents in general.

The average commute time for Wahiawa workers is almost half an hour. (In normal traffic conditions it takes about half an hour to drive to Downtown Honolulu, the island's employment center.) However, a full quarter of Wahiawa workers have commutes of 45 minutes or more. (Only 16% of the total island workforce face such long commutes.) As shown in Exhibit 2-H, at least a quarter of Wahiawa workers work in Wahiawa itself, meaning Wahiawa is predominantly a commuter town but one that still offers regional job opportunities. (By comparison, only a tenth of Mililani workers work in the Mililani area, even though Mililani Town is only about three miles closer to Honolulu.)

2.3.2 Whitmore Village

Whitmore is located about a mile northwest of Wahiawa, off the main highway on a road that terminates at a U.S. Navy communications station (NCTAMS EASTPAC). Whitmore's origins as a Dole plantation camp are still evident but are becoming less obvious as new affordable housing subdivisions change the face and composition of the village.

POPULATION. With almost 3,400 residents, Whitmore Village is predominantly Filipino. The population is younger than those of either Wahiawa or the County. Almost 40% of Whitmore residents are foreign-born, compared to only 16% for the County, and over half of Whitmore Village residents speak a foreign language at home. (Presumably most of these residents would speak a Filipino language.)

HOUSING. Whitmore has close to 850 units, with very few vacancies. Whitmore Village's housing stock is generally newer than the County's, since about two-thirds of its structures were built within the last ten years. Furthermore, basic amenities have improved in Whitmore units over the last decade; by 1990, no homes lacked complete plumbing.

More than four-fifths of the Whitmore housing stock is single-family, and the remainder is mainly apartments. However, more than 40% of all Whitmore homes are crowded. Furthermore, the village has many more persons per household than the islandwide norm or than in Wahiawa.

EXHIBIT 2-G: LABOR FORCE CHARACTERISTICS, 1980-1990 (1)

	HONOLULU COUNTY 1980	HONOLULU COUNTY 1990	Wahiawa 1980	Wahiawa 1990	Whitmore Village 1980	Whitmore Village 1990	Poamoho Camp (2) 1980	Poamoho Camp (2) 1990	Schofield Barracks 1980	Schofield Barracks 1990	Wheeler Field (3) 1980	Wheeler Field (3) 1990
POPULATION AGED 16 & OVER	574,903	651,920	12,739	13,164	1,582	2,438	N/A	188	13,187	13,526	N/A	1,707
In Armed Forces	10%	8%	10%	5%	2%	2%	N/A	0%	72%	68%	N/A	54%
POTENTIAL CIVILIAN LABOR FORCE	516,877	598,371	11,517	12,457	1,549	2,389	N/A	188	3,701	4,274	N/A	780
In Civilian Labor Force	66%	69%	61%	66%	62%	68%	N/A	72%	34%	59%	N/A	66%
CIVILIAN LABOR FORCE	339,863	410,023	6,980	8,267	967	1,621	N/A	136	1,258	2,519	N/A	515
MALE												
Labor force participation (4)	75%	75%	72%	73%	72%	71%	N/A	68%	55%	74%	N/A	85%
Unemployed	5%	4%	4%	6%	7%	3%	N/A	17%	11%	3%	N/A	10%
FEMALE												
Labor force participation (4)	58%	63%	51%	60%	52%	64%	N/A	77%	32%	56%	N/A	60%
Unemployed	5%	3%	10%	6%	5%	6%	N/A	9%	22%	8%	N/A	11%
EMPLOYED CIVILIAN LABOR FORCE	324,113	395,611	6,496	7,751	907	1,544	N/A	118	1,001	2,335	N/A	460
BY SELECTED INDUSTRY												
Agriculture, forestry, fisheries, mining	2%	2%	3%	3%	6%	8%	N/A	29%	3%	0%	N/A	2%
Construction	7%	7%	9%	10%	9%	15%	N/A	0%	1%	4%	N/A	4%
Manufacturing	8%	6%	7%	6%	22%	13%	N/A	27%	3%	5%	N/A	5%
Transportation	7%	7%	6%	6%	4%	5%	N/A	1%	0%	1%	N/A	4%
Retail trade	20%	19%	21%	21%	14%	22%	N/A	13%	32%	20%	N/A	33%
Finance, insurance, real estate	8%	8%	5%	6%	4%	6%	N/A	0%	6%	6%	N/A	3%
Personal, entertainment, recreation	8%	8%	5%	7%	5%	7%	N/A	14%	7%	6%	N/A	5%
Health, education, professional	18%	22%	17%	20%	7%	12%	N/A	4%	25%	32%	N/A	23%
Public administration	11%	9%	17%	11%	16%	6%	N/A	4%	19%	19%	N/A	14%
BY OCCUPATION												
Managerial, professional	25%	28%	17%	18%	7%	7%	N/A	0%	21%	23%	N/A	19%
Technical, sales, support	34%	35%	30%	33%	18%	27%	N/A	15%	38%	42%	N/A	36%
Service	18%	17%	20%	21%	19%	22%	N/A	14%	31%	23%	N/A	25%
Farming, forestry, fishing	2%	2%	3%	3%	8%	6%	N/A	31%	3%	0%	N/A	0%
Precision, craft, repair	11%	10%	17%	14%	15%	13%	N/A	12%	2%	7%	N/A	11%
Operators, cleaners, laborers	11%	9%	13%	11%	34%	24%	N/A	28%	4%	5%	N/A	9%
COMMUTE TO WORK												
More than 45 minutes	13%	16%	23%	25%	22%	25%	N/A	25%	25%	4%	N/A	11%
Mean travel time (minutes)	22.6	24.8	26.1	28.0	22.1	28.4	N/A	28.6	10.4	11.0	N/A	19.8

NOTES: N/A Data not available.
(1) Based on 15% sample; hence, figures represent estimates only.
(2) Coterminous with Block Group 2 of Census Tract 91.
(3) Previously known as Wheeler AFB. There was no Wheeler AFB CDP prior to 1990.
(4) Calculated by dividing "Civilian Labor Force" by "Potential Civilian Labor Force."

SOURCES: U.S. Bureau of the Census, 1992, 1981b.

EXHIBIT 2-H: COMMUTING CHARACTERISTICS, 1980-1990 (1)

	Total Workers (2) 1980	Total Workers (2) 1990	% Working in Area (3) 1980	% Working in Area (3) 1990
STUDY AREA				
Wahiawa	6,976	8,212	33%	25%
Whitmore Village	939	1,542	20%	10%
Schofield Barracks	8,540	11,290	35%	59%
Wheeler Field (4)	N/A	1,325	N/A	16%
OTHER OAHU				
Honolulu	168,731	193,364	91%	89%
Mililani	9,629	16,003	6%	9%
Waipahu	11,164	14,400	17%	16%

NOTES: (1) Based on 15% sample; hence, figures represent estimates only.
(2) All civilian and military workers aged 16 and over who reported place of work.
(3) That is, those working in same Census Designated Place (CDP) as where they reside.
(4) Previously known as Wheeler AFB.

SOURCES: U.S. Bureau of the Census, 1992, 1981b.

Whitmore has the most affordable civilian homes in the study area, which probably helps explain why the village's homeownership rate (70%) is far above the County average.

INCOME. The village median household income is by far the highest in the study area, and higher even than the County's. Since Whitmore Village has more people per household than in nearby communities, high household incomes do not indicate wealth. Relatively few families are below the poverty line. However, Whitmore has a notably higher rate of households receiving social security, retirement, and public assistance income than islandwide.

LABOR. Whitmore's female civilian workforce has an unemployment rate twice the Oahu average. Construction and manufacturing industry jobs account for much larger shares of the Whitmore workforce than they do for Oahu, and many are in laboring and service occupations. Agriculture accounts for a significantly larger portion of workers in Whitmore Village than in either the rest of the study area or the County generally.

Whitmore is very much a commuter community, since only a tenth of the town's workers actually work in Whitmore itself.

2.3.3 Poamoho Camp

A few miles north of Wahiawa, near the crossroads of Kamehameha Highway, Kaukonahua Road, and Kamananui Road, Poamoho Camp maintains strong plantation roots. Present-day Poamoho is actually an amalgamation of three area Del Monte camps that were moved to the site during the 1930s. All of the Poamoho households include either current or retired Del Monte workers.

The Del Monte-owned units are on land leased from the Galbraith Trust. This lease will be subject to renegotiation in 1994. The Trust has indicated it has no plans to alter the existing camp in any way.

POPULATION. During the last decade, the number of Poamoho Camp residents has dropped to 280 persons. Four-fifths of Poamoho residents are Filipino, many of whom were born abroad. Prior to World War Two, Japanese were the dominant ethnic group in the camp, but as the Japanese moved they were replaced by Filipino immigrants.

HOUSING. With just under 70 houses, Poamoho is the only civilian community in the study area whose has housing stock has actually decreased. Since 1980, 20 units have been demolished due to substandard conditions.

The Poamoho housing stock is comprised almost entirely of single-family units, except for about a tenth which are temporary or mobile structures. The limited housing stock means almost half of Poamoho homes are crowded. The camp has many more persons per household than the islandwide norm.

As a continuing plantation community on unsubdivided land, nearly all Poamoho homes are still rented from Del Monte at modest rents. (The median rent is $137 per month.)

2.3.4 Schofield Barracks

In terms of land area, Schofield Barracks is the largest military base in the State. Its training grounds cover sizable tracts of densely covered rugged terrain in the greater Wahiawa region. The developed portion of the base is immediately west of Wahiawa, separated by Lake Wilson.

Schofield is home to the Tropic Lightning Light Infantry Division. Tropic Lightning has seen action in every major U.S. conflict since World War Two. The most recent deployment of Schofield units occurred during Desert Storm in the Persian Gulf. As light infantry, Tropic Lightning are trained for combat in adverse terrain impenetrable to mechanized units. The mountainous and densely-wooded East Range of the base is an ideal proving ground for Schofield's troops.

In recent years, the U.S. Armed Forces have increasingly recruited and retained married personnel. Schofield's population is comprised of a large number of families in addition to single personnel. Consequently, the base feels more like a civilian town, complete with social and recreational facilities, than what the term "barracks" suggests. This normalization of army life has accompanied efforts to curb drug abuse and alcoholism in the ranks. The net result of these measures has been the creation of a career soldier more dedicated to the Army's mission and less likely to cause off-base strife.

POPULATION. Schofield's population of more than 19,500 has increased somewhat over the last decade, even though other large U.S. military installations around the world are facing downsizing or closure. Hawaii's diverse geography and strategic position in the Pacific make Schofield ideal for both jungle training and timely mobilization for Asian and Latin American destinations.

As a military settlement, Schofield is understandably very unlike neighboring civilian communities. Three of Oahu's four major ethnic groups -- Japanese, Filipinos, and Hawaiians -- are barely represented at the base. Caucasians are the largest group by far (almost two-thirds of the residents), followed by Blacks who comprise almost a quarter of the population.

The population is young, with well over half in the 18 to 34 age group. About a third of the population is made up of school age or preschool age dependents. Although Schofield has far fewer college graduates than islandwide averages, it proportionately outranks the County in terms of high school graduates.

About 95% of the base's residents were born outside Hawaii, and less than a tenth were living in Hawaii in 1985. Similarly, all householders moved into their homes within the last five years.

HOUSING. Although it has the largest population in the study area, Schofield Barracks has about 2,000 units less than Wahiawa. This is because almost a third of Schofield residents are housed in barracks, not homes.

The base's housing stock has almost no vacancies and is fairly old. About 95% of the structures on base are more than 10 years old. While Schofield has more persons per household than the County, its homes are significantly less crowded than the County average.

INCOME. Since military wages are the main source of income, Schofield's median household income is far below the islandwide median. Furthermore, comparatively few Schofield households receive supplementary income, such as social security and public assistance.

Median rents in Schofield Barracks are much cheaper than the County's and only 13% of the households pay a third or more of their incomes for rental costs. Affordable housing and bargain-priced commissary goods help to counterbalance low base incomes.

LABOR. Almost 70% of persons aged 16 and over are in the armed forces. Of Schofield's large adult civilian population, only 59% are in the labor force (this is the lowest labor force participation rate in the study area).

While the unemployment rate for female civilians is still high, it has dropped drastically since 1980. Furthermore, the female labor force participation rate has almost doubled since 1980.

The mean commuting time for Schofield is only around ten minutes, since 60% of Schofield workers work on base.

2.3.5 <u>Wheeler Field</u>

Stretching south from Wahiawa towards Mililani, Wheeler has been an Air Force installation since World War Two. Control was only recently reassumed by the Army to provide support for Schofield Barracks. A Navy housing area, Camp Stover, is also on the base. Wheeler shares many characteristics with Schofield Barracks.

POPULATION. Of Wheeler's population of 2,600, more than a tenth were locally-born, compared to only 6% in Schofield.

HOUSING. The base has around 700 units, almost none of which are vacant. Only a tenth of Wheeler's residents are housed in group quarters. Because Wheeler's population is mainly comprised of families, about three-quarters of the houses are single-family units.

Wheeler homes are the least crowded in the study area. Homeownership is negligible.

INCOME. Despite a low median household income, there is little disparity between the rich and poor in Wheeler. Most household incomes fall into the middle range compared to the County, where more than half of all household incomes are in either the lowest or highest categories.

Rents and renter costs for Wheeler are the highest in the study area, but still resemble islandwide medians. Despite higher costs, Wheeler has the lowest incidence of persons below the poverty level out of the study area communities.

LABOR. Because of the large number of dependents on base, only around 55% of Wheeler residents aged 16 and over are actually uniformed personnel.

Even though labor force participation is high (particularly for males), the unemployment rate for the base's civilian labor force is the highest in the study area.

About a third of Wheeler's civilian workers work in the retail industry, compared to only a fifth of County workers. The average commute of 20 minutes indicates that many Wheeler workers commute some distance. Furthermore, only 16% of all workers work on base.

3.0 FORCES FOR CHANGE

Socio-economic trends now under way, apart from the project, will shape the overall future of Central Oahu and the surrounding regions. This section summarizes those trends and lists planned and proposed projects likely to affect residents of study area communities.

The basic future scenario for Central Oahu is one of rapid residential growth outpacing job growth. If present trends continue, the southern portion of Central Oahu will concentrate heavily on housing development. Most workers will commute, creating bedroom communities highly dependent on regional centers for services and recreation. Heavy traffic, especially near the H-1/H-2 interchange, will affect the daily lives of Leeward and Central Oahu residents.

3.1 ISLANDWIDE TRENDS

Islandwide trends must be taken into account when considering any large-scale residential project on Oahu. The pressure for affordable housing is such that the whole island has basically become one market -- that is, potential homebuyers are more concerned with being able to afford a decent home rather than worrying about that home's particular location.

The City and County of Honolulu has attempted in its General Plan to distribute anticipated housing growth (affordable and market) to areas that have available land and are still within reasonable commuting distances of Honolulu. Ewa has been earmarked for high residential growth. To a lesser extent than Ewa, nearby Central Oahu is expected to house much of the island's new population.

Similarly, many companies find it economical to move office operations to sites well outside the central business district. Besides offering cheaper leases, non-Honolulu locations usually have less congested traffic routes, of benefit to both workers and employers. Principal new commercial areas include:

- **Kapolei.** As the site of Oahu's second city, growth is encouraged in Kapolei and the surrounding Ewa area. City agencies and the Bank of Hawaii are relocating support operations to Kapolei. Construction of office structures is already underway. The State also has Kapolei land on which it plans to build.

- **Mililani.** Like Ewa, Central Oahu has available land for development. Light industrial parks are located in Waipio Gentry and Wahiawa. As discussed below, Castle and Cooke's Mililani Technology Park could accommodate substantial growth.

- **Hawaii Kai.** Although land is more scarce in Hawaii Kai than in many other parts of Oahu, the area is relatively close to Downtown Honolulu. Furthermore, a large portion of the island's professionals live in nearby communities, making Hawaii Kai a convenient location for both staff and clients.

3.2 CENTRAL OAHU/NORTH SHORE

Exhibit 3-A displays population and employment projections for 2010. According to the City and County Department of General Planning, residential development in Central Oahu will be widespread and fairly dense. The area population will exceed 157,000 in 2010. Central Oahu will have 15.7% of the island's population, but only 10.4% of the island's military and civilian jobs. (The number of military personnel, mainly based at Schofield, is expected to remain at division strength -- approximately 10,000 soldiers.)

Possible employment opportunities in the region are displayed in Exhibit 3-B. Most of the listed projects have been in operation for some time and are merely facing expansion. Beyond 1995, only a Royal Kunia golf course has a definite timetable -- the other course and the Kuilima Expansion have uncertain schedules.

With relatively few job-generating projects to support the expected increase in the regional population, many future residents will commute long distances. Most Central Oahu and North Shore workers already suffer from commuting problems such as traffic gridlocks and decreased leisure time. These conditions will only worsen unless new employment opportunities in the region accompany residential growth.

3.2.1 <u>Residential Development</u>

The southern portion of Central Oahu (Mililani to Waipahu) is slated for heavy residential development. New subdivisions are planned, along with expansions to existing projects. Far less activity is planned for the North Shore, but projects in the region could affect Central Oahu's employment base. Exhibit 3-C summarizes residential projects known to have most of their approvals. Many projects are required to include affordable housing as a condition of their permits.

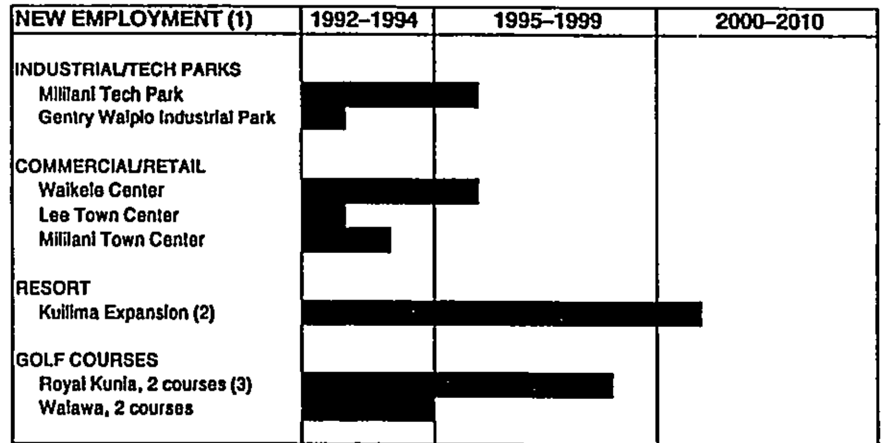
EXHIBIT 3-A: POPULATION & EMPLOYMENT PROJECTIONS, 1990-2010 (1)

	STATE		Honolulu County		Central Oahu	
	1990	2010 (2)	1990	2010 (3)	1990	2010 (3)
POPULATION	1,108,229	1,435,500	836,231	999,500	130,474	157,016
HOUSING UNITS	389,810	N/A	281,683	383,488	36,260	50,152
TOTAL JOBS	611,000	789,100	505,451	603,458	47,022	63,052
MILITARY JOBS (4)	68,400	68,400	66,400	66,400	10,200	10,200
CIVILIAN JOBS	542,600	720,700	439,051	537,058	36,822	52,852

NOTES: N/A Data not available.
(1) 2010 numbers are projections; 1990 numbers are actual Census counts (except for "Military Jobs" and State "Total Jobs" which are projections).
(2) From State M-K projections.
(3) From unpublished Honolulu City & County Department of General Planning estimates based upon State M-K series.
(4) Military jobs for Central Oahu interpolated by Community Resources, Inc., based on 1990 Census count of workers in "Armed Forces" at Schofield Barracks and Wheeler Field. The number of uniformed personnel at these bases is assumed to remain constant over time.

SOURCES: Honolulu City & County Department of General Planning, 1992; Hawaii State DBED, 1988; U.S. Bureau of the Census, 1991a.

EXHIBIT 3-B: SELECTED NEW EMPLOYMENT PROSPECTS, 1992-2010



NOTES: (1) Employment centers that attract study area residents may lie outside the area.
(2) Timetable is now on hold.
(3) Timetable for second course is not yet available.

SOURCES: Honolulu City & County, 1992; Atwater/Stanney Consultants, 1992.

EXHIBIT 3-C: PLANNED RESIDENTIAL PROJECTS, 1992-2010

BY PROJECT NAME	Existing Units (1)	Planned Units	Total Existing & Planned Units
STUDY AREA			
Schofield Barracks (2)	3,583	202	3,785
Wahiawa (3)	5,893	476	6,369
Whitmore Village (4)	1,145	8	1,153
Wilikina Elderly	0	64	64
REMAINDER OF CENTRAL OAHU			
Crestview	0	191	191
Crown Elderly	0	444	444
Manager's Drive	0	470	470
Melemanu Woodlands	0	1,281	1,281
Mililani (2)	8,900	31	8,931
Mililani Mauka (Phases I & II)	264	4,231	4,495
Royal Kunia (Phases I & II)	152	3,019	3,171
Waiawa Gentry (Phases I & II)	0	2,675	2,675
Waikele	298	2,482	2,780
Waipahu (2)	7,739	618	8,357
NORTH SHORE			
Lihi Lani	0	180	180
Mokuleia Beach Condo	N/A	85	85

BY LOCATION (5)	1992-1994	1995-1999	2000-2010	TOTAL 1992-2010
CENTRAL OAHU				
Study Area	449	301	0	750
Remainder of Central Oahu	5,486	6,097	3,859	15,442
Unknown (6)	138	227	0	365
TOTAL	6,073	6,625	3,859	16,557

NOTES: N/A Data not available.
(1) The number of existing units for the entire Central Oahu area is greater than the sum of the projects listed here.
(2) Existing units for these projects are as of April 1, 1990; all others as of June 30, 1991.
(3) Existing units as of April 1, 1990 plus 128 units of the Wahiawa Elderly housing project.
(4) Existing units as of April 1, 1990 plus 306 units of the Kani Kani Subdivision.
(5) Does not include existing units.
(6) Includes miscellaneous projects not mentioned by project name in the first table.

SOURCES: Honolulu City & County, 1992, 1991; Atwater/Stanney Consultants, 1992; U.S. Bureau of the Census, 1991a.

Current timetables suggest that over 15,000 units will be built in the area from Waipahu to Mililani by 2010. Major projects are:

MILILANI MAUKA. Castle and Cooke Properties, Inc. -- Dole Food Company, Inc.'s property development arm -- is particularly active in Central Oahu with ongoing residential developments based around Mililani. As an eastwards extension of Mililani Town, Mililani Mauka is the largest of Castle and Cooke's present housing projects. Plans call for a total of 4,500 units on 1,200 acres. About half of the homes will be affordable. As of June 1991, 264 units had already been built.

ROYAL KUNIA. This project is located north of Village Park on land that is now predominantly canefield. Some 152 of the project's more than 3,000 units have been built. A number of homes will be designated affordable and elderly (Atwater/Stanney Consultants, 1992). A golf course will also be part of the community's recreational facilities. Phase I's 2,019 units are scheduled for completion by 1999. Phase II's timetable has yet to be determined.

WAIAWA GENTRY. Pending zoning approvals, Gentry's construction of 2,675 units on Waiawa Ridge would begin in 1994 and end in 1999 (Atwater/Stanney Consultants, 1992). Some 30% of the units would be affordable.

WAIKELE. As of June 1991, some 298 units of the Waikele subdivision's 2,780 total units were built, and another 446 were under construction (Atwater/Stanney Consultants, 1992). The community will have a mix of affordable and market homes, centered around the golf course which is almost ready for business. Other project-related facilities include an H-1 overpass and a water reservoir.

MELEMANU WOODLANDS. Located in the woods along the Waikakalaua Stream near Mililani Technology Park, this project would have an eventual build-out of 1,281 units (mostly multifamily) on 70 acres (Atwater/Stanney Consultants, 1992). Some 15% of the homes will be priced below 80% of the median income bracket.

SUMMITT DEVELOPMENT. Robert-Maxwell & Company plans to develop almost 600 residential units northeast of the Mililani Mauka community (Wahiawa Neighborhood Board Minutes, 1992). Some 60% of the units would be affordable, and the remainder would be for gap group and market buyers (personal communication, Ramona Mullahey, Planner, December 1992).

RECREATIONAL COMMUNITIES. Recreational communities are residential developments that appeal to an upscale clientele (many of whom use the unit as a vacation home). Such communities usually provide some recreational facilities for public use at no charge or at very low rates. Two have been recently proposed.

- **Mokulela.** According to an application filed in 1991, Mokulela Land Company intends to develop a master-planned community consisting primarily of 365 residential units (both single-family and multifamily), and two 18-hole golf courses (Belt Collins & Associates, 1991). However, the company did not submit an EIS for the 1992 Development Plan review. The current status of this project is unknown.

- **Lihi Lani.** Slated for 300 acres in the Pupukea area, this proposed Obayashi development would include a golf course, various other recreation facilities, 120 market lots, and 180 affordable housing units. The affordable units would be broken out into 70 single-family homes, 30 townhouses for families making 80% to 120% of the median income, and 80 single-family homes for the "gap group" (those making 120% to 140% of the median) (personal communication, Jeff Overton, Planner, Group 70 International, November 9, 1992). The project has received City Development Plan approvals, but still needs State Land Use and City zoning permits.

3.2.2 Agriculture

The main regional agricultural operations are Dole's pineapple plantations in Central Oahu and its Waialua Sugar Company on the North Shore. Del Monte's Kunia-based pineapple operation and Oahu Sugar's nearby Waipahu activity are also important employment centers. Agriculture was Central Oahu's first major industry and it continues to occupy a cherished position in the minds of many area residents. Even in the face of a shortage of land for housing, many people are unwilling to see a decline in agriculture's role.

DOLE FOOD COMPANY, INC. Dole recently closed its Iwilei cannery and has reduced its Central Oahu acreage near urban areas. Nevertheless, the company plans to maintain pineapple operations in Central Oahu for the foreseeable future (personal communication, Wally Miyahira, Senior Vice President, Castle and Cooke Properties, November 2, 1992).

The viability of Dole's nearby Waialua Sugar Company depends on continued price subsidies. Dole supports its sugar operation, even though the plantation's workforce is gradually shrinking through attrition (personal communication, George Fraser, President, Waialua Sugar Company, January 15, 1992). Waialua Sugar's future has been uncertain since 1987, when plans to close the plantation were announced. In 1990 this uncertainty intensified with Dole Chairman David Murdock's statement that he saw no long-term future for large-scale agriculture in Hawaii.

3.2.3 Visitor Industry

Central Oahu is not a prime location for resort development. The North Shore, on the other hand, is one of Oahu's most scenic areas. Not only is the region a favorite tourist destination, but it also serves island residents. Some of the North Shore visitor industry possibilities that could eventually provide jobs for Central Oahu residents include:

KUILIMA RESORT EXPANSION. Permits for additional hotels and condominiums at Kuilima had already been granted when the resort was purchased by Asahi Jyuken in 1988. Construction on Phase I of the expansion had just begun when it was abruptly halted in September 1991, due to a sluggish economy and financing problems in Japan.

According to mid-1991 plans, Phase I of the expansion would have created about 1,600 new jobs on-site by the end of 1996. With full buildout of the expansion, some 2,900 new on-site jobs were expected, plus many more indirect jobs throughout the North Shore. Although not likely to reach fruition in the near term, the plans provide estimates of the size and scope of growth allowable under present land use permits.

KAMEHAMEHA SCHOOLS/BISHOP ESTATE. Bishop Estate developed preliminary and unofficial concepts for long-range development of its Kawailoa lands. Potential components included commercial, recreational, and low-density resort projects. Since the Trustees did not approve these concepts, Estate staff expect to revise plans for the Kawailoa area soon (personal communication, Elaine Brown, North Shore Land Agent, KS/BE, November 9, 1992).

3.2.4 Industry and Transportation

New projects to increase industry (and thus jobs) in the entire region are few (see Exhibit 3-B). Similarly, construction of major roadways is limited to the Haleiwa Bypass.

MILILANI TECHNOLOGY PARK. Immediately south of Wahiawa, Castle and Cooke Properties is continuing to expand the Mililani Tech Park. Lot construction on the 120-acre property began in 1987 and is due to finish by 1995. A few firms have moved on site, and occupy separate buildings on two- or four-acre lots. Current tenants include Oceanic Cable and Verifone.

AMERON QUARRY. A rock quarry is proposed by Ameron for a 153-acre site above Waialua (personal communication, Thomas E. Bastis, President, Ameron (HC&D), January 17, 1992; Waite, 1992). The quarry would employ about 40 persons and would mainly feed new construction in Central Oahu. Operations would begin in

1995 and continue for 20 years (land use permits have not yet been obtained, so this timetable is uncertain).

HALEIWA BYPASS. Under construction since 1991, the Bypass is intended to relieve the serious problem of traffic congestion in Haleiwa. Phases I and II should be complete by July 1993 (personal communication, Charles Yonamine, Area Engineer, Construction and Maintenance Branch, Hawaii State Department of Transportation, November 10, 1992). The last phase of the project is still in the design stage. It will provide access from Kamehameha Highway to Haleiwa. Local merchants have expressed concern about the highway's possible effect on the town's economy.

3.3 STUDY AREA

With land in Wahiawa very limited, and with land in surrounding communities tied up in agriculture or military use, the study area itself has few proposed developments on the immediate horizon:

WILIKINA ELDERLY HOUSING. Construction of the Teval Corporation's Wilikina Elderly Housing Project began in September of 1992 (Pacific Business News, 1992). Located on Wilikina Drive, the 1.5-acre site will eventually include a six-story structure comprised of 45 studios and 19 one-bedroom rental units for low- and moderate-income elderly households. Construction completion is slated for the end of 1993.

WHITMORE VILLAGE EXPANSION. The area between Whitmore Village and the project site -- now in cultivation or used for Dole Food's local office and truck yard -- is viewed by some in Wahiawa as a likely site for urban expansion. According to Castle and Cooke Properties Senior Vice President, Wally Miyahira, eventual construction of additional housing at Whitmore Village is possible, but no plans or timetables have been established by the company (personal communication, November 2, 1992).

4.0 ECONOMIC AND DEMOGRAPHIC IMPACTS

This chapter provides calculations of quantifiable socio-economic impacts. Chapters 5 and 6 deal with changes and impacts that are more appropriately discussed in qualitative terms. Some economic matters, such as the impact of the project on existing businesses, cannot be quantified with any precision, and are hence discussed in later chapters.

4.1 OVERVIEW

The analysis flows from market assumptions that the project (1) will fill housing and commercial support needs not filled by other proposed projects, and (2) will not significantly affect the rate of growth in those other projects. In this sense, there are few islandwide or statewide impacts, because the population would be somewhere else on island anyway (even if only in overly crowded existing housing). However, the project would affect the Wahiawa study area by attracting people and economic activity which might not otherwise be in that particular geographical location.

The project is expected to house about 8,000 residents and feature 3,400 permanent on-site jobs (plus 3,050 secondary jobs elsewhere in Hawaii) by the year 2010. Construction activities will also generate about 200 jobs on-site, on average, from 1996 to 2010. (Total direct construction jobs would amount to about 3,750 person-years over the 15-year period. An additional 7,950 person-years -- an average of 530 jobs annually -- would be supported elsewhere in Hawaii's economy.) The daytime de facto population will roughly equal the normal residential population, since people commuting to work away from their homes will be replaced by roughly equal numbers of in-commuting workers and customers. Over time, a significant number of project residents (especially secondary household workers) may be expected to take jobs in the project employment centers. Personal income from construction-related wages will peak at about $25 million annually, and full build-out of the employment centers will generate more than $150 million per year for permanent workers. Much of this money would now re-enter the Oahu economy through Wahiawa businesses and financial institutions rather than in some other part of the island.

Government costs and revenues will be limited to "locational" questions: What new costs would government incur just because these residents and workplaces are located at a planned community in Wahiawa, vs. being dispersed or located in other planned new communities? What new revenues would result? The analysis indicates that concentrated development would be less costly (and in fact a net plus) for both the State and County governments than would be the geographical alternatives.

4.2 THE CONCEPT OF "IMPACT" AND THE WAHIAWA LANDS PROJECT

In socio-economic impact analysis, an "impact" is usually defined as the **difference between two possible futures, with and without the proposed project,** rather than the difference between present conditions and likely future ones. Yet, for the surrounding community, the difference between the current situation and the future with project can profoundly affect perceptions of any project.

This report deals with both clearcut "impacts" and also with the sort of change from present conditions which people might actually experience. It should be noted that the experience of change can affect people's sense of their community, and hence it can itself constitute a social impact.

The Wahiawa Lands project provides space and buildings to meet demands for housing and workspace that will arise on Oahu with or without the project. It responds to existing and anticipated needs, rather than attracting new capital, visitors, and residents from off-island. From a strict analytical perspective, the project does not involve additional economic impacts on the Island and State. Rather, it simply provides a specific location for funnelling indirect and induced impacts of other activities -- above all, tourism -- that are providing capital for economic growth. That is, tourism and other primary industries generate new dollars and population which would otherwise go outside Hawaii; the remaining question is where to locate consequent housing and commercial growth, not whether the consequent growth is to occur.

Impacts of the Wahiawa Lands project derive above all from (a) location and (b) the integration of project components into a single planned community, since new housing and workspace would likely be developed elsewhere in response to demand.

The importance of a project's location may be great for nearby communities, and much smaller for the people and government of larger areas. For the study area, the Wahiawa Lands project will mean extensive changes; for the island economy as a whole, the project's impact is likely to be minimal.

The impact is small for the islandwide and Statewide economies so long as:

Condition (1): The project affects pineapple production slightly or not at all. The project site now is highly productive pineapple land. Del Monte is seeking replacement land. When and if alternative lands are found, questions would likely remain concerning the profitability of cultivation on the new site.

This report assumes that, after lease negotiations with Galbraith Trust and leasing of replacement lands from other landholders, Del Monte will be able to maintain

production and profits at or near current levels. A technical assessment of the project's agricultural impacts has been made by Decision Analysts Hawaii, Inc. (1992).

Condition (2): The project meets demand for housing and commercial spaces beyond that provided in projects permitted (and in some cases developed) by the State and County. The market assessment for the project finds its housing and commercial components to be viable within a 15- to 20-year timeframe (Atwater/Stanney Consultants, 1992). That finding is based on analysis of competing developments in the Central and Leeward Oahu areas.

Without the project, demand for housing and commercial space could lead to a combination of (a) faster development in existing subdivisions and communities such as Mililani, Waikele, and Kapolei, and (b) greater pressure for infill development in older urban areas. In both cases, some demand for additional development would likely remain unmet after the year 2000, and the Wahiawa Lands project is proposed to address that unmet need.

Exhibit 4-A surveys some of the major features of the with- and without-project futures. It shows several differences as important for the local area. Relatively few differences are identified for the island and state, since many aspects of the project could, and likely would, occur at other sites if the project did not exist.

4.3 EMPLOYMENT

The proposed development involves short-term construction jobs and continuing jobs in operations housed on site. The number of construction jobs varies from day to day for any building, and from year to year as different phases of a project are built out. Construction jobs are accordingly estimated in terms of the average number of full-time equivalent jobs created during a period of time, and measured in person-years. In contrast, operations jobs are permanent.

Construction and operations both involve direct jobs, and both stimulate indirect and induced jobs:

- Indirect jobs are created by spending on goods and services needed to support project construction and operations; and
- Induced jobs are created when workers in direct jobs spend their money to buy goods and services.

EXHIBIT 4–A: OVERVIEW OF FUTURE WITH VS. WITHOUT PROJECT

SHARED FEATURES
Gradual growth in Oahu economy, population Spread of population away from Honolulu Plantation agriculture's future depends on price supports and world prices; long-term viability of Hawaii sugar and pineapple in doubt

AREA	WITH PROJECT	WITHOUT PROJECT
ON SITE	Urban development on site (Limited near-term agriculture possible) Housing on site Housing near jobs Various jobs located on site Public golf course New recreation areas	Near-term agriculture on-site Long-term use unknown Housing in Ewa, Central Oahu new communities; more infill, crowding in older urban areas Some homes near jobs in Ewa; many far from jobs Most jobs would be in Primary Urban Center or Ewa Pent-up demand for golf at low rates Local need for recreation areas unmet
WAHIAWA/ CENTRAL OAHU	Increase in Wahiawa population Younger population Increase in Wahiawa jobs Increased diversity of jobs in Wahiawa New area links Schofield, Wahiawa, Whitmore Village Wahiawa a regional center	Population stable Little to attract young families Wahiawa residents mainly commute Economy based on military, pineapple Local populations meet only in retail areas Dispersed regional population, no shared center
OAHU/ STATE	Project as planned, mixed-use development Some additional cost for new infrastructure possible	Potentially, greater crowding or faster development in other communities Cost of expanding and replacing infrastructure in other areas; possible cost of earlier infrastructure development

Indirect and induced jobs are created throughout the economy, not just in the construction industry or the industry of a project operation. The number of indirect and induced jobs in Hawaii associated with a project can be estimated using the State's model of relations among industries.

Direct operations jobs are, in the present case, located on site. As a rule of thumb, 80% of direct construction jobs are on site, and the remaining 20% consist of off-site jobs (in offices and company supply yards). Indirect jobs are not likely to be concentrated or located near the project. Since induced jobs depend on employees' spending, these tend to cluster near a project and near employees' homes.

4.3.1 Construction

On the Wahiawa lands project, construction is slated to begin in 1996. The first houses and apartments would be available for occupancy in 1998. Both housing and other facilities are projected to develop at a steady pace for about ten years.

Exhibit 4-B shows construction spending (estimated by Community Resources, Inc. in 1992 dollars) and full-time jobs created annually, on average, by project construction. Total construction spending is estimated as about $535 million. Over 15 years (1996-2010), the annual average construction spending would be about $36 million, about 1% of the value of construction put in place on Oahu in 1991 (Bank of Hawaii, 1992).

Direct construction jobs would involve over 3,750 person-years, over a 15-year period, or an average of 250 jobs for any given year.

About two indirect and induced jobs are created for every construction job. On the Wahiawa Lands project, an average of about 530 indirect and induced jobs annually would be supported by construction spending through 2010. Since construction workers are not expected to live near a temporary job site, there is no reason to expect construction workers' spending to be a significant stimulus to the regional economy.

4.3.2 Operations

A few direct operations jobs are projected as being created in the late 1990s. With major developments in the business center and community "core," the number of jobs on site would exceed 1,000 by the year 2000, and then climb to 3,400 as of 2010, as shown in Exhibit 4-C. Operations jobs would be of several types:

EXHIBIT 4-B: CONSTRUCTION SPENDING AND EMPLOYMENT

	ANNUAL AVERAGES: 1996-2000	2001-2005	2006-2010	Cumulative, 1996-2010
CONSTRUCTION SPENDING ($1,000s)				
Earthmoving and Other Heavy Construction	$20,920	$12,000	$0	$164,600
Single Family Construction	$10,452	$18,486	$9,594,000	$192,660
Buildings and Multifamily Construction	$13,577	$16,307	$5,678,667	$177,813
TOTAL	$44,949	$46,793	$15,273	$535,073
DIRECT CONSTRUCTION EMPLOYMENT (1) (AVERAGE ANNUAL FULL-TIME JOBS)				
On-Site (2)	237	268	97	3,011
Off-Site	59	67	24	753
TOTAL	296	335	121	3,763
INDIRECT AND INDUCED EMPLOYMENT				
Average annual jobs, Statewide (2)	612	710	264	7,932

NOTES: (1) Based on 1991 average ratio of one construction job for every $136,600 spent on construction (adjusted by current construction cost indices). Ratio further adapted slightly to reflect labor intensity of different types of construction.

(2) On-site jobs estimated as 80% of all construction jobs.

(3) Based on employment multipliers developed by DBEDT from State Input-Output model (Heavy Construction — 1.97 indirect and induced jobs per direct job; Single Family — 2.29; Building an Multifamily — 1.97 [average of commercial — 1.76, and multifamily — 2.17]).

SOURCES: Hawaii State DBED, 1992; Hawaii State 1982 Input-Output Model (unpublished tables).

EXHIBIT 4-C: DIRECT OPERATIONS EMPLOYMENT, BY LOCATION IN PROJECT

	2000	2005	2010
RESIDENTIAL AREAS (1)	16	50	64
COMMERCIAL AREAS (2)			
Convenience Store Areas	145	290	436
Mixed Use "Core"	174	348	523
Business Center	643	1,073	1,437
Light Industrial	120	479	719
OTHER AREAS (3)			
Schools	60	120	120
Civic and Parks	20	34	47
Golf Course	40	40	40
Pineapple Museum	25	25	25
DIRECT OPERATIONS EMPLOYMENT	1,243	2,459	3,410

NOTES: (1) Estimated on the basis of occupied units, with more jobs expected in high-density areas.

(2) Estimated on the basis of jobs per square feet of net usable space, with ratios varying from one job per 200 square feet in convenience shops, to one job per 1,500 square feet in the light industrial area.

(3) Estimated on the basis of comparable operations in Hawaii (e.g., Central District public elementary schools).

- A few jobs are likely to be located in residential areas, involving household and personal care, along with rental management;
- Convenience stores would provide retail jobs;
- In the "core" and business center, health care (including elderly care) is expected to be a major activity;
- Elsewhere in the business center, back office jobs (in banking and finance, and in business services) would grow over time;
- A factory outlet center, suggested as a potential employment generator (Atwater/Stanney Consultants, 1992) in the business center, would provide retail jobs as of about 2000;
- The industrial area would provide jobs in warehousing and maintenance and repair industries;
- Other areas would provide jobs in education, landscaping, recreation, and retail operations.

Among the employment sources proposed for the project site, two deserve additional discussion:

- "Back office" operations in the business center would involve an appreciable number of white-collar jobs at a location that is inexpensive, compared to central sites, and attractive to employees who live nearby. Arguably, some of those jobs could be relocated to Mainland areas where sites, facilities, and personnel are all cheaper.
- The proposed factory outlet center would be unlike existing malls and planned "power centers" in Hawaii. Tenants would largely stress distinctive goods and known brands, rather than discount pricing. Customers would include both visitors and residents.

Arguably, these operations make a difference for the Island and State economies. Some "back office" operations retain jobs that might go elsewhere; the outlet center would garner a share of visitor spending. However, the project cannot take credit for the impact of these operations, which could easily be located in other projects outside central Honolulu.

Exhibit 4-D shows the assignment of direct operations jobs to industries. Indirect and induced jobs would develop along with direct jobs. Unlike the indirect and induced jobs associated with construction, the jobs shown in Exhibit 4-E would be permanent.

4.3.3 Labor Supply in Relation to Projected Employment

On Oahu, unemployment has been low for many years. Even in a recessionary period, islandwide unemployment is low compared to Mainland levels. Nonetheless, the jobs likely to be located in the project will probably be filled almost entirely by Island residents, for several reasons:

- The project's commercial and industrial areas are expected to house activities already found on Oahu;
- The project's location will make those jobs especially appealing to Central Oahu residents;
- The study area includes cases of high reported unemployment and low labor force participation. Women's labor force participation is below the Island average in all study area communities, especially at Schofield Barracks (as shown in Exhibit 2-F). These figures point to a pool of persons outside the labor market (and, it is likely, to others who are underemployed) many of whom would be interested in jobs on the project site.

  Roughly 5,000 military spouses live in the study area and nearby. Members of this group have expressed interest in more, and more diverse, jobs near their homes (National Military Family Association, 1987). Employment specialists dealing with military spouses expect continuing demand for jobs near Schofield Barracks (personal communications, Barbara Rybczyk, Executive Director, Joint Employee Management System, February 1992; Linda Keller, Office of the Community Commander, Schofield Barracks, February 1992).

  Moonlighting by some 6% of active duty military with dependents was also indicated by the 1987 survey. That finding suggests that 200 or more members of the Armed Forces may have, or be looking for jobs near, Schofield Barracks.

4.4 INCOME

Exhibit 4-E totals the wages and salaries likely to be associated with the project. Construction-related wages (for direct, indirect, and induced jobs) are expected to exceed

EXHIBIT 4-D: DIRECT, INDIRECT, AND INDUCED OPERATIONS EMPLOYMENT

	2000	2005	2010
DIRECT EMPLOYMENT, BY INDUSTRY (1)			
Agriculture (Landscaping)	26	26	26
Maintenance/Repair	60	240	359
Truck/Warehouse	60	240	359
Retail Trade	599	744	889
Eating and Drinking	68	126	184
Banking and Finance	112	336	560
Personal Services	81	180	259
Business Services	37	112	187
Amusement Services	10	10	10
Health, Professional Services	123	312	436
Education	67	134	141
TOTAL	1,243	2,459	3,410
INDIRECT AND INDUCED EMPLOYMENT (2) (BY TYPE OF DIRECT JOB)			
Agriculture (Landscaping)	12	12	12
Maintenance/Repair	79	316	474
Truck/Warehouse	69	278	417
Retail Trade	341	424	507
Eating and Drinking	61	112	164
Banking and Finance	120	360	599
Personal Services	67	148	212
Business Services	19	56	93
Amusement Services	5	5	5
Health, Professional Services	147	371	518
Education	29	58	60
TOTAL	948	2,139	3,063
DIRECT, INDIRECT, AND INDUCED EMPLOYMENT	2,191	4,599	6,473

NOTES: (1) Direct jobs shown in Exhibit 4-C allocated by Community Resources, Inc. to industries included in the Hawaii State Input-Output Model.
(2) Indirect and induced jobs estimated using Input-Output Model's Type II employment multipliers.

EXHIBIT 4-E: PERSONAL INCOME ASSOCIATED WITH PROJECT JOBS

	ANNUAL AVERAGE INCOME ($1000s): 1996-2000	2001-2005	2006-2010
DIRECT JOBS (1)			
Construction	$12,305.9	$13,477.4	$4,698.6
Operations	$11,091.9	$42,375.2	$67,576.7
INDIRECT AND INDUCED JOBS (2)			
Construction	$15,466.1	$17,959.3	$6,681.5
Operations	$10,569.8	$42,606.5	$69,008.5
TOTAL DIRECT, INDIRECT, AND INDUCED JOBS	$49,433.6	$116,418.4	$147,963.3

NOTES: (1) Incomes estimated from 1991 industry averages (for industries broken out in Exhibit 4-D). Average wages adjusted to 1992 dollars according to increases in the Consumer Price Index (CPI-U, Honolulu, mid-1991 to mid-1992).
(2) Indirect and induced jobs fall into many industry categories; hence, average wages reported for all industries were used to estimate income.

SOURCES: Hawaii State DLIR, 1992; Hawaii State DBED, 1992.

$25 million annually at their high point, and then to decline. Operations-related wages would be modest before 2000, but climb to over $150 million by 2010.

4.5 POPULATION AND HOUSING

4.5.1 Resident Population On Site

The project site currently has no population -- no residents will be displaced. (Again, at Poamoho Camp, which is also included in the DP Amendment application, no displacement is proposed.)

The population living on the project site is expected to reach nearly 2,000 by the year 2000, and to exceed 8,000 by 2010, as shown in Exhibit 4-F. It is assumed that:

- For most of the project, household sizes will be a bit smaller than the current averages in Wahiawa and Whitmore Village (shown in Exhibit 2-D), and comparable to the current islandwide average household size. This assumes that demand for housing will remain high, but crowding will diminish.

- The project will be suitable for many elderly households. The low household size estimate for multi-family units in Exhibit 4-F follows from this assumption. (However, elderly households and housing designed for the elderly could also be found in other housing types in the project.)

The design and market estimates developed to date suggest that the project will house Oahu residents, most of whom will have household incomes ranging from 80% to 120% of the island average. The project will likely appeal to people who work in the project's business center, its other commercial/industrial areas, Wahiawa businesses, and Mililani Tech Park. Some military demand is also anticipated, largely from families of personnel with high enlisted or officer rank. (Military families will nearly all seek rentals, since their tours on-island normally last only three years.)

Families living in the project are likely to consist largely of middle-income younger working families. With some housing developed specifically for the elderly, the age distribution will include more seniors than in other new subdivisions. Overall, the project is expected to mirror the State's projected age distribution.

Most residents are expected to move from other sites on Oahu, especially Ewa and Central Oahu. In view of military families' need for housing, which leads many to rent in Mililani and other areas, an appreciable minority of families on-site could be military. The project has no housing for tourists -- no visitors or part-time residents are projected in the residential population.

EXHIBIT 4-F: ON-SITE HOUSING AND RESIDENT POPULATION

	2000	2005	2010
OCCUPIED UNITS (1)			
Market Single Family	202	617	1,168
Affordable Single Family	120	234	234
Medium Density	133	626	627
Multifamily	250	693	862
TOTAL	705	2,170	2,890
POPULATION			
Market Single Family (2)	626	1,914	3,620
Affordable Single Family (2)	371	724	724
Medium Density (3)	400	1,879	1,881
Multifamily (4)	550	1,524	1,896
TOTAL	1,947	6,041	8,121

NOTES: (1) See Exhibit 1-D for general buildout schedule. Occupancy based on market report and assumption that 5% to 10% of units will be vacant at any time.
(2) Average household size estimated as 3.1 persons/household.
(3) Average household size estimated as 3.0 persons/household.
(4) Average household size estimated as 2.2 persons/household.

4.5.2 Population and Housing Associated with Project Employment

As jobs develop at the project site, people from all over Oahu will likely fill them. Many residents of nearby communities will be especially interested in these jobs. Some will be interested in jobs near Wahiawa or Schofield, but not further from home. At first, few of those working on site will live there, and vice versa. Over time, people working on site will find study area homes especially convenient, and will tend to live in the study area or the Central Oahu/North Shore region. Again, over time, project residents will number among those especially interested in jobs at the project site. In the following calculations, this process is foreshortened, to reach a maximal-impact assessment of the regional housing impacts of project-related employment.

Jobs associated with project operations will support a Statewide population of about 13,600 people (workers and dependents) in 2010, as shown in Exhibit 4-G. Of these, an estimated 7,700 people could well live in the Central Oahu and North Shore Development Plan areas. Project-related workers could occupy about 900 households in the region in 2000, and over 2,500 in 2010.

(Both the Central Oahu and North Shore areas are treated as likely home sites for the bulk of the direct and induced workers associated with project operations, since Haleiwa and Waialua on the North Shore are as close to Wahiawa as leeward Central Oahu projects, and these towns have limited employment bases. However, given the limited North Shore housing stock, the large majority of the operations workforce living near the project site would expectably live in the Central Oahu area.)

Demand for new or additional housing occurs as young adults develop both their own families and the resources to live independently. Despite Hawaii's stable economy, new household formation tends to occur at low rates, due in part to high housing costs. Arguably, with an expanded housing supply, increasing numbers of young families will be able to establish themselves independently on Oahu. However, since part of the project workforce will likely be military spouses (who are not likely to seek new homes), total new housing demand from project workers is likely to be in the low to moderate range.

Exhibit 4-G shows both low and high estimates of new housing demand from workforce households. It should be stressed that demand for new housing translates into action only over some years' time. Estimates of 2010 housing demand provide an estimate of the number of families looking seriously for additional housing at that time, and the number of new rental or for-sale units eventually needed by this workforce population.

The total Statewide housing demand -- combining existing housing arrangements with new demand -- associated with the 2010 project-related workforce would amount to 5,200 to 5,800 units. Of these, some 3,000 to 3,300 units would likely be located in the Central Oahu/North Shore region.

EXHIBIT 4-G: POPULATION AND HOUSING DEMAND ASSOCIATED WITH ON-SITE JOBS

	2000	2005	2010
OPERATIONS JOBS (1)			
Direct On-Site Operations Jobs	1,243	2,459	3,410
Indirect and Induced Operations Jobs	948	2,139	3,063
TOTAL	2,191	4,599	6,473
CENTRAL OAHU/NORTH SHORE SHARE OF DIRECT, INDIRECT, & INDUCED OPERATIONS JOBS (2)	1,279	2,609	3,647
POPULATION SUPPORTED BY WORKFORCE, INCLUDING WORKERS (3)			
Total (Statewide)	4,601	9,657	13,593
Central Oahu/North Shore Share	2,686	5,479	7,659
WORKFORCE HOUSEHOLDS (4)			
Total (Statewide)	1,524	3,198	4,501
Central Oahu/North Shore Share	889	1,814	2,536
ESTIMATED DEMAND FOR NEW HOUSING			
Low (5)			
Total (Statewide)	229	480	675
Central Oahu/North Shore Share	133	272	380
High (6)			
Total (Statewide)	457	959	1,350
Central Oahu/North Shore Share	267	544	761

NOTES: (1) From Exhibit 4-D.
(2) Assumes 80% of direct operations jobs, and 30% of indirect and induced operations jobs will go to Central Oahu/North Shore residents.
(3) Assumes 2.1 persons for every operations job, based on 1990 County average of 1.46 workers per household.
(4) Based on 1990 County average of 3.02 persons per household.
(5) Estimates 15% of worker households will require new housing.
(6) Estimates 30% of worker households will require new housing.

The project's housing stock and regional housing demand are nearly balanced; as indicated by the fact that "Housing Sock Minus Regional Demand" approaches zero in 2010:

	2000	2005	2010
On-Site Occupied Housing Units	705	2,170	2,890
Estimated Workforce Regional Housing Demand:			
1. Workforce Households	889	1,814	2,536
2. Workforce Households + New Demand)			
Low Estimate*	1,022	2,086	2,916
High Estimate*	1,156	2,358	3,297
On Site Housing Stock Minus Regional Demand			
1. Workforce Households Only	-184	356	354
2. Households + New Demand			
Low Estimate*	-317	84	-26
High Estimate*	-451	-188	-407

* See Exhibit 4-G.

These calculations indicate that the project theoretically could house the regional workforce associated with its operations and could also provide housing covering much of the new demand that the workforce could generate. (There is no expectation that people working on the project site would only live on-site. Over time, they would tend to live in the study area and region.)

The above calculations suggest that, by locating new jobs in Central Oahu, the project will not create any sudden surge in demand for housing in the area. Hence the project's overall design limits greatly the potential for strains on regional resources that could be expected with a new project in Central Oahu.

4.5.3 De Facto Population

The total number of people actually on the project site (residents at home, workers, customers, etc.) will change from time to time and as the project is built out. Exhibit 4-H provides estimates of de facto population under weekday and weekend conditions. Given

EXHIBIT 4-H: DE FACTO POPULATION ESTIMATES (1)

	2000	2005	2010
WEEKDAY			
RESIDENTS			
Single Family and Medium Density (2)	279	903	1,245
Multifamily (3)	220	610	758
WORKFORCE (4)	1,057	2,090	2,899
PEOPLE VISITING THE SITE			
Shoppers (5)	968	1,458	1,871
Students (6)	757	1,514	1,514
Golfers (7)	100	100	100
Visitors to other Recreation, Cultural Sites	150	150	150
TOTAL	3,531	6,826	8,538
WEEKEND			
RESIDENTS			
Single Family and Medium Density (8)	838	2,710	3,735
Multifamily (8)	330	914	1,137
WORKFORCE (9)	249	492	682
PEOPLE VISITING THE SITE			
Shoppers (10)	1,065	1,604	2,059
Golfers (11)	120	120	120
Visitors to other Recreation, Cultural Sites (11)	180	180	180
TOTAL	2,782	6,021	7,913
PERSONS PER ACRE			
Weekday	4.1	7.9	9.9
Weekend	3.2	7.0	9.2

NOTES: (1) De facto population includes all persons present on site. De facto population changes from hour to hour and day to day. The estimates provided here can be read for total numbers — in the same range as the full residential population — or for indications of the numbers of people expected to visit different project areas.
(2) Assumes 20% of these residents on site.
(3) Assumes 40% of these residents on site.
(4) Assumes 85% of total workers on site.
(5) Based on one shopper per 250 square feet of commercial space.
(6) Based on DOE ratio of 12.6 elementary school children per teacher.
(7) Based on an expected average of 250 rounds per day, maximum of 40% on the course or at clubhouse at one time.
(8) Assumes 60% of these residents on site.
(9) Assumes 20% of total workers on site.
(10) Assumes 110% of average use.
(11) Assumes 120% of average use.

the complexity of the project, these estimates are rough. Still, they serve to suggest that the size of the population on the site will change little from hour to hour -- de facto and residential population totals are very similar by 2005. Commuters will leave their homes on weekdays, but workers and shoppers will come in comparable numbers to the site.

The density of use shown in Exhibit 4-H can be compared to 1990 residential population densities for study area and nearby communities (U.S. Department of Commerce, Bureau of the Census, 1991b):

Census Designated Place	Residents per acre, 1990
Study Area:	
Schofield Barracks	11.3
Wahiawa	12.9
Wheeler	1.8
Whitmore Village	5.9
Other Communities:	
Mililani	11.8
Haleiwa	2.1
Waialua	5.1

Estimates of density can be greatly affected by the way boundaries are drawn. Nonetheless, these figures suggest (a) that the region currently includes two sorts of communities, with relatively dense and light populations, and (b) the proposed project would in time come to resemble the denser communities, but would be significantly less dense than these are today. (The highest density in Exhibit 4-H is 77% of Wahiawa's 1990 figure.)

Some of those expected to spend time at cultural resources and stores in the project would likely be visitors to Oahu; most would be residents. Since the project is located on the route now taken by visitors on tours around the island, stops at the Pineapple Museum or other sites could easily be added. The project's components would likely affect the overall numbers of tourists travelling around the island only marginally.

4.5.4 Housing, Population, and Employment in Relation to City and County Policies

The City and County General Plan, as revised in early 1989, includes guidelines for population growth in order to (a) meet housing needs (Objective C, Policy 2); (b) avoid an "undesirable spreading of development"; and (c) keep population densities in outlying

areas "consistent with the character of development and environmental qualities desired for such areas" (Objective C, Policy 3).

In some respects, the proposal is consistent with these policies:

- The Wahiawa Lands adjoin an existing town, and are planned to complement it;
- The Wahiawa Lands appear largely to lie within the "urban fringe" area;
- The density of the development will be less than that now found in the adjacent community; and
- The project would provide much new housing for Oahu residents.

However, the Plan guidelines have been translated into projected population ranges (as shown in Exhibit 4-I). The project appears to be inconsistent with those guidelines.

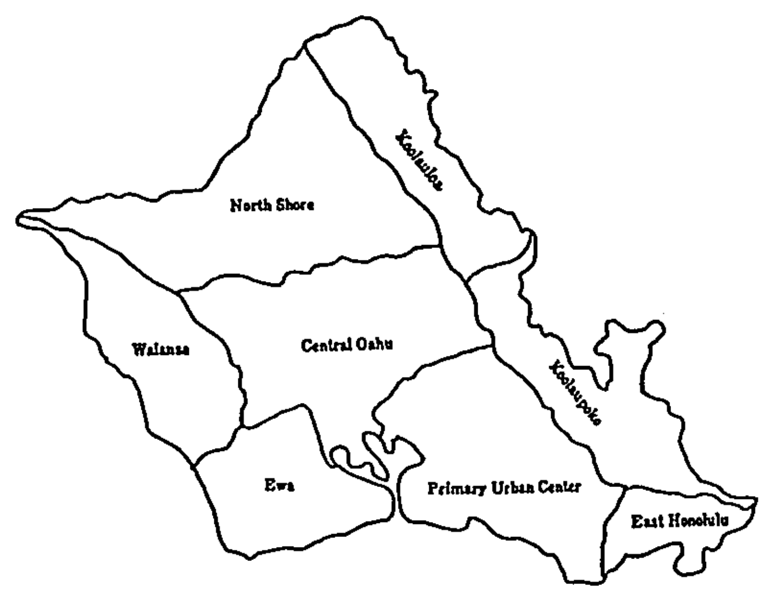
The 1990 population of the Central Oahu and North Shore Development Plan areas (146,427 persons) is already about 80% of the maximum population target for the combined areas. Proposals for which Development Plan approvals have already been given could house all or nearly all the remaining 20%. The project would add another 8,100 people to the region, about 4.4% of the total for the two areas.

The proposal comes at a time when government projections and policies governing land use are under discussion, and could soon be changed:

- The State's M-K Series Projections, on which the City's population projections and guidelines depend, will be reviewed and replaced on the basis of 1990 Census data.
- The M-K Series assumption that economic growth will shift nearly entirely from Oahu to the other islands in the coming years may be questioned in light of low occupancies at Neighbor Island resorts. Consequently, population growth could be more concentrated on Oahu than was projected.
- In response to development proposals that could lead to an overall development of housing in Central Oahu and the North Shore at or beyond General Plan guidelines for 2010, both the City and County Department of General Planning and the City Council have shown favor towards proposals that increased the stock of affordable housing.

EXHIBIT 4-I: TARGET POPULATIONS FOR DEVELOPMENT PLAN AREAS

	1980		2010	
	Resident Population	% of Total	Project Range of Population	Target % of Total
OAHU TOTAL	762,565	100.0%	949,500 - 1,049,500	95.0% - 105.0%
Primary Urban Center	417,240	54.7%	450,800 - 497,800	45.1% - 49.8%
Ewa	35,523	4.7%	119,900 - 132,900	12.0% - 13.3%
CENTRAL OAHU (2)	101,685	13.3%	148,900 - 164,900	14.9% - 16.5%
East Honolulu	43,213	5.7%	53,000 - 58,000	5.3% - 5.8%
Koolaupoko	109,373	14.3%	109,900 - 121,900	11.0% - 12.2%
Koolauloa	10,983	1.4%	13,000 - 14,000	1.3% - 1.4%
North Shore	13,061	1.7%	16,000 - 18,000	1.6% - 1.8%
Waianae	31,487	4.1%	38,000 - 42,000	3.8% - 4.2%



NOTES: (1) Population ranges based on target percentages specified in the General Plan and the Hawaii State DBED Series M-K population projection of 999,500 for the year 2010.
(2) Includes the project site.

SOURCE: Honolulu City & County, 1989.

The ongoing evolution of City and County population policy makes the project's "fit" with policy far from clear.

An important additional consideration is the combination of jobs and housing in the project. This would encourage short-distance commuting by Central Oahu and nearby North Shore residents, rather than the long commute to the Primary Urban Center that increasingly congests Oahu's highways. Consequently, the project is in the long term not expected to contribute greatly to the traffic congestion of great concern to residents and policy makers alike.

(With more jobs in the project and at Mililani Tech Park, the Wahiawa area could become increasingly a regional center, rather than a suburban "urban-fringe" area fully dependent on links to Honolulu. Presumably this increased level of local community organization would be compatible with General Plan aims.)

4.6 FISCAL IMPACTS

4.6.1 Approach

The project involves no new capital flows from outside Hawaii. It is expected to house Oahu residents, and not to attract new residents from off-island. It is an indirect effect of the overall growth of the island and State economies, not a new stimulus. This means that its economic impact is, for government entities, minimal or nil. As a result, its fiscal impacts -- the revenues and costs for government bodies associated with the project -- are also small.

The question of locational impacts remains: will development of this new community commit government bodies to additional costs not offset by new revenues? Specific government obligations and developer contributions will be identified in the development process. At this point, a general approach can be taken. Some government revenues and costs can properly be attributed to the project as a source of locational, rather than direct economic, impacts. A narrow range of revenue flows can be considered:

Revenue/Cost Flow	County	State
Construction spending		Excise, Income taxes
Planned development	Real Property taxes	
	Urban Devel. CIP, Highways, Mass Transit Spending	Urban Devel. CIP, Highways Spending

The impact of new project development for government costs occurs over a limited term. The costs arise to the extent that government must spend unusually large amounts to accommodate needs arising in new locations. Over time, infrastructure will likely be developed, and residents' need for services will be at average levels (or lower).

To reach a worst-case estimate of the implications of new community development for government spending, it was assumed that government spending on functions sensitive to locational impacts would double during the project's construction period.

This approach sets aside revenues connected with operations on the site, along with revenues and costs attributable to the project's populations, as likely to arise with or without the project.

In addition, golf spending at the project can be considered as a new revenue stream, since pent-up demand for golf at controlled rates is so great that tee times could be filled simply by those who now play very rarely due to the cost of golf. However, government income from golf is not counted in this analysis, since it is possible the golf course could be a municipal course.

In the following sections, project-related revenues are set against costs estimated with reference to the average cost per person of various government functions. The method used to estimate government costs is chosen because it is (a) highly conservative, and likely to overestimate actual costs; and (b) sensitive to the scope of the project.

The actual costs of services to a new community are "marginal costs" -- for additional services -- not "average" ones. However, the average cost method is used as a conservative estimate of future spending. When a project is being planned, a marginal cost approach may not be possible or appropriate. The costs of many particular

improvements and services can be pinpointed, but the marginal cost to government attributable to a project may not be clear, for several reasons:

- It is difficult to specify the share attributable to a development, apart from pre-existing demand, or the impact of a new planned development, rather than infill and crowding;

- A new development may be subject to exactions for new infrastructure, and thus in important ways may be less costly for government than infill and crowding; and

- The amount and kind of developer contributions offsetting government costs are negotiated through the permit process. Over time, estimates of both costs and potential contributions become more specific.
For example, the plan considered in this report includes two six-acre elementary school sites. The State Department of Education has responded by (a) estimating future school populations for elementary, intermediate, and high schools in the area and (b) requesting that elementary school sites be eight acres if beside a park or ten to 12 acres if not (C. Toguchi, response to Application for Development Plan Amendment and Environmental Assessment, Wahiawa Lands Development, September 25, 1992). Further discussions between the developer and the Department could lead to (a) revision of the size of planned school sites; (b) consolidation of the sites, since the estimated elementary school population is smaller than that in most new elementary schools; or (c) contributions to the Department other than those shown in the plan. Since the impact of the project on Department operations has not been identified in detail, estimates of future costs must be highly preliminary and uncertain.

4.6.2 <u>City and County of Honolulu</u>

The City and County would gain in real property tax revenues throughout the life of the project, as shown in Exhibit 4-J. Increased revenues would climb to about $3 million annually as the project is built out.

(Currently, property taxes on the project site are low, since the site is subject to a 20-year agricultural dedication. That dedication expires in 1994.)

Exhibit 4-K shows the calculations used to estimate the average cost per new resident of additional City and County spending in support of a new community. Exhibit 4-L provides an estimate of the balance of revenues. It shows a cumulative balance of $13.1 million as of 2010, and a positive ratio of revenues to costs.

EXHIBIT 4–J: CHANGES IN REAL PROPERTY VALUES AND TAXES, WAHIAWA LANDS PROJECT (1)

	1992 (2)	1996	2000	2005	2010
A. AREAS (ACRES)					
ACREAGE TO BE DEVELOPED (3)	670	666	319	118	11
NEWLY DEVELOPED ACREAGE (ANNUAL)					
Improved Residential		0	28	38	2
Unimproved Residential		4	30	29	0
Apartment		0	4	0	0
Commercial, Industrial		0	22	4	6
Golf Course, Clubhouse (4)		0	204	0	0
CUMULATIVE DEVELOPED ACREAGE					
Improved Residential		0	71	219	313
Unimproved Residential		4	30	29	0
Apartment		0	16	35	46
Commercial, Industrial		0	30	64	97
Golf Course, Clubhouse (4)		0	204	204	204
TOTAL AREA DEVELOPED		4	351	552	659
B. VALUES ($1,000s)					
ACREAGE TO BE DEVELOPED (3)		$33,310	$15,957	$5,911	$537
ANNUAL NEW DEVELOPED LAND VALUE					
Improved Residential		$0	$35,700	$49,920	$4,992
Unimproved Residential		$380	$2,985	$2,944	$0
Apartment		$0	$2,820	$376	$0
Commercial, Industrial		$0	$18,113	$6,280	$4,833
Golf Course, Clubhouse (4)		$0	$20,000	$0	$0
CUMULATIVE DEVELOPED LAND VALUE					
Improved Residential		$0	$65,652	$229,080	$361,368
Unimproved Residential		$380	$2,985	$2,944	$0
Apartment		$0	$21,855	$72,427	$90,052
Commercial, Industrial		$0	$22,980	$52,473	$79,920
Golf Course, Clubhouse (4)		$0	$20,000	$20,000	$20,000
ANNUAL NEW IMPROVED VALUE					
Residential, Apt.		$0	$20,160	$21,744	$2,160
Commercial, Industrial		$0	$9,772	$3,505	$5,317
Golf Course, Clubhouse (4)		$0	$250	$0	$0
CUMULATIVE IMPROVED VALUE					
Residential, Apt.		$0	$40,410	$131,118	$195,108
Commercial, Industrial		$0	$14,322	$37,015	$63,020
Golf Course, Clubhouse (4)		$0	$250	$250	$250
TOTAL VALUE (LAND + IMPROVED)		$33,690	$204,411	$551,219	$810,255

EXHIBIT 4–J (CONTINUED)

	1992 (2)	1996	2000	2005	2010
C. EXEMPTIONS ($1,000s) (5)					
VALUE					
Improved Residential		$0	$16,400	$60,240	$85,680
Apartment		$0	$4,650	$15,410	$19,160
CUMULATIVE TAXABLE LAND VALUE					
Improved Residential		$0	$49,252	$168,840	$275,688
Apartment		$0	$17,205	$57,017	$70,892
D. TAXES ($1,000s)					
ACREAGE TO BE DEVELOPED (3)		$300	$144	$53	$5
DEVELOPED LAND VALUE					
Improved Residential		$0	$154	$527	$860
Unimproved Residential		$1	$12	$12	$0
Apartment		$0	$61	$201	$250
Commercial, Industrial		$0	$222	$506	$770
Golf Course, Clubhouse (4)		$0	$172	$172	$172
IMPROVED VALUE					
Residential, Apt.		$0	$158	$514	$765
Commercial, Industrial		$0	$122	$315	$536
Golf Course, Clubhouse (4)		$0	$2	$2	$2
TOTAL		$301	$1,045	$2,301	$3,360
E. INCREASE IN TAX REVENUES ($1,000s)					
TAX REVENUES BEFORE DEVELOPMENT (6)	$5				
DIFFERENCE IN TAX REVENUES					
TOTAL TAXES:					
Annual		$296	$1,040	$2,296	$3,355
Cumulative		$296	$2,529	$11,376	$26,337
TAXES, EXCLUDING GOLF					
Annual		$296	$866	$2,122	$3,181
Cumulative		$296	$2,355	$10,331	$24,422

NOTES:
(1) All figures in thousands of dollars, except "Areas" (in acres).
(2) Analysis based on increase in value from current levels. Increases due to preconstruction rezoning are not calculated.
(3) Excluded from this analysis: areas for roadways, parks, schools, and civic uses. Poamoho Camp is also excluded, as the landowner does not plan development there.
(4) Golf course and clubhouse separated to indicate impact of treating these as comparable to municipal facilities.
(5) Based on expected average exemptions in the various residential types:
Residential 1 exemption/unit ($40,000/unit)
Apartment 1 exemption/2 units ($20,000/unit)
(6) Average tax per acre ($7.51) estimated from Real Property tax records of Galbraith lands, separating out areas completely or nearly all in future project development area.

SOURCES: Honolulu City & County 1992–1993 real property tax rates; City & County tax records.

EXHIBIT 4-K: PER CAPITA ALLOCATION OF GOVERNMENT EXPENDITURES, CITY & COUNTY OF HONOLULU

	1990 EXPENDITURES	Service Population Includes Visitors?	Average Expenditures per Resident (2)	Average Expenditures per Visitor (2)	Additional Expenditures per Resident (3)
FUNCTION (1)					
General Government	$75,006,586	No	$89	—	—
Public Safety	$152,963,360	Yes	$168	$168	—
Highways	$26,065,514	Yes	$29	$29	$29
Health and Sanitation	$70,099,321	Yes	$77	$77	—
Economic and Urban Development	$16,744,798	No	$20	—	$20
Recreation	$44,600,318	Yes	$49	$49	—
Mass Transit	$53,233,609	No	$63	—	$63
Interest	$48,805,135	No	$58	—	—
Bond Redemption	$27,372,000	No	$33	—	—
Retirement and Pension	$13,514,496	No	$16	—	—
Cash Capital Improvements	$40,340,199	Yes	$44	$44	$44
Miscellaneous	$45,807,556	No	$55	—	—
TOTAL	$614,552,892		$700	$366	$156
ADJUSTED TOTAL (4) (1992 Dollars)			$795	$416	$177

NOTES: (1) From Tax Foundation of Hawaii, 1991.
(2) Based on 1990 mid-year population estimates for Honolulu County:

Resident	De Facto
839,300	913,100

(3) Estimated by CRI to cover additional government costs associated with private development of new communities.
(4) Based on increases in Consumer Price Index-Urban, Honolulu.

SOURCES: Hawaii State DBED, 1991a, 1991b; Tax Foundation of Hawaii, 1991.

EXHIBIT 4-L: BALANCE OF HONOLULU COUNTY REVENUES OVER COSTS ASSOCIATED WITH PROJECT

(in $1,000s)	1996 (1)	2000	2005	2010
REVENUES (2)	$296	$866	$2,122	$3,181
COSTS (3)				
Resident Population	0	1,947	6,041	8,121
Additional Costs, New Project (Average per person)	$0.2	$0.2	$0.2	$0.2
ANNUAL TOTAL	$0	$345	$1,071	$1,440
BALANCE (4)				
Annual Balance	$296	$521	$1,051	$1,741
Cumulative Balance	$296	$1,698	$5,667	$13,118
Ratio of Cumulative Revenues to Costs	N/A	3.6	2.2	2.2

NOTES: N/A Data not available.
(1) 1996 shown as sample year, since there would be no population or development yielding increased real property taxes in earlier years.
(2) From Exhibit 4-J, excluding revenues from the golf course.
(3) From Exhibit 4-K.
(4) Balance is calculated for entire construction period. Additional costs analyzed here would end during that phase (but are treated as continuing throughout the phase).

4.6.3 State of Hawaii

State revenues associated with the locational impact of the project are shown in Exhibit 4-M. The revenues are all construction-related, since revenues associated with operations are not clearly dependent on the creation of the project as a new community. State revenues will climb to $5.6 million annually at the height of construction, then diminish at the end of the period.

Exhibit 4-N shows the estimated cost to the State per resident of development of a new community, during the construction period. As the resident population increases, that cost would rise from $1.3 million in 2000 to $5.5 million in 2010, as shown in Exhibit 4-O. The cumulative balance of project development is estimated as $7.2 million, and the ratio of revenues to costs is positive throughout the period of development.

EXHIBIT 4-M: SELECTED STATE REVENUES ASSOCIATED WITH PROJECT

(in 1,000s)	1996	2000	2005	2010
REVENUES				
EXCISE TAXES				
Construction Spending (1)	$1,351	$1,191	$2,486	$123
Construction-Related Workforce Spending (2)	$490	$537	$1,103	$52
CORPORATE INCOME TAX (3)				
Construction	$208	$183	$382	$19
PERSONAL INCOME TAX (4)				
Construction-Related Workforce Incomes	$688	$754	$1,547	$73
ANNUAL TOTAL	$2,737	$2,664	$5,517	$268

NOTES: (1) Calculated at 4.167% of direct spending.
(2) Calculated at 4.167% of workforce income spent on taxable items. Disposable income estimated from 1988-1989 U.S. Bureau of Labor Statistics Survey.
(3) Calculated at 6.4% of profits, with 10% profit margin assumed.
(4) Calculated at 4.04% of wages.

SOURCE: Hawaii State DBED 1991a; Tax Foundation of Hawaii, 1991.

EXHIBIT 4-N: PER CAPITA ALLOCATION OF GOVERNMENT EXPENDITURES, STATE OF HAWAII

	1990 EXPENDITURES	Service Population Includes Visitors?	Average Expenditures per Resident (2)	Average Expenditures per Visitor (2)	Additional Expenditures per Resident (3)
FUNCTION (1)					
General Government	$331,005,886	No	$297	—	—
Public Safety	$131,689,766	Yes	$105	$105	—
Highways	$79,841,432	Yes	$63	$63	$63
Natural Resources	$45,750,104	Yes	$36	$36	—
Health and Sanitation	$186,316,810	Yes	$148	$148	—
Hospitals and Institutions	$167,947,449	No	$151	—	—
Public Welfare	$474,658,760	No	$426	—	—
Education	$1,122,513,037	No	$1,008	—	—
Recreation	$43,950,676	Yes	$35	$35	—
Utilities	$212,061,969	No	$190	—	—
Debt Service	$272,820,336	No	$245	—	—
Retirement and Pension	$71,299,611	No	$64	—	—
Employees' Health & Hospital Insurance	$1,013,474	No	$1	—	—
Unemployment Compensation	$47,845,711	No	$43	—	—
Grants-in-Aid to Counties	$73,471,454	No	$66	—	—
Urban Redevelopment & Housing	$321,005,449	No	$288	—	$288
Cash Capital Improvements	$303,833,695	Yes	$242	$242	$242
Miscellaneous	$87,479,422	No	$79	—	—
TOTAL	$3,974,505,041		$3,488	$629	$593
ADJUSTED TOTAL (4) (1992 Dollars)			$3,962	$715	$674

NOTES: (1) From Tax Foundation of Hawaii, 1991.
(2) Based on 1990 mid-year population estimates for the State:
Resident 1,113,500; De Facto 1,257,600
(3) Estimated by CRI to cover additional government costs associated with private development of new communities.
(4) Based on increases in Consumer Price Index-Urban, Honolulu.

SOURCES: Hawaii State DBED, 1991a, 1991b; Tax Foundation of Hawaii, 1991.

EXHIBIT 4-O: BALANCE OF STATE REVENUES OVER COSTS ASSOCIATED WITH PROJECT

(in $1,000s)	1996	2000	2005	2010
REVENUES (1)	$2,737	$2,664	$5,517	$268
COSTS (2)				
Resident Population	0	1,947	6,041	8,121
Additional Costs, New Project (Average per person)	$1	$1	$1	$1
ANNUAL TOTAL	$0	$1,312	$4,071	$5,473
BALANCE (3)				
Annual Balance	$2,737	$1,352	$1,446	($5,205) (4)
Cumulative Balance	$2,737	$20,655	$27,543	$9,914
Ratio of Cumulative Revenues to Costs	N/A	9.3	2.6	1.2

NOTES: N/A Data not available.
(1) From Exhibit 4-M.
(2) From Exhibit 4-N.
(3) Balance is calculated for entire construction period. Additional costs analyzed here would end during that phase (but are treated as continuing throughout the phase).
(4) Parentheses indicate a negative number.

5.0 FIT WITH SURROUNDING COMMUNITIES

The project's social "fit" or compatibility with existing nearby communities cannot be fully predicted or guaranteed. Still, available evidence suggests that the project can over time be integrated with Wahiawa and Whitmore Village. Such integration would depend on design decisions and continuing community involvement. While many residents appear receptive towards the project's key features (housing and jobs), considerable resistance to a new development on the project site must be recognized.

5.1 APPROACH

5.1.1 "Fit" or Compatibility

On several occasions, project representatives have stressed the aim of making the project compatible with Wahiawa. Nearby residents have discussed the project as changing not just the project site but the character of the adjacent community.

The idea of "fit" or "compatibility" with existing communities is complex. Both "compatibility" and "community character" depend on personal viewpoints. Compatibility can be a matter of similarity -- the new project should not seem jarringly different. Yet it also can be a result of a new project meeting needs that the community did not meet elsewhere.

General understandings of these matters emerge through public discussions. This assessment cannot predict the outcome of those discussions. Instead it can summarize major themes likely to emerge and help to inform those discussions. Judgments of the project's compatibility with the community are left to the readers.

In this chapter, perceptions and concerns expressed by study area residents are grouped under a few headings. Factors likely to support or qualify resident concerns when and if the project is developed are noted.

(Resident concerns with engineering, infrastructure, and resource issues are not discussed here. Technical reports from other consultants address these concerns. It is assumed that permitting authorities will not allow the project to proceed unless effective solutions are found to problems of water supply and the like.)

5.1.2 Sources

This chapter draws on three major sources: statements at community meetings, a survey conducted in August 1992, and interviews conducted by Community Resources, Inc. (CRI) staff in September, October, and November 1992. These provide different types of information about community understandings and concerns:

COMMUNITY MEETINGS. Meetings provide evidence of community concerns. They give some community members an opportunity to express their views in detail.

A series of meetings of the Citizen's Advisory Committee for the project have brought together community leaders and project representatives. Detailed minutes were kept. These included questions raised by members of the community. Also, the October 1992 meeting of the Wahiawa Neighborhood Board included a presentation concerning the project, followed by discussion. (Minutes of the Wahiawa Neighborhood Board for the last two years were also reviewed to identify major concerns that recur in community discussions.)

SURVEY. Any survey provides a snapshot of community opinion. Opinions change as more information is available about a project and various parties state their points of view in public debate. Nonetheless, a random-sample survey provides valuable information about community views, as distinct from the perceptions of a few leaders or outspoken residents.

The August 1992 survey was framed to (a) identify community concerns about development that would expand Wahiawa; (b) learn, in a preliminary way, how the community would react to potential project components; yet (c) not ask residents to favor or oppose the project since there had been little publicity about the project at that time. The survey questions and responses are shown in Appendix A.

COMMUNITY INTERVIEWS. CRI staff conducted open-ended interviews with a variety of "key informants," persons likely to know about the issues and concerns important to different groups in the community. The interview process focused on residents of Wahiawa (including Whitmore Village), but a few leaders from other communities in the region also contributed their perspectives. (See Appendix B for a list of interviewees.)

The interviews provided opportunities to discuss concerns at some length, and to consider alternatives and potential mitigations. Appendix C provides a list of the issues and concerns mentioned in the interviews. Informants were shown a map and project description that differ from the current project description only in detail. The interview handout is also included in Appendix C.

5.2 COMPATIBILITY WITH WAHIAWA AND WHITMORE VILLAGE

Exhibit 5-A summarizes the major opportunities for the project to "fit" with Wahiawa and Whitmore Village, along with major potential problems of fit.

5.2.1 Community Character

The project could be compatible with valued elements of Wahiawa's community character. It could respond to felt needs of existing residents and support a long-term process of renewal. However, strong resident concerns about the effect of the project on Wahiawa's character and economy remain.

Historically, Wahiawa has been an independent community. Surrounded by pineapple fields and military bases, Wahiawa was the only town in upland Central Oahu until the development of Mililani. It has combined the institutions and services of a district center (court, police station), plantation town (stores, some recreation areas), and Army base town (entertainment areas). With the highway improvements finished in recent years, Wahiawa residents can commute to the urban center, and servicemen can quickly reach Waikiki and other entertainment areas serving the whole island.

The result is that Wahiawa, while generally prosperous, seems in decline or even "raunchy" to some outsiders. Both commercial and residential areas have seen recent improvements, but overall town planning is constrained by geography and the mix of uses it supports.

The project could help revitalize community character by creating a greater Wahiawa. Many residents said they feel Wahiawa lost its prominence in Central Oahu when Mililani was developed. With new commercial and civic areas, in addition to existing ones, Wahiawa could regain a central role.

Additional housing and jobs would help Wahiawa to retain its younger people. **However, Wahiawa residents have stressed a "small town" quality to Wahiawa,** especially felt in residential areas, that may be jeopardized by the project. Some thought the project would overshadow older parts of Wahiawa, making them less desirable.

Project development would enable Whitmore Village to be more closely linked to the rest of the community. (Survey respondents now tend to see Whitmore as separate.) On the other hand, some praised the view over open fields on Whitmore Avenue when leaving Whitmore Village, and regretted the loss of a feeling of isolation due to the project.

Residents expressed concern that the project would result in a loss of agricultural or rural identity for Wahiawa. Project development means that the sight

EXHIBIT 5-A: PROJECT COMPATIBILITY WITH THE WAHIAWA COMMUNITY

	OPPORTUNITIES FOR FIT	POTENTIAL PROBLEMS OF FIT
COMMUNITY CHARACTER	Revitalization Housing for Wahiawa families Integration of Whitmore with greater Wahiawa Help meet need for elderly housing Golf course preserves open space, provides recreation Project design	Potential shift of Wahiawa "center of gravity" to new area Loss of agricultural identity Loss of "small town" feeling due to project size Change due to new residents Inappropriate for Wahiawa; preference for agriculture Project design
ECONOMY	More commercial activity More jobs in area	Potential competition with existing businesses
SOCIAL LIFE	More public recreation resources; enhancement of Lake Wilson New housing and increased variety of housing in Wahiawa	Resources located away from older parts of Wahiawa
DAILY ACTIVITIES	Shorter commutes for some with nearby jobs Convenient shopping for Whitmore Additional retail outlets serving all of Wahiawa	Construction noise and dust Traffic

(and, at times, noise and dust) of pineapple cultivation will be distant from homes now at the edge of Wahiawa. On the other hand, the project need not threaten the viability of pineapple cultivation (Decision Analysts Hawaii, Inc. [1992].)

Several Wahiawa residents thought that new residents of the project would be more affluent that most in Wahiawa and would tend not to respect the town's history and lifestyle. However, the prices proposed for new housing in the project are in line with Wahiawa prices, making it possible for many project residents to share roots and attitudes with residents of older neighborhoods.

Relatively few people in Wahiawa now work on the plantations (as shown in Exhibit 2-F). The town's agricultural identity is more a matter of atmosphere and support for the industry than of economic dependence. Consequently, that identity may be strengthened or weakened by project design decisions. These could be crucial in developing a "country" atmosphere compatible with Wahiawa rather than a "suburban" one.

The golf course included in the project would preserve open space and serve as a recreation resource for the community. However, many residents commented that a golf course is inappropriate in Wahiawa, especially as a use of land now in agriculture. Some golfers expressed this reservation, but others expressed interest in playing on the course.

5.2.3 Economy

Operational jobs and retail outlets on the project site would be welcome to many, according to the survey and interviews. Stores, theaters, and sit-down restaurants were mentioned as desirable. However, several Wahiawa residents expressed concern that stores along Wahiawa's main commercial streets could suffer from competition. They pointed to Mililani as a development that had attracted patrons away from Wahiawa.

5.2.4 Social Life

Throughout Hawaii, the transformation from a plantation economy to a service economy has weakened many people's ties to their home communities. Family and neighborhood ties are said to have weakened. People find that the time and space to share in group activities, such as recreation, are in short supply.

Wahiawa residents believed that their community needs more recreation space and facilities, especially ball fields. The project includes several parks. Several residents thought these would be valuable additions.

A potential problem of fit has to do with access to the recreation facilities, location away from older parts of Wahiawa. This may be especially problematic for small children and the elderly, who cannot travel independently.

The project would create a larger and more diverse housing stock to meet the varied housing needs of Wahiawa families. According to some residents, some former Wahiawa residents have purchased homes in Mililani because it offered new and more varied types of housing while allowing them to live in Central Oahu.

To the extent that project site jobs will enable area residents to work near home, the project will help them free up time for family and community life.

5.2.5 Daily Activities

The project would bring changes in everyday life for nearby residents. Increased traffic, construction traffic, and noise and dirt from construction were mentioned as disadvantages following from the project. Whitmore residents would find convenience stores more easily available. Residents of all study area communities would find a wider range of stores nearby.

Wahiawa residents strongly doubted whether infrastructural improvements would keep pace with new demands created by the project. They thought that bridges and road improvements would be built very slowly, and would fail to mitigate traffic congestion.

5.3 COMPATIBILITY WITH OTHER STUDY AREA COMMUNITIES

The preceding analysis deals with Wahiawa and Whitmore Village, but not Poamoho Camp and Schofield Barracks. The latter two areas have distinctive populations with concerns likely to be different from those of most Wahiawa residents. In both cases, questions of compatibility depend on decisions and actions independent of the project:

- POAMOHO CAMP. The project will affect this community by (a) changing its Development Plan designation to reflect its residential nature, and (b) bringing urban development much closer than at present. However, the future of the community depends above all on Del Monte, not the project.

  Like many plantation camps, Poamoho has not been subdivided. Residents rent their homes from Del Monte. As landowner, the Galbraith Trust expects that Del Monte's lease on the Poamoho Camp site will be renewed. Residents have expressed interest in buying their homes from Del Monte. Del Monte officials and Galbraith Trust representatives have expressed willingness to increase Camp residents' security of tenure. However, the concerned parties have not met to discuss specific plans for the community.

- SCHOFIELD BARRACKS. Army officials based at Schofield refused requests for interviews concerning social impacts because the project is a civilian concern outside their mission (personal communication, Mrs. Janet Lackey, Assistant Public Affairs Officer, 25th Light Infantry Division, US Army, October 1992). The following comments derive from conversations with Army personnel and Schofield residents prior to the interview process, and with others with insight into Schofield residents' concerns.

  "Compatibility" with surrounding areas is much less of a concern for this community than others, because (a) the base forms a separate community; (b) personnel assigned to Schofield rarely stay longer than three years; and (c) Schofield residents may rely on Wahiawa for limited retail services, but most look elsewhere -- to stores on base, malls, and Waikiki -- to meet most of their needs for goods and entertainment.

  Should the project include housing for military families -- a possibility discussed with the Oahu Consolidated Family Housing Office but not worked out in any detail -- it would respond to a pressing need of Schofield personnel. Moreover, development of off-base housing for some families could allow enlisted personnel with low incomes to move on base. The result would be improved housing conditions and, possibly, a slight decrease in conflict between military and civilians in Wahiawa, since off-base residents would increasingly be higher in rank and income.

6.0 SOCIAL IMPACTS

6.1 OVERVIEW

Impacts on community organization, family life, values and lifestyle do not follow automatically from the nature and size of a project. They depend on details of planning, dialogue with the surrounding community, and interaction with other forces and events. Hence the aim of this chapter is to identify tendencies, dangers and opportunities, not predict what must happen.

Most social impacts are not inevitable. They can be reduced or avoided. Chapter 7 deals with measures to mitigate potential adverse impacts or respond to problems in achieving compatibility with the surrounding communities.

Major social impacts of the project include:

- The project would strengthen the local economy of upland Central Oahu by combining housing and employment generators in an area that has seen little employment growth.
- By providing new housing, the project would help to lessen social strains associated with crowding and the high cost of scarce housing.
- By expanding the urban area of Wahiawa, the project would tend to change the town's identity in several ways:
  - With pineapple cultivation moved away from more settled areas, Wahiawa's identity as a plantation town would tend to fade.
  - Whitmore Village would be more likely to be viewed as part of Wahiawa.
  - With a greater range of commercial outlets and job centers, Wahiawa would be viewed less as an Army base town, and more as a regional focus for upland Central Oahu and the nearby North Shore.
  - In the long run, the location of jobs near housing could make participation in community affairs easier for adults, helping to perpetuate volunteer activities and community organization.

The eventual outcome of these changes would greatly depend on community attitudes and organization in both the new and old parts of greater Wahiawa.

- If project components tend to complement, not compete with, similar resources in Wahiawa, Wahiawa residents would come to depend on old and new parts of town alike. Existing commercial areas could draw on a large client base. The project could encourage a general revitalization of Wahiawa. Otherwise, the project could have an adverse effect, mainly by drawing customers from existing commercial areas.

This summary leaves open the question of whether older parts of Wahiawa would in the long run be helped or harmed by the project. That question depends far too much on planning decisions and community efforts to support the town to be answered definitively here.

6.2 DEVELOPMENT OF SOCIAL IMPACTS OVER TIME

Some social impacts would be immediately apparent. Others would emerge over a period of decades. Exhibit 6-A provides a model of the development of these impacts.

In the early years of project development, the displacement of pineapple from the site would be striking. Construction impacts could cause irritation, but new buildings could be no less jarring for Wahiawa residents. Some now see urban Oahu as ending at Mililani, and Wahiawa as an isolated small town. Development north of Wahiawa could move the bounds of the larger urban area beyond Wahiawa.

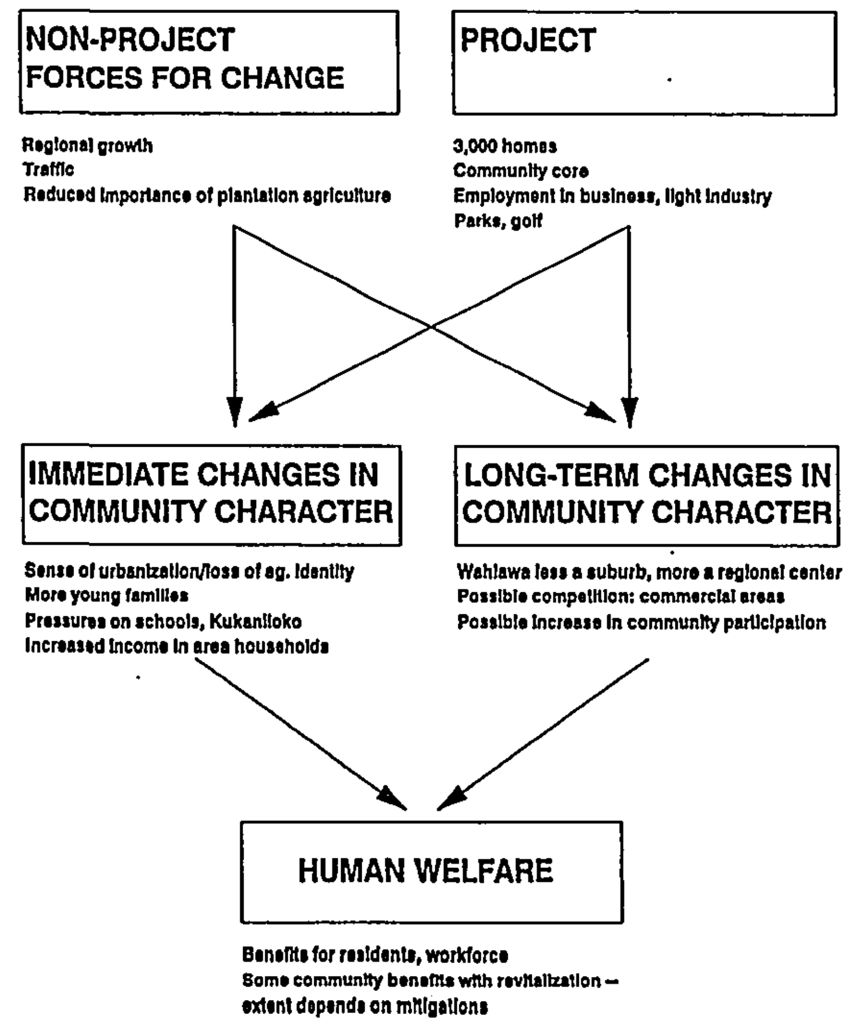
Similarly, early project development and consequent traffic would be of concern to some Waialua and Haleiwa residents as bringing urban problems closer to their "country" homes.

As the project develops, jobs and new housing would encourage young families to stay or come to the Wahiawa area. While project neighborhoods would not be particularly fancy, the project would offer a range of housing types and prices, increasing Wahiawa's appeal to Oahu residents.

Some military families will likely live in the project, much as such families rent in Mililani now.

(As noted previously, much of the operational workforce would in time be attracted to the general area, not just to the project site. Military spouses are expected to form a significant part of the workers on site, so households on military reservations as well as in civilian communities would prosper. Again, North Shore residents face very limited local job opportunities, and North Shore's sugar industry faces an even more uncertain than Central Oahu's pineapple plantations. Hence, project jobs would expand opportunities for residents of Waialua and Haleiwa.)

EXHIBIT 6-A: SOCIAL IMPACT MODEL



With increased population would come some increased patronage for commercial areas. At the same time, increases in the school population would add to existing problems in local schools, which are already operating at or beyond capacity.

As the project approaches build-out, greater Wahiawa could become a regional center. With many adults living and working in the town, participation in volunteer activities and community life could increase.

6.3 SOCIAL IMPACTS ON EXISTING SITES AND ACTIVITIES

6.3.1 Agriculture

Project impacts on the feasibility of agricultural operations are examined in a separate technical report (Decision Analysts Hawaii, Inc., 1992). In a discussion with CRI personnel, Wally Miyahira, Senior Vice President of Castle and Cooke Properties, felt the project should not adversely affect Dole Food Company's pineapple operations (November 2, 1992). Del Monte officials are currently working with other major land owners to replace the land that would be lost to the project. Comments on the social role of agriculture can be added here.

Even if pineapple operations continue at current levels, the future of pineapple will remain in doubt for Central Oahu residents. The project contributes to the perception that the industry is threatened by development, whether or not its viability is at stake. Uncertainty over Del Monte's ability to transfer operations from the project site to other lands would tend to strengthen that perception.

Moreover, project development could well indicate that the Wahiawa community supports taking of pineapple land for new housing and commercial development, as did most of the sample surveyed in August 1992. The fact that the town depends very little nowadays on agriculture would become obvious.

6.3.2 Existing Commercial Areas in Wahiawa

Project impacts on existing urban areas are far from certain. In the worst case, development of the new commercial areas and "core" could make existing retail outlets less viable if the project offers much the same merchandise and services, but with easier access or parking. Again, if the new commercial areas provide nearly all the goods and services needed by families in the area at competitive cost, much of the older commercial area could be restricted to dependence on young servicemen only as a customer base.

On the other hand, growth in the client base could help Wahiawa merchants to redevelop the older commercial area. The recent redevelopment of a supermarket and growth of a small community retail area around it show that Wahiawa can retain customers, despite competition from Mililani. Project site jobs would be likely to attract new buyers to older residential areas in Wahiawa, not just to the project site, replacing (or adding to) the client base.

Informants noted that new subdivisions around Waipahu could be closely comparable to the proposed development. Waikele, Gentry Waipio, and West Loch all contribute to the local population and economy. Their impact on Waipahu's older commercial area is as yet not apparent. The impact could be negative: strong concern has been expressed that new commercial outlets, notably the Waikele Power Center, will draw customers away from older Waipahu stores. On the other hand, urban growth has brought Waipahu expanded services (notably, St. Francis West Medical Center, and local outlets of Long's Drugs and Blockbuster Video) and helped to support historic preservation at the Waipahu Culture Garden Park.

6.3.3 Public Schools

The Environmental Impact Statement for the Wahiawa Lands Project will address the impact of the project on public facilities, including schools. However, project impacts may go beyond adding to the number of students and schools.

The local intermediate and public schools serve both established residents and military dependents, who may be poorly prepared to deal with each other's cultural peculiarities. Interpersonal conflicts at Leilehua High School in 1986-1987 were interpreted by many as evidence of widespread social tensions. So long as Wahiawa and Wahiawa's schools are populated only by two groups with little in common, this sort of interpretation will likely recur.

By increasing the sheer number of students served by an aging school plant, the project will tend to exacerbate existing problems. In the long run, however, changes in Wahiawa's economic base and increases in the number of military families living in Wahiawa could help to reduce conflict between military and civilian youth.

6.3.4 Poamoho Camp

Located across Kamehameha Highway from Poamoho Camp, the bulk of the project would likely affect the camp by increasing traffic on the highway, bringing road improvements, and providing stores nearby. (Single family housing and part of the golf course would be immediately across the highway from the Camp.)

The Pineapple Museum would be on the same side of the highway as Poamoho Camp. There could be little contact between the Camp and the tourists likely to visit the Museum. Alternatively, Poamoho Camp could be pointed out as an example of a mature plantation camp and recognized as a historical resource.

The key point is that Camp residents will face decisions concerning the visibility or privacy they desire, and will need to communicate these to Del Monte officials and Museum planners. In light of the distance between Poamoho Camp and the proposed Museum site, either historical interpretation or privacy could be achieved.

6.3.5 Kukaniloko

The Kukaniloko Birthing Stones, once a site reserved for high-ranking chiefs, now stand in a small woods in the midst of pineapple fields. The State now owns a five-acre site around the Birthing Stones, but has not acted to preserve the site. Plans to provide six more acres to buffer the site could help State planners and their cultural advisors to develop and implement a historic preservation plan for the site.

In public meetings, some Hawaiians have spoken eloquently of the sacredness of the Kukaniloko site, and questioned the appropriateness of urban development nearby. Mechanized agriculture was seen as more in keeping with the site, even though it destroys archaeological evidence.

Project development would bring road improvements and make the site more visible. It hence puts pressure on policy makers to decide on a specific plan for the site either permitting or barring casual visitors.

6.4 HUMAN WELFARE

For this report, CRI discussed potential project impacts on human welfare with social service providers active in the area. CRI has conducted similar discussions with specialists serving adjacent regions in past years. CRI draws the following conclusions from these discussions:

- Low incomes and lack of affordable housing are often central causes of social problems in the region. By creating jobs and expanding the supply of affordable housing, the project can be of general benefit.
- If the project brings improved services and facilities (notably for the elderly), others in the community would benefit.

- Crime is not a major problem in Wahlawa. With the project, the incidence of crimes such as burglary would grow apace with residential development No major change in the level or type of crime was anticipated (personal communication, Lieutenant Daniel Saragosa, acting Captain, Wahlawa Station, November 1992).
- However, some newcomers to the region view Wahlawa as an unknown, dangerous area. With project development, their anxiety could decrease.

In sum, the project could be beneficial to residents of study area communities -- but its impact on the overall welfare of the area as a whole is likely to be small in comparison to the overall trends identified in Chapter 3.

7.0 MITIGATIONS

This chapter includes an independent consultant's assessment of potential steps to mitigate anticipated socio-economic impacts of the project and to maximize project compatibility with adjacent communities. This chapter does not imply any decision or commitment to take some or all of the steps mentioned.

Furthermore, this chapter emphasizes an ongoing community involvement process. That process could generate specific actions and recommendations not included here or even contrary to suggestions made here. As the outcome of community discussions, such actions would likely be more appropriate ways to assure compatibility between Wahiawa and the project than alternative suggestions made here.

Exhibit 7-A lists mitigation measures and the various opportunities, concerns, or potential impacts to which they respond. Major themes of importance include:

COMMUNITY INVOLVEMENT. The ongoing effort to make the project compatible with the surrounding community demands continuing community involvement. Community perceptions of the project as more or less open to input affect judgments of compatibility.

With continuing community involvement, the project can go far towards supporting the revitalization of Wahiawa. The community involvement process can both pursue the general aim of encouraging Wahiawa residents to view the project as a resource for their community and develop plans to mitigate potential adverse impacts (competition threatening existing commercial areas; unwanted intrusions in Poamoho Camp).

REGIONAL ECONOMY. Project planners, developers, and, eventually, occupants can support the regional economy by (a) recognizing pineapple cultivation as basic to Central Oahu's economy and (b) minimizing competition between old and new commercial areas while encouraging cooperation in the redevelopment of older areas.

DESIGN. In line with the Galbraith Trust's aim of making the project compatible with Wahiawa, project design should support residents' views of their community as "country," emphasizing open space.

TRANSPORT. Project plans already work to reduce automobile use on the site. This project theme can be strengthened by the development of local transport

EXHIBIT 7-A: POSSIBLE MITIGATION MEASURES

	MEASURE	OPPORTUNITY, CONCERN, OR POTENTIAL IMPACT
COMMUNITY INVOLVEMENT	Continuing input on plans, design Identification of community strengths and needs (so project can respond to needs, aspirations)	Design project as valuable extension of Wahiawa
	Discuss ways to avoid competition with existing areas	Avoid potential competition with existing businesses
	Develop recreation plans to encourage Wahiawa/Whitmore residents to use new facilities	Encourage involvement of existing community with project and new residents
	Work with Poamoho Camp residents and Del Monte to address Camp's future; develop plan concerning impact of Museum visitors	Minimize potential disruption at Poamoho Camp
	Work with State, Advisory group for Kukaniloko	Help make preservation and interpretation of site sensitive to stakeholder concerns
	Provide up-to-date information about project and project impacts through planning phase and early construction	Respond to community concerns
REGIONAL ECONOMY	Support pineapple workers and growers; warn potential buyers that cultivation brings dust, noise, traffic	Avoid potential impacts on pineapple operations and workers
	Minimize competition between existing, new commercial areas	Encourage redevelopment of existing commercial areas
DESIGN	Develop design concepts and standards to emphasize open space Make higher density areas fit "country town" rather than "urban center" visions	Counter expectations that the project is just a suburb, presumably an upscale one
TRANSPORT	Discourage automobile use in project site; offer small-scale transport alternatives	Avoid adding to existing traffic congestion; underline project's identity as alternative to suburbs; link old and new sections of Wahiawa

alternatives. A small transport system could be restricted to the project or could link the project to other Wahiawa areas, encouraging shared use of recreation resources, elderly facilities, or other components of interest to the whole community.

APPENDIX A: A PLANNING SURVEY OF WAHIAWA RESIDENTS

Sample Size: 402 | Accuracy: +or-5%

Hello, my name is ____ from Datametric Research, a Hawaii research company. We're doing a short survey about community issues in the Wahiawa area. This is strictly an opinion poll. We're not selling anything.

In order to give everyone an equal chance to be interviewed, I need to talk with whatever adult, 18 or older, living there and is home right now, and had the MOST RECENT BIRTHDAY. Would you be that person?

(IF "YES", PROCEED. IF NOT, ASK TO SPEAK TO THAT PERSON. REPEAT FIRST PARAGRAPH, THEN PROCEED.)

By the way, all your answers will be kept strictly confidential.

1. Is your home in the Whitmore Village area above Lake Wilson, or somewhere else in Wahiawa?

(Note: Whitmore Village was deliberately oversampled.)

WHITMORE VILLAGE	25%
ELSEWHERE IN WAHIAWA	75%

2. Do you feel Whitmore Village is a real part of Wahiawa, kind of a suburb of Wahiawa, or is it pretty much a separate community to itself?

REAL PART OF WAHIAWA	32%
SUBURB OF WAHIAWA	14%
SEPARATE COMMUNITY	44%
DON'T KNOW/NO OPINION	9%

(IF "SUBURB" OR "SEPARATE"): OK, when I talk about Wahiawa or the Wahiawa area, I'll mean the whole area, including Whitmore and other small residential communities very near Wahiawa.

3. If Wahiawa ever expands, what sort of things does Wahiawa really NEED that could be built on the edge of town? (RECORD VERBATIM) Anything else?

(Note: Answers later coded into these categories.)

RECREATION FACILITIES	23%
SHOPPING—STORE, GROCERY	12%
HOUSING—AFFORDABLE & MARKET	13%
TRAFFIC SOLUTIONS, MORE ROADS	10%
ENTERTAINMENT—MOVIE THEATER	7%
SCHOOLS	3%
EATING PLACES, RESTAURANTS	2%
OTHER	6%
NONE	6%
DON'T KNOW/REFUSED	18%

4. What sort of things, if any, do you think should never get built in any new part of Wahlawa— things that just don't fit with this particular community? (RECORD VERBATIM) Anything else?

(Note: Answers later coded into these categories.)

HIGHRISES, BIG BUILDINGS	24%
BARS	12%
GOLF COURSES	8%
HOTELS	5%
HOUSING—AFFORDABLE & MARKET	6%
INDUSTRIAL COMPLEXES	4%
FAST FOOD	2%
STORES/OTHER BUSINESS	4%
OTHER	3%
DON'T KNOW/REFUSED	33%

5. Galbraith Estate wants to develop some 800 acres of its land on the northern edge of Wahlawa, just above Lake Wilson. It's basically the pineapple area, immediately outside town, as you drive up to Poamoho and Haleiwa. If you take Wilikina and Kamananui, it's the land to your right, starting across from Schofield's McNair Gate. If you take Kamehameha Highway, it's the land on either side before Poamoho. Does that give you a fairly clear idea of the area I'm talking about?

YES	97%
NO/NOT SURE	3%

6. How much would you say you've heard or read about plans to develop this particular area — a fair amount, a little, or nothing at all?

FAIR AMOUNT	13%
A LITTLE	37%
NOTHING AT ALL	49%
NO REPLY	1%

7. The main thing Galbraith wants to build there is fee-simple housing — at least 60% affordable housing — plus some job-creating activities. Right now that land is leased to Del Monte for pineapple. It's been good pineapple land, but the lease is about to end.

Assuming the project doesn't hurt Del Monte or its workers, do you feel it's more important to keep these 800 acres in pineapple, or to use them for new housing and jobs?

KEEP IN PINEAPPLE	19%
USE FOR HOUSING/JOBS	60%
DEPENDS/MIXED FEELING	16%
DON'T KNOW/NO OPINION	5%

8. Galbraith's plans are not final yet. Right now, it's looking at a 20-year project to build about 3,000 new homes — including some military family housing. That compares to roughly 11,000 existing military and civilian units in Wahlawa, Whitmore, Schofield, and Wheeler. Based on your sense of housing needs, does that sort of 20-year increase seem like too much, too little, or just about right, for Wahlawa?

TOO MUCH	28%
TOO LITTLE	7%
ABOUT RIGHT	53%
DON'T KNOW/NO OPINION	12%

8a. (IF "TOO MUCH"): If 3,000 seems like too much over 20 years, how much of an increase would you say is about right (READ CATEGORIES)

(Note: Asked only of the 28% who said "TOO MUCH" above.)

ABOUT 2,500	3%
ABOUT 2,000	6%
ABOUT 1,500	14%
ABOUT 1,000	21%
ABOUT 500	15%
NONE AT ALL	21%
DON'T KNOW/NO OPINION	20%

9. If Galbraith does build lots of new homes, some people say Galbraith also should create lots of new jobs in the same place, to help Wahlawa's economy and reduce traffic to Honolulu. Other people say Wahlawa doesn't need many new jobs now, and the jobs would just bring outside commuters to town. What do you say: Create new Wahlawa jobs along with housing, or just build the housing?

JOBS WITH HOUSING	73%
JUST THE HOUSING	13%
NEITHER ONE	6%
JOBS OK, NOT HOUSING	4%
DON'T KNOW/NO OPINION	4%

10. In addition to parks, schools, and community facilities, here are some other ideas that Galbraith and its planners have looked at. For each one, please tell me if you think it would be GOOD for Wahiawa, or WRONG for Wahiawa. (START AT THE "X")

	GOOD	WRONG	DEPENDS/ MIXED FEELINGS	DON'T KNOW/NO OPINION
a. Homes priced for families making around $50,000.	56%	33%	8%	4%
b. Homes priced for families making $80,000 or more.	42%	46%	9%	4%
c. About 500 military officer family homes near Schofield.	56%	32%	8%	4%
d. A mixed low-rise office and light industry job center.	57%	30%	11%	3%
e. A small second "downtown" shopping area away from Wahiawa's present downtown.	57%	28%	12%	3%
f. Small discount factory outlet stores.	62%	27%	9%	2%
g. A new hospital area.	43%	43%	11%	2%
h. Another pineapple visitor center like Dole's.	36%	55%	8%	2%
i. A business park where companies would build their own offices	45%	41%	10%	4%
(ASK LAST)				
j. A low-fee public golf course.	26%	67%	6%	2%

10z. (IF "WRONG" OR "DEPENDS/MIXED FEELINGS" ON 10j GOLF COURSE): If the public golf course is needed to keep housing prices low, and if it is guaranteed never to become private, would you feel it is acceptable, or would it still be wrong?

(Note: Asked only of the 73% who said "WRONG FOR WAHIAWA" or had mixed feelings on above question.)

ACCEPTABLE	24%
STILL WRONG	56%
MIXED/DEPENDS	9%
DON'T KNOW/NO OPINION	11%

11. Given the things that Galbraith is thinking about right now, what do you think would be the main PROBLEMS for Wahiawa if this project gets built? (RECORD VERBATIM)

(Note: Answers later coded into these categories.)

TRAFFIC	51%
OVERCROWDING	10%
WATER SHORTAGE	8%
CRIME	2%
OTHER	7%
NONE	7%
DON'T KNOW/REFUSED	16%

12. And what do you think would be the main OPPORTUNITIES or BENEFITS for Wahiawa if the project gets built? (RECORD VERBATIM)

(Note: Answers later coded into these categories.)

JOBS	35%
HOUSING	26%
MORE BUSINESS/SHOPS	6%
BETTER ECONOMY FOR WAHIAWA	6%
MORE RECREATION/ENTERTAINMENT	1%
CONVENIENCE	4%
OTHER	4%
NONE	2%
DON'T KNOW/REFUSED	17%

13. Finally, I'd like to get a little information about you and your household, just for statistical purposes. First, how long have you lived in the Wahiawa area? (IF MORE THAN 20 YEARS, ASK IF THAT IS "WHOLE LIFE")

WHOLE LIFE	35%
20+ YEARS, NOT LIFE	22%
11 TO 20 YEARS	11%
6 TO 10 YEARS	12%
5 YEARS OR LESS	18%
NO REPLY	2%

14. How would you describe your ethnic group?

CAUCASIAN	19%
FILIPINO	13%
HAWAIIAN/PART HAWAIIAN	12%
JAPANESE	28%
MIXED/OTHER	28%
NO REPLY	1%

15. And is your age (READ CATEGORIES) . . .

18 TO 34	28%
35 TO 49	27%
50 TO 64	19%
65 OR OLDER	25%
NO REPLY	1%

16. In this household, are any of the main wage-earners in the military?

YES, MILITARY	17%
NO, NOT MILITARY	82%
NO REPLY	1%

17. Because of today's high housing costs, sometimes people have to share housing, rent rooms, or double up with family members. If housing were more affordable, would anyone in this household get their own place, separate from others in the household?

YES	37%
NO	60%
DON'T KNOW	3%

17a. (IF "YES")
Realistically, would that person be looking to buy or to rent?

(Note: Asked only of the 37% who said "YES" above.)

BUY	54%
RENT	37%
DON'T KNOW	9%

18. Is any adult in this household unemployed AND actively looking for a full-time job?

YES	15%
NO	83%
DON'T KNOW	2%

19. What would you say is the current combined yearly income for all household members, from all sources . . . (READ CATEGORIES)

LESS THAN $20,000	19%
$20,000 TO $39,000	30%
$40,000 TO $59,000	22%
$60,000 OR MORE	21%
NO REPLY	8%

20. SEX (DO NOT ASK, JUST RECORD)

MALE	49%
FEMALE	51%

That's all the questions I have. Thank you very much for your assistance.

APPENDIX B: KEY INFORMANTS

The following list includes persons interviewed by Community Resources, Inc. in October 1992. Positions and/or organizational affiliations are mentioned to indicate the scope and variety of interested parties. Interviewees were NOT asked to speak on behalf of their organizations.

KEY INFORMANT	POSITION AND/OR ORGANIZATION
Steve Allen	Second Vice Chair, Unit 4305, ILWU Local 142 Member, Community Advisory Committee, Galbraith Project Wahiawa Resident
Dante Arios	Counselor, Leilehua High School Wahiawa Resident
Glen Arita	Counselor, Leilehua High School
Daniel Au	Teacher, Leilehua High School
James Awai	Chair, North Shore Neighborhood Board Community Liason Officer, Office of Senator Gerald Hagino
Sheri Bentley	Member, Central Oahu/North Shore Master Plan Task Force Treasurer, Wahiawa Neighborhood Board First Vice President, Whitmore Seniors Second Vice President, Waikiki Business and Professional Women's Club Treasurer, Friends of Mililani Library Former Member, Mililani Neighborhood Board Former Member, Board of Directors, Arthritis Foundation
Darrlyn Bunda	Vice Chair, Mililani Neighborhood Board Director, Mililani Town Association Member, Central Oahu/North Shore Master Plan Task Force Executive Director, Leeward Oahu Transportation Management Association
Hiram Diamond	Member, Neighborhood Commission Member/Former President, Hawaiian Civic Club Member, Wahiawa Lions Club Wahiawa Community Business Association Member, Community Advisory Committee, Galbraith Project Wahiawa Resident
Sharleen Douglas	Counselor, Leilehua High School Wahiawa Resident
Julie Ferguson	Community Ombudsman, NCTAMS EASTPAC NCTAMS EASTPAC Resident
Father Clarence Fisher	Parish Priest, Our Lady of Sorrows Wahiawa Resident

KEY INFORMANT	POSITION AND/OR ORGANIZATION
Karen Funakura	North Central Unit, Financial, Food Stamps and Medical Assistance, Hawaii State Department of Human Services
Earl Fusato	Officer, Board of Directors, Ho'ala School
Tom Hrdlicka	Owner, Tom's Golf Club Repair Professional Golfer
Lee Ideoka	Appraiser, Real Property Tax Assessment Branch, Honolulu City & County Department of Finance
Cheryl Ito	Recreation Director, Whitmore Community Park Wahiawa Resident
Jack Kampfer	Chair, Wahiawa Neighborhood Board Member/Former President, Wahiawa Lions Club
Cal Kawamoto	Chair, Waipahu Neighborhood Board Executive Director, Waipahu Culture Garden Park President, Waipahu Businessmen's Association Member, Board of Directors, Wahiawa General Hospital
Fred Lau	Member, Waialua Community Association Board of Directors Former President, North Shore Communities for Quality Development
Marilyn Lee	Chair, Mililani Neighborhood Board President, PTSA, Mililani High School
Tom Lenchanko	Member, Hawaiian Civic Club Wahiawa Resident
John Martin	Communications Mate, NCTAMS EASTPAC Wheeler Field Resident
Sydney Medeiros	Wahiawa Unit Supervisor, Financial, Food Stamps and Medical Assistance, Hawaii State Department of Human Services
Norman Minehira	Principal, Leilehua High School
Nancy Miura	Wahiawa Resident
Eileen Miyagi	Counselor, Leilehua High School
Nancy Moore	President, American University Women Secretary/Treasurer, Wilikina Park Elderly Housing Secretary, Age to Perfection Elderly Day Care
Leo Rodby	Visitor Center Staff, Wahiawa Botanical Gardens Wahiawa Resident

KEY INFORMANT	POSITION AND/OR ORGANIZATION
Walter Rodby	Member, Wahiawa Neighborhood Board Wahiawa Resident
John Sadowski	Teacher, Leilehua High School
LT Daniel Saragosa	Acting Captain, Wahiawa Police Station
Libby Smithe	Member/Office Manager, Baord of Directors, Wahiawa Community Business Association Clerk, Representative Robert Bunda Member, Community Advisory Committee, Galbraith Project Wahiawa Resident
Vivian Sugami	Wahiawa Counseling Services, Adult Mental Health Division, Hawaii State Department of Health
Tetl Uchida	Retired Del Monte Supervisor Poamoho Camp Resident
Betty Ulano	Chair, Whitmore Seniors Former Officer, Whitmore Filipino Association Whitmore Village Resident
Annette Yamaguchi	Member/Former Chair, Waipahu Neighborhood Baord Member, Board of Directors, Wahipahu Community Foundation Founder/Chair, CAN-DO (Creative Alernatives in Neighborhoods and Developing Options) Assistant Secretary, Leeward Lions Club Member, TIFE (The Institute for Family Enrichment) Founder/Executive Director, PFCCA (Professional Family Child Care Association) Member, Waiphau Community Associatioin Member, Waipahu Business Association Director, Community Development, YMCA of Honolulu, Leeward YMCA

APPENDIX C: PROJECT-RELATED COMMUNITY ISSUES AND CONCERNS (1)

ISSUES/CONCERNS	THE WAHIAWA COMMUNITY	OTHER COMMUNITIES
Housing in General	o Low density important; creates needed housing	o Diversification of housing supply promotes socio-economic diversity; generates construction jobs
Affordable Housing	o Could address islandwide need, but some suspect will not meet needs of poor families; could be too expensive for Wahiawa residents	o Addresses islandwide need
Economy	o General approval for more jobs in area; despite jobs residents will work elsewhere; provides needed economic stimulation; competition with existing businesses	o Despite new jobs residents will work elsewhere; increased competition for existing businesses; questions about types of jobs project would generate
Elderly Housing	o Seen as addressing needs of an aging community	
Whitmore Village	o Convenient shopping and civic facilities	
Parks	o Badly needed by the community, especially playing fields	o General approval for more regional recreation facilities; interest in increased access to Lake Wilson
Loss of Agriculture	o Acceptable if creates more housing; loss of rural identity; decreased supply of agricultural land; loss of jobs	o Acceptable if creates more housing; consider sites with less impact on pineapple operations
Future of Central Oahu	o Seems to contradict plans to limit growth and support agriculture in Central Oahu	o Contradicts plans to concentrate growth in Ewa; development should be limited to keep the "country country"

ISSUES/CONCERNS	THE WAHIAWA COMMUNITY	OTHER COMMUNITIES
Community Identity	o Potential division of old and new Wahiawa; new community facilities may cater to project residents only	o Could help to revitalize Wahiawa; duplication of existing facilities (such as a light industrial area) not conducive to good relationship between old and new Wahiawa
Project Design	o Need to preserve small town, country character; project too large; preference for low-key and not suburban design; importance of open green space	o Important to acknowledge agricultural ties through design; size of project too large; important to integrate old and new communities
Military Housing	o Expected down-scale of military; military's own plans may meet needs; less land for civilian use; may free units for civilian use	o Military's own housing plans may meet needs; may free units for civilians
Limited Infrastructure	o Water supply; traffic; wastewater treatment facilities; schools; approval for improvements due to developer contributions	
Project Residents	o May change community composition, especially affluent residents	o May strengthen Wahiawa's political clout; expectation there will be little interaction between old and new
Golf Course	o Inappropriate for Wahiawa; community does not need; expectation that fees will be high; preserves open space	o Must be a public course with low rates; general environmental concerns
Kukaniloko Birth Stone	o Preserves a valued cultural site; proximity of golf course threatens integrity of site	o General approval for preservation of the site
Developer	o Suspicion concerning willingness to listen to community input	

NOTE: (1) This table summarizes views expressed by various key informants. Wahiawa/Whitmore residents tended to see Wahiawa as a stable plantation town; others saw the town and its future without the project differently. Neither group was unanimous — this table lists major themes, not a detailed consensus.

September 1992

PROPOSED WAHIAWA LANDS DEVELOPMENT (GALBRAITH TRUST LAND)

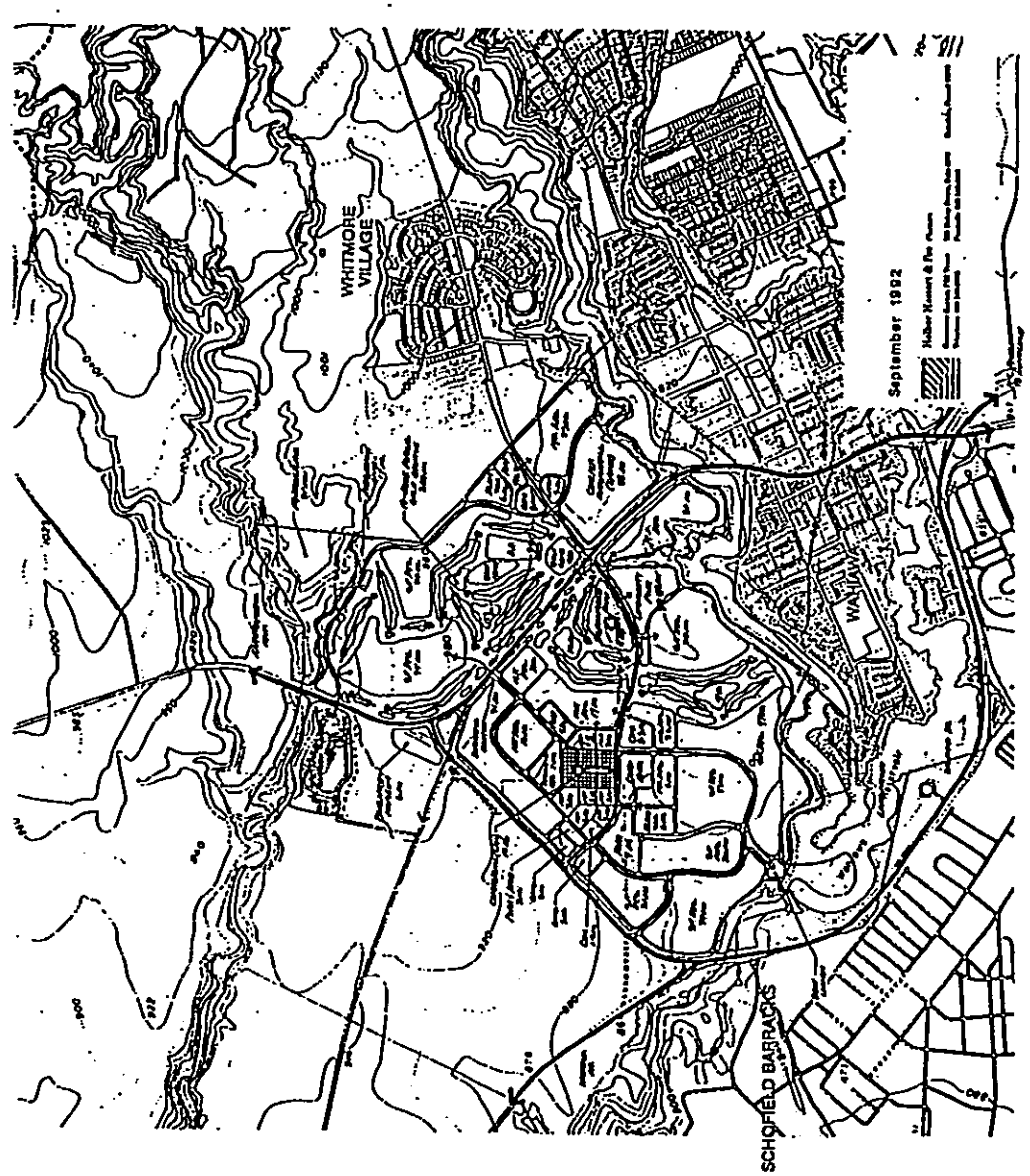
The Galbraith Trust owns about 2,000 acres in Central Oahu that are now largely used for pineapple cultivation. The Trust is considering development of about 850 acres next to Wahiawa and Schofield Barracks. A preliminary plan has been developed on the basis of studies and discussions with members of the community.

The proposed development would take about 15 to 20 years to build out. The Trust's planners hope it would form an addition to Wahiawa, supporting that community. It includes:

- A total of about 3,000 residential units, with most being affordable. Both single family and multifamily areas would be developed. The project would include both homes for sale and rentals. About 500 units could be leased for military family housing near Schofield Barracks.
- A community "core" area would have a small commercial/mixed use area at its center. Both business and civic areas would be nearby, along with some housing. Housing and facilities for the elderly would probably be near the "core." The design of the core would encourage people to walk to nearby facilities.
- A range of job opportunities, allowing many people living in the project and the Wahiawa area to work on-site, rather than commuting. Jobs would be located in:
  - A light industrial area -- across the reservoir from the Wahiawa Industrial Center -- mainly devoted to warehouses;
  - A business area, likely to have office and some commercial jobs; and
  - Shops serving the local community.
- Parks along Lake Wilson, with a boat ramp and a community park with ball fields.
- Park land surrounding State land at the Wahiawa Birthing Stones (Kukaniloko) site.
- A public golf course with reasonable rates.

In order to support pineapple operations and workers, the Trust expects to: (a) re-lease most of its lands to Del Monte; (b) assist Del Monte to find alternate fields to use in place of the project site; and (c) provide a site for a Pineapple Museum near the existing triangle. Poamoho Camp is on Galbraith land, but the Trust has no plan to include the camp in the new development. Both the Trust and DelMonte have expressed willingness to find a solution that will work out well for Camp residents.

Community Resources, Inc. is conducting independent interviews as part of a social impact assessment of the proposed development. We want to understand the views of the community about the future of Wahiawa and this project. If you have any question about the project, please call the planners (Gail Uyetake or Tom Fee, Helber Hastert & Fee, 545-2055).



APPENDIX D: REFERENCES

Atwater/Stanney Consultants. Market Assessment of the Wahiawa Lands. Prepared in association with Community Resources, Inc. for Hawaiian Trust Company. Honolulu, HI; 1992.

Bank of Hawaii Research Department. Construction In Hawaii, 1992: Twenty-Sixth Annual Report on Hawaii's Construction Industry. Honolulu, HI; 1992.

Belt Collins & Associates. Application for Development Plan Amendment and Environmental Assessment: Mokuleia, Oahu, Hawaii. Prepared for Mokuleia Land Company. Honolulu, HI; 1991.

Community Resources, Inc. Potential Year 2005 Employment Levels and Distribution for Central and Leeward Oahu: Supplemental Report. Prepared for Mililani Town, Inc. Honolulu, HI; 1986.

Datametric Research. A Planning Survey of Wahiawa Residents. Prepared for Community Resources, Inc. and Hawaiian Trust Company. Honolulu, HI; 1992.

Hawaii State DBED (Department of Business, Economic Development, and Tourism). Unpublished update of the 1992 Hawaii State Data Book. Honolulu, HI; 1992.

Hawaii State DBED (Department of Business, Economic Development, and Tourism). The State of Hawaii Data Book 1991: A Statistical Abstract. Honolulu, HI; 1991a.

Hawaii State DBED (Department of Business, Economic Development, and Tourism). Quarterly Statistical and Economic Report, 3rd & 4th Quarters 1991. Honolulu, HI; 1991b.

Hawaii State DLIR (Department of Labor and Industrial Relations). 1991 Employment and Payrolls in Hawaii. Honolulu, HI; 1992.

Hawaii State DPED (Department of Planning and Economic Development). Community Profiles for Hawaii. Honolulu, HI; 1973.

Helber Hastert & Fee, Planners. Application for Development Plan Amendment and Environmental Assessment, 1993 Annual Review: Wahiawa Lands Development. Prepared for Hawaiian Trust Company. Honolulu, HI; 1992.

Honolulu City & County Department of General Planning. Personal communication, Steve Young, Research Statistician. August 1992.

Honolulu City & County Department of General Planning. Development Plan Status Review: Fiscal Year 1992. Honolulu, HI; 1992.

Honolulu City & County Department of General Planning. Development Plan Status Review: Fiscal Year 1991. Honolulu, HI; 1991.

Honolulu City & County Department of General Planning. General Plan: Objectives and Policies. Supplement One to the 1988 Edition. Honolulu, HI; 1989.

Koebig & Koebig, Inc. Wahiawa Fresh Water Park Master Plan. Prepared for the Hawaii State Deparment of Land and Natural Resources Division of State Parks. Honolulu, HI; 1975.

National Military Family Association, Hawaii Chapter. Hawaii Final Report, Quality of Life Survey, 1987. Honolulu, HI; 1987.

Nedbalek, Lani. Wahiawa: From Dream to Community. Wonder View Press: Mililani, HI; 1984.

Pacific Business News. "Elderly Housing Project Set." Honolulu, HI; A-33, 8/31/92.

Tax Foundation of Hawaii. Government in Hawaii, 1991: A Handbook of Financial Statistics. Honolulu, HI; 1991.

United States Department of Commerce, Bureau of the Census. 1990 Census of Population and Housing, Summary Tape File 3-A: Alaska, Hawaii, Oregon, CD90-3A-02. Washington, D.C.; 1992.

United States Department of Commerce, Bureau of the Census. 1990 Census of Population and Housing, Summary Tape File 1-A: Pacific Division, Vol I, CD90-1A-9-1. Washington, D.C.; 1991a.

United States Department of Commerce, Bureau of the Census. 1990 Census of Population and Housing: Summary Population and Housing Characteristics, Hawaii, 1990 CPH-1-13. Washington, D.C.; 1991b.

United States Department of Commerce, Bureau of the Census. 1980 Census of Population and Housing: Census Tracts, Hawaii, Selected Areas, PHC80-2-13. Washington D.C.; 1983a.

United States Department of Commerce, Bureau of the Census. 1980 Census of Population and Housing: Census Tracts, Honolulu, Hawaii SMSA, PHC80-2-183. Washington D.C.; 1983b.

United States Department of Commerce, Bureau of the Census. 1980 Census of Population and Housing, Summary Tape File 1-A: Hawaii. Available on microfiche, Hawaii State DBED library, Honolulu, HI. Washington, D.C.; 1981a.

United States Department of Commerce, Bureau of the Census. 1980 Census of Population and Housing, Summary Tape File 3-A: Hawaii. Available on microfiche, Hawaii State DBED library, Honolulu, HI. Washington, D.C.; 1981b.

United States Department of Commerce, Bureau of the Census. Block Statistics: Honolulu, Hawaii SMSA, PHC80-1-183. Washington, D.C.; 1981c.

United States Department of Commerce, Bureau of the Census. U.S. Census of Population and Housing, 1960: Census Tracts, Honolulu, Hawaii SMSA, PHC(1)-62. Washington D.C.; 1962.

United States Department of Commerce, Bureau of the Census. U.S. Census of Population, 1950: General Characteristics, Hawaii, Vol. II, Part 52, Chapter B. Washington D.C.; 1952a.

United States Department of Commerce, Bureau of the Census. U.S. Census of Population, 1950: Census Tract Statistics, Honolulu, Territory of Hawaii, Vol. III, Chapter 62. Washington D.C.; 1952b.

United States Department of Commerce, Bureau of the Census. Sixteenth Census of the U.S., 1940: Population, Second Series, Characteristics of the Population, Hawaii. Washington D.C.; 1943.

Waite, David. "North Shore Group Opposes HC&D's Plan for New Quarry," Honolulu Advertiser. Honolulu, HI; A-5, 10/20/92.

APPENDIX I

Market Assessment

Gail W. Atwater/James W. Stanney

MARKET ASSESSMENT
OF THE WAHIAWA LANDS

Prepared for
Helber, Hastert & Fee Planners

Prepared by

Gail W. Atwater
and
James W. Stanney
Consultants

In association with
Community Resources, Inc.

December 1992

MARKET ASSESSMENT
FOR THE WAHIAWA LANDS

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LIST OF EXHIBITS

Section I
INTRODUCTION

Section I

INTRODUCTION

OVERVIEW

Gail W. Atwater and James W. Stanney were contracted by Community Resources, Inc. (CRI) on behalf of Helber Hastert & Fee Planners and their client Hawaiian Trust Company, to recommend and assess the market feasibility of residential and support retail developments on the property generally known as the Wahiawa Lands. These analyses are contained in the first six sections of this report. An additional request was made to assess several commercial uses and a golf course. These secondary analyses were contracted at a reduced scope and are included as the final two chapters of this Market Assessment report.

PURPOSE AND OBJECTIVES

The purpose of the Market Assessment was to evaluate the overall market potential of the subject property, estimate the absorption of proposed land uses and assess the property's relationship to other Oahu master planned communities. The specific objectives of the evaluation were to:

- **Conduct a Site Review and Analyze Existing Conditions.** This included evaluating the site relative to its development potential and analyzing general economic trends and indicators supporting residential and commercial development on the subject parcel.
- **Analyze Supply and Demand Conditions for Residential and Commercial Development.** The supply analysis included evaluating planned and proposed projects. Demand analyses included reviewing relevant trends, analyzing the oversupply or shortfall of supply versus demand and describing the products and target markets for the subject property.
- **Estimate Absorption and Pricing for Residential Development.** These analyses included: developing absorption estimates for various residential products based on their ability to satisfy potential demand; estimating pricing structures for the products to be developed at the subject site; and adjusting the pricing for locational attributes. It should be noted that prices are stated in 1992 dollars.
- **Evaluate Market Potential for Neighborhood Commercial Development on the Subject Property.** This analysis included defining a trade area, evaluating the existing and proposed supply, and assessing areas of unsatisfied retail demand.

At the client's request, two ancillary investigations were conducted which placed greater reliance on rule of thumb indicators, interviews and published information.

- **Investigate the Market Potential of Employment Generators on the Subject Property.** This included evaluating the market potential for employment generating land uses. These analyses were based on the property's physical location and characteristics, existing and projected market conditions and market perceptions, evaluation of local, regional and national trends in the development of large parcels of land and the consultants' experience.
- **Assess the Market Potential of a Public Golf Course.** The golf course analysis included preparing an overview of the golf course industry on Oahu, analyzing the supply and demand factors, estimating the market performance and recommending the positioning of a public play golf course to be developed on the subject property.

METHODOLOGY

To accomplish these objectives, the scope of our work included, but was not limited to:

- Discussions with Helber Hastert and Fee and Hawaiian Trust Company, Limited regarding the project and the property.
- Several inspections and evaluations of the site and its surrounding area in order to determine its physical attributes and relationship to other properties in the market. This evaluation did not include any engineering or environmental considerations, but encompassed an evaluation of the site's accessibility, visibility, proximity to other towns, developments and military installations, physical layout, appearance and their potential effect on the marketability of the property.
- Analysis of economic and demographic data pertaining to the market area and an evaluation of the present economic climate. These analyses were used in the estimation of future growth potential in the residential and commercial markets.
- Analyses of housing supply based on published data and interviews with real estate agents and developers of residential projects, which could be potentially competitive with the subject property. Additions to supply were based on public and private sources of information.
- Calculations of demand with guidance from the State of Hawaii's Series M-K population projections and other demographic documents prepared by public and private sources. Conclusions relating to macro and regional demand were estimated by both "build up" and gravity analyses.

- Estimations of the subject property's performance, using capture rates and taking into consideration its attributes and disadvantages relative to competing projects and the historic performance of similar developments.

- Analyses of the market potential of employment generators and the proposed golf course. This effort placed a greater reliance on rule of thumb indicators, published information and a limited number of selected interviews.

Section II

EXECUTIVE SUMMARY

Section II
EXECUTIVE SUMMARY

Property Location	Between Wilikina Drive and Whitmore Village, north of Lake Wilson in the area of Central Oahu generally known as Wahiawa
Size	Approximately 800 acres of a 2,000+ acre parcel.
Physical Attributes	Gently sloping terrain
	Excellent access
	Cool climate
Economic Environment	Moderate to strong long term growth trends in both commercial and residential indicators, with demonstrated pent up residential and retail demand.
Residential	
Supply/Demand Shortfall	6,330 - 12,217 units
Planned Units	1,236 Single Family Market-Priced Homes 246 Single Family Affordable Units 660 Medium Density Units 958 Multi-Family Units
Year Sales Begin	1997
Average Annual Absorption	225 - 250 units
Capture Rate of Total Oahu Residential Market	3.0 to 8.5 percent
Retail	
Potential Need for New Retail Space by 2010	390,000 square feet
Target Tenants	Food stores, apparel stores, home furnishings, drug store, "sit down" restaurants
Additional Uses	Employment: Light industrial, back office, outlet center and health care facilities; Recreation: 18-hole municipal or reduced rate daily fee golf course, several parks.

Section III
SITE DESCRIPTION

Section III

SITE DESCRIPTION

INTRODUCTION

The Wahiawa Lands site is located just north of the town of Wahiawa, a town of 17,000 persons in Central Oahu. Lake Wilson forms the physical separation of the subject property and the existing Wahiawa community.

The subject site and its relationship to the island of Oahu is indicated in Exhibit III-1, *Location Map.*.

SITE BOUNDARIES

The entire Wahiawa Lands property encompasses an irregular shaped parcel in excess of 2,000 acres. The proposed development would consist of approximately 800 acres of land located in the south central portion of the larger parcel.

The majority of this parcel can be defined as the area north of Lake Wilson and located southwest of Kamehameha Highway and southeast of Wilikina Drive/Kamananui Road.

An additional area extending east of Kamehameha Highway has also been included within the development plan. This area extends easterly toward the Whitmore Village community. Land holdings in this area are located both north and south of Whitmore Avenue. The northern area extends to Kamananui Road and the southern parcel to Lake Wilson.

The land is currently leased to Del Monte Corporation and planted in pineapple.

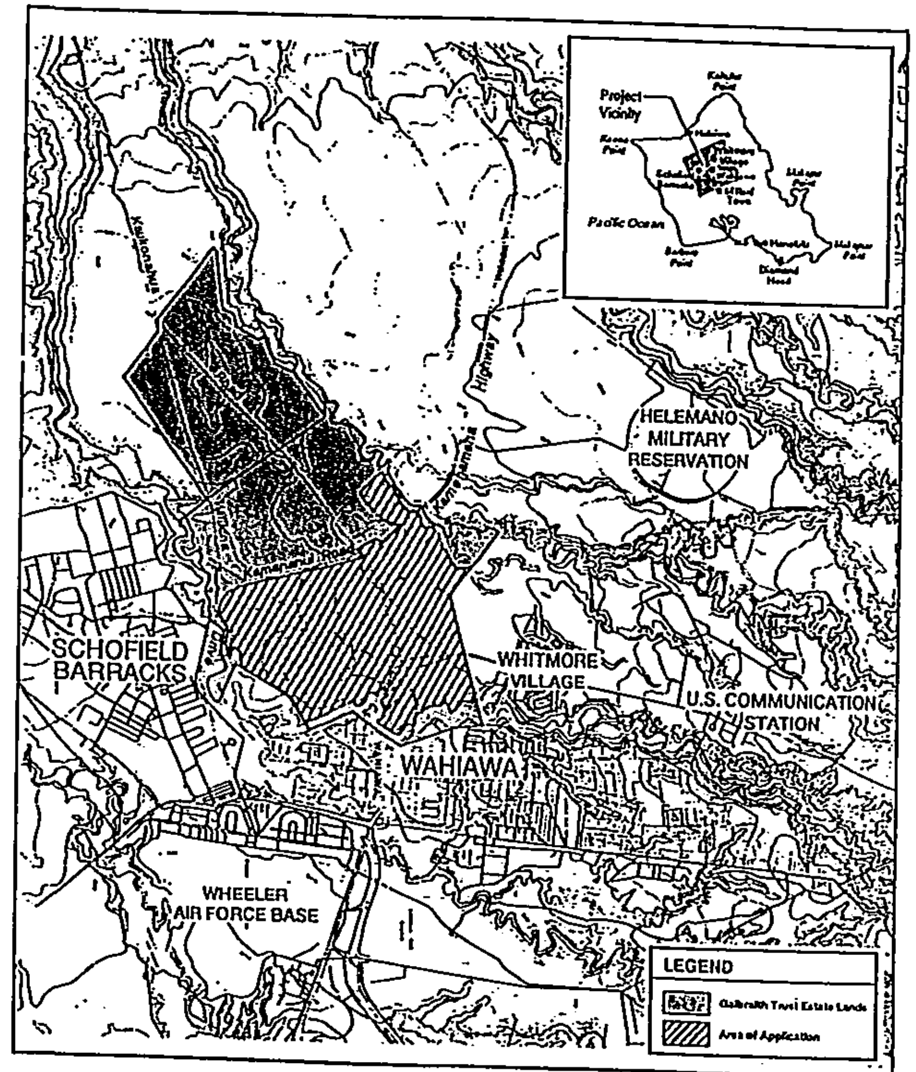
SURROUNDING USES

Wahiawa

The Wahiawa community serves both as an active part of Central Oahu and the gateway to the North Shore of Oahu. Wahiawa's dual identity is evidenced by the town's existing services which serve not only the local community but residents of the North Shore as well. Improvements to the subject property should help further Wahiawa's role as the gateway to the North Shore. Furthermore, the property will provide an area for expansion of existing facilities where growth is limited by physical constraints.

Exhibit III-1
Wahiawa Lands

Location Map



Poamoho Camp

Located north of the eastern portion of the property's proposed development area, Poamoho Camp is an older plantation workers' housing project.

Whitmore Village

Near the subject project's eastern boundary is the community of Whitmore Village. Structures in Whitmore Village are newer than those in the Poamoho Camp area. However, over time modifications and additions to residential units in Whitmore Village have created an image of a high density single family development with little design conformity.

Few services are provided to residents of Poamoho Camp and Whitmore Village. The proposed community's employment and public uses should therefore benefit the existing population base.

Schofield Barracks

Schofield Barracks is a major United States Army base located across Wilikina Drive from the subject property. The base therefore shares access with the subject parcel and influences traffic patterns to and from the site. Army officials of the base have expressed a strong interest in the housing component of the proposed development.

Other Uses

Lands further to the north, west and east of the property are primarily in agricultural or conservation uses. The subject property benefits from a rural atmosphere and is provided with excellent views of the Waianae mountain range.

The views of the Waianae range are enhanced by the subject's topography which slopes gently to the west. The western orientation benefits from a less prevalent layer of cloud cover than that which often obscures views of the Koolau range to the east.

PROPERTY ACCESS

The subject development will have two primary access routes: Kamehameha Highway (State Route 80) and Kamananui Road (State Route 803)/Wilikina Drive (State Route 99)). Both routes provide access to H-1 south of the site. H-1 in turn provides access to Ewa in the west and Primary Urban Center employment in the southeast.

Kamehameha Highway is a major arterial. After its junction with Wilikina Drive, this road serves as the area's primary access to the North Shore.

Wilikina Drive is a surface arterial. This road is largely an extension of H-2, though at a lower capacity and with numerous traffic signals. These signals are located primarily at or near various Schofield Barracks gates. Crossing Lake Wilson, Wilikina Drive forms the western boundary of the area of proposed development.

Kamananui Road branches off of Wilikina Drive north of the Lake Wilson Bridge. Kamananui Road forms the northwestern boundary of the area to be developed. Further along to the northeast, Kamananui Road intersects with Kamehameha Highway. The intersection is in the area of Del Monte Corporation's pineapple varietal garden south of Poamoho Camp.

Kamananui Road and Kamehameha Highway are further connected by a plantation road south of their intersection near the pineapple varietal garden. A road generally following this alignment will be improved as part of the master plan. This road, which approximates an extension of Whitmore Avenue, will provide access into the heart of the project.

PROPERTY VISIBILITY

Northbound Visibility

The subject property is not visible when traveling north on Kamehameha Highway and Wilikina Drive until after crossing the respective bridges. On Kamehameha Highway, the parcel area to the west is obscured by a cliff forming a physical buffer which ends shortly before the junction with Whitmore Avenue. This area is intended for light industrial and support retail services. The area north of Whitmore Avenue is intended to include a golf course running from the northwest to the southeast. The course would be surrounded by housing and should create an impressive entry statement for the development.

Southbound Visibility

Traveling south, the gently rolling pineapple fields which comprise the parcel are visible from both access roads.

View Plane

The major view plane is toward the Waianae Mountains, extending in a northwest/southeast direction across the parcel. Residential development will be largely concentrated in the area between Wilikina Drive/Kamananui Road and Kamehameha Highway south of the plantation road. These sites will benefit from topography that provides views of the Waianae mountain range and Lake Wilson.

CONCLUSION

The subject site is well served by existing roads. This ease of access combined with the area's cool climate should be attractive to potential residents. Additionally the subject site's topography should provide excellent views and offer an easily developable site.

Section IV

AREA REVIEW

Section IV

AREA REVIEW

INTRODUCTION

The subject property is located in the community of Wahiawa in the central portion of the island of Oahu. The word Oahu means "the gathering place" in Hawaiian. True to its name, the island serves as Hawaii's governmental, commercial and cultural center. Oahu is one county (the City and County of Honolulu) and in fact one city with many communities. Local economists use the expression, "As Oahu goes, so goes the State" to indicate the impact of Oahu's performance on Hawaii as a whole. Although the capital island possesses only ten percent of the State's land area, three-quarters of its population lives and works there.

Oahu's strategic location between the West Coast and Asia places it 2,400 statute miles from San Francisco and 4,000 miles from Tokyo. Due to its location, Oahu serves as the gateway to both the Mainland U.S. and Asia/Pacific regions. Facilitating the gateway position is the island's Honolulu International Airport which serves over 12 million overseas and interisland passengers annually.

PURPOSE OF THE AREA REVIEW

The Area Review presents an overview and analysis of major economic trends both in the State of Hawaii and the island of Oahu. Three key indicators offer economic support for the proposed residential and commercial development on the subject property:

- General Trends
- Residential Indicators
- Commercial Indicators

GENERAL TRENDS

Hawaii versus Mainland U.S. Economic Trends

Hawaii's economic growth over the past decades indicates the strength and resiliency needed for continued expansion of both housing and commercial markets. Over time, economic indicators such as employment, visitor expenditures, and inflation have consistently exhibited more vigor and strength than the Mainland U.S.

In the 1980s Hawaii's economic growth rate far outpaced the rest of the nation. Hawaii economists argued it was not sustainable over the long run. Indeed it was not. The peak of this strong development cycle appears to have occurred in 1990. An analysis of long term trends (50 years) appears to indicate an approximately nine-year business cycle.

Although real growth in Hawaii continued after 1990, the slowdown in the rate of growth reflected the impact of:

- Slackening of tourism as a result of the ongoing U.S. recession;
- Economic problems in Japan which have slowed the rate of foreign investment in Hawaii;
- The credit crunch brought about by regulatory responses to the Savings and Loan crisis; and
- Losses suffered by individuals, businesses and local insurance companies as a result of Hurricane Iniki's destruction on Kauai and parts of Oahu.

Beginning in 1991, Hawaii began to experience a more sustainable rate of economic growth. This economic correction should be viewed in the larger context of the entire nation. According to Bank of Hawaii economists, two factors are notable in comparing Hawaii's economic performance with the other 49 states':

Hawaii business cycles lag Mainland cycles. The turning point for Hawaii's business cycle appears to lag between two to six quarters behind comparable turning points for the U.S. Mainland economic indicators. For example, a drop in Hawaii's tax revenue growth appeared roughly one year after the Mainland contraction in revenue growth.

Hawaii's dips are shallower. The extent of any decline from the cyclical peak for Hawaii's economic indicators has been proportionately smaller than corresponding declines in Mainland time series. For example, retail sales on the Mainland dipped five percent between 1989 and 1991. In contrast, Hawaii's peaked in 1990 and remained at only two percent below the peak in 1992.

Transportation

Supporting growth of development on Oahu is a transportation system which includes land, air and sea modes. While most of Hawaii's visitors and residents arrive and travel interisland by air, nearly all of the goods needed in the islands arrive through its harbors.

Land transportation. Hawaii maintains a system of 4,101 miles of interstate, state and county roads. Oahu has two interstate highways, H-1 and H-2 (which is currently being widened), with a third, H-3, currently under construction. Public street transportation is limited to Oahu's TheBus service which served 76 million passengers in 1990.

Ocean transportation. According to the State Department of Transportation's Harbors Division, four-fifths of the goods required by Hawaii are imported, and 98% percent of those arrive by sea. The interisland cargo system supplies Neighbor Islands with over 5 million tons of goods per year. Oahu has two deep draft commercial harbors, Honolulu Harbor and Barbers Point. A third, the famous Pearl Harbor, is controlled by the U.S. Navy. Recently a ferry system between Barbers Point and Honolulu Harbor has been introduced. So far little support has been shown for the system. However, it is hoped that ridership will increase with increases in the population of the island's Leeward area.

Air transportation. The advent of overseas air transportation revolutionized Hawaii's economy. Prior to the introduction of regular air service to Honolulu, access was limited to ocean liners and other forms of sea-based transportation. By 1990, only two out of every thousand arrivals to Hawaii was by ship. Almost all scheduled interisland passenger travel is now by air.

RESIDENTIAL INDICATORS

Population growth can be closely correlated with household formation, which in turn increase the demand for housing. Specific social and economic indicators which support the demand for future residential development on Oahu include:

- Population Growth
- Household Formations
- Income trends
- Residential building permit trends
- Oahu's for-sale residential market

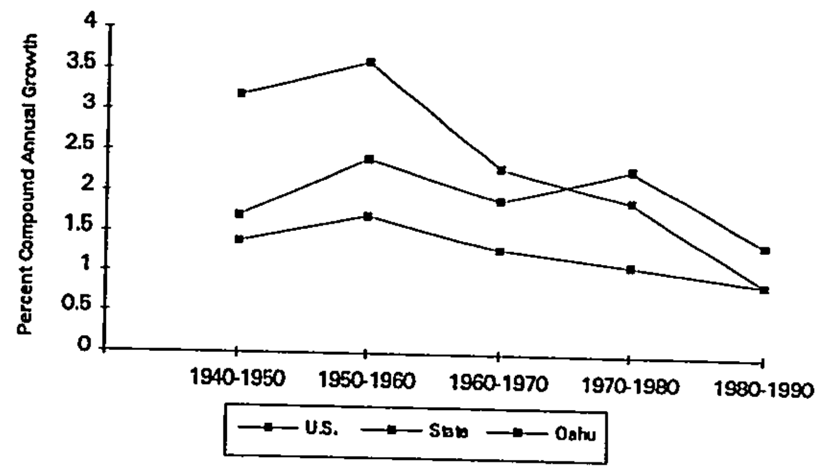
Population Growth

Historical Trends. Oahu has experienced population growth in all time periods since 1950. Since the spike in growth following statehood in 1959, Oahu's population growth rate has gradually tapered off while greater increases were seen on the Neighbor Islands, as shown in Exhibit

IV-1, *Population Trends, 1940-1990.* Despite the deceleration in the rate of growth, the absolute number of Oahu residents continues to climb.

Exhibit IV-1
Wahiawa Lands

Population Trends, 1940-1990



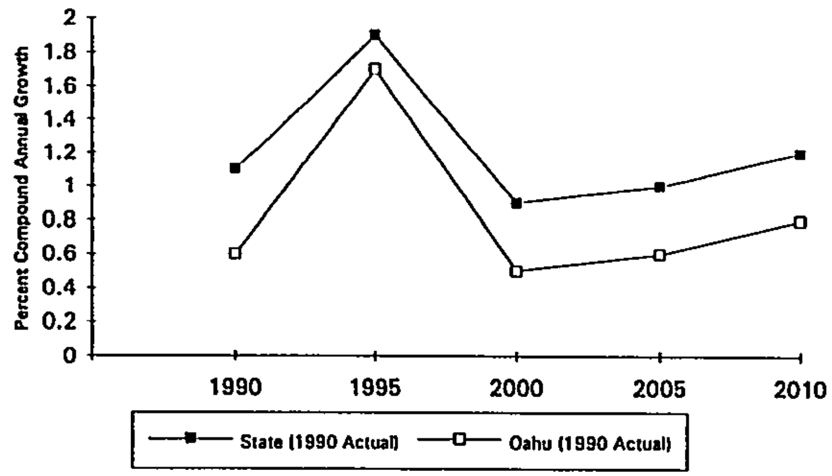
Population Projections. Oahu's resident population is expected to grow by 20 percent in absolute numbers between 1990 and 2010, according to the State's Series M-K projections. Population trends illustrated in Exhibit IV-2, *Population Projections - State and Oahu (Series M-K)* on the following page can be summarized as follows:

- Compound annual growth in population in both the State and Oahu is expected to remain positive, with a range from 0.6 percent to almost 2 percent along the trend line shown in Exhibit IV-2.
- The lower end of these growth rates falls below the percentage growth experienced in the 1980s. However, as the base population increases, the absolute changes are not materially different.
- Between 1980 and 1990 Oahu's population grew by 73,666 persons. Between 1990 and 2000 absolute growth is expected to increase to 96,569 persons, before falling off to 66,700 persons in the 2000 to 2010 period. As such on average while the percentage change in

population is expected to gradually decline, the absolute growth may actually approximate or exceed the level experienced in the 1980s.

Exhibit IV-2
Wahiawa Lands

Population Projections
State and Oahu (Series M-K)



NOTE: The chart above was constructed using actual 1990 U.S. Census data. If it were constructed using the Series M-K 1990 projections prepared in 1988, compound annual growth between 1990 and 1995 would have somewhat flattened the spike seen between 1990 and 1995. [The Oahu compound annual growth rate would have been 1.2 rather than 0.6 between 1990 and 1995; the State's growth rate would have been 1.6 rather than 1.1.] Since the 1990 Census is believed to be somewhat understated, the actual trend may be closer to original M-K projections, i.e. with less of a spike.

Household Formations

Several factors relating to new household formations will support the demand for future residential development on Oahu:

The rate of growth in the housing stock typically lags population growth in Hawaii, creating latent demand for new residential housing product. As shown in Exhibit IV-3, *Trends: Population, Housing Stock and Households*, the expected increase in housing stock on Oahu is expected to be double the rate of population growth between 1980 and 2010.

Household size in Hawaii ranked second among the fifty states 1990 with 3.01 persons, reflecting among other factors the frequent doubling up of many households. However, a decrease in household size is expected over time. This decline is expected to follow a national demographic trend toward smaller family units and the expectation that the availability of affordable housing on Oahu will enable many doubled up families to acquire their own homes.

Exhibit IV-3 illustrates Oahu's historic and projected trends in population, housing stock and household formation.

Exhibit IV-3
Wahiawa Lands

Trends: Oahu Population, Housing Stock and Households

Year	Oahu Population	Housing Stock	Persons per Household
1980	762,565	230,214	3.15
1985	811,094	272,214	3.02
1990	836,231	265,304	3.02
1995	910,400	311,700	2.91
2000	932,800	338,600	2.76
2005	961,100	359,600	2.68
2010	999,500	383,500	2.62
Percent Change (1980-2010)	31%	67%	-17%
Compound Annual Growth (1990-2010)	0.91%	1.86%	N/A
Source: Department of General Planning, based on M-K projections			

Income Trends

Personal income in Hawaii doubled between 1980 and 1990, reflecting a growing economy. However, according to statistics quoted by the Bank of Hawaii, real personal income growth in Hawaii decelerated during the 1980s, reaching a low in 1991 and beginning a recovery in 1992. This trend, when evaluated with housing price trends, is a strong indicator for the development of affordable housing.

Residential Building Permit Trends

Exhibit IV-4, *Oahu Building Permit Trends*, illustrates the historic trends in permitting activity in the City and County of Honolulu from 1962 through 1991. Housing categories include single family detached, duplex, multi-family and total residential units permitted. The average annual permitting levels during this period were 2,507 single family units, 143 duplex units and 3,683 multifamily units.

Although the pattern of building permits does not present clearly definable real estate cycles as one might expect, real estate cycles are more apparent in the progression of resale housing prices discussed in the following section.

Exhibit IV-4
Wahiawa Lands

Oahu Building Permit Trends
1962 - 1991

Year	SFD		Duplex		Multi Family		Residential		Total
1962	3654		170		4076		7900		7079
1963	3354	-8.21%	190	11.76%	2891	-29.07%	6435	-18.54%	7147
1964	3671	9.45%	80	-52.63%	2868	-0.80%	6629	3.01%	7871
1965	4512	22.91%	132	46.67%	5551	93.55%	10195	53.79%	9636
1966	2944	-34.75%	52	-60.61%	6320	13.85%	9316	-8.62%	4859
1967	3005	2.07%	46	-11.54%	3159	-50.02%	6210	-33.34%	8126
1968	3683	22.56%	330	617.39%	6043	91.29%	10056	61.93%	9664
1969	3569	-3.10%	286	-13.33%	7285	20.55%	11140	10.78%	8502
1970	3809	6.72%	212	-25.87%	3957	-45.68%	7978	-28.38%	9217
1971	3771	-1.00%	70	-66.98%	4017	1.52%	7858	-1.50%	9642
1972	3352	-11.11%	112	60.00%	6902	71.82%	10366	31.92%	9830
1973	3008	-10.26%	312	178.57%	9745	41.19%	13065	26.04%	9485
1974	1626	-45.94%	464	48.72%	11070	13.60%	13160	0.73%	6954
1975	1078	-33.70%	112	-75.86%	4240	-61.70%	5430	-58.74%	5309
1976	1326	23.01%	56	-50.00%	3142	-25.90%	4524	-16.69%	5635
1977	2210	66.67%	84	50.00%	2389	-23.97%	4683	3.51%	7058
1978	2076	-6.11%	260	209.52%	2111	-11.64%	4446	-5.06%	9187
1979	3046	46.80%	134	-48.46%	1854	-12.17%	5034	13.23%	10188
1980	1650	-45.83%	46	-65.67%	3365	81.50%	5061	0.54%	8069
1981	768	-53.45%	42	-8.70%	1873	-44.34%	2683	-46.99%	6976
1982	891	16.02%	32	-23.81%	2553	36.31%	3476	29.56%	5281
1983	1562	75.31%	60	87.50%	1220	-52.21%	2842	-18.24%	5835
1984	2199	40.78%	112	86.67%	942	-22.79%	3253	14.46%	7666
1985	2313	5.18%	124	10.71%	1781	89.07%	4218	29.66%	8946
1986	2024	-12.49%	112	-9.68%	2076	16.56%	4212	-0.14%	6760
1987	2684	32.61%	124	10.71%	785	-62.19%	3593	-14.70%	7764
1988	2001	-25.45%	172	38.71%	1377	75.41%	3550	-1.20%	7747
1989	2026	1.25%	124	-27.91%	1852	34.50%	4002	12.73%	7955
1990	2054	1.38%	150	20.97%	1171	-36.77%	3375	-15.67%	8851
1991	1335	-35.00%	70	-53.33%	3885	231.77%	5290	56.74%	7860

Source: Building Department, City and County of Honolulu

Oahu's For-Sale Residential Market

Overall Resale Market. Oahu has experienced an upward trend in the price of resold residential units over time. According to purchased data from Locations, Inc., compound annual growth (CAG) rates in residential resales were as follows:

Exhibit IV-5
Wahiawa Lands

Increases in the Average Resale Prices of Single Family and Multifamily Homes on Oahu

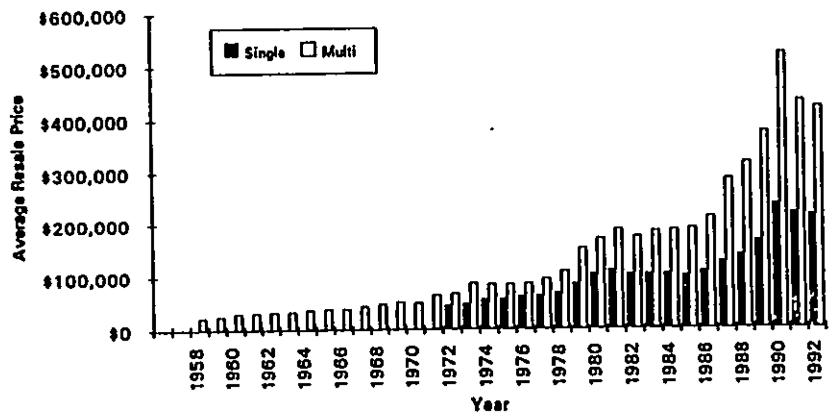
Time Frame	Type of Product	Low	1991	CAG Rate Oahu
1958 - 1991	Single Family	$23,000	$430,000	9.3%
1972 - 1991	Multi-Family	$44,000	$213,000	8.8%

Source: Locations, Inc.

Year-by-year residential resale pricing trends on Oahu are presented graphically on the following page in Exhibit IV-6, *Trends in Average Resale Prices on Oahu: Single Family (1958-1991) and Multifamily (1972-1991)*. The trend line of the chart indicates a series of real estate cycles of approximately nine years in duration with minor subcycles.

Exhibit IV-6
Wahiawa Lands

Trends in Average Resale Prices on Oahu: Single Family (1958-1991) and Multifamily (1972-1991)



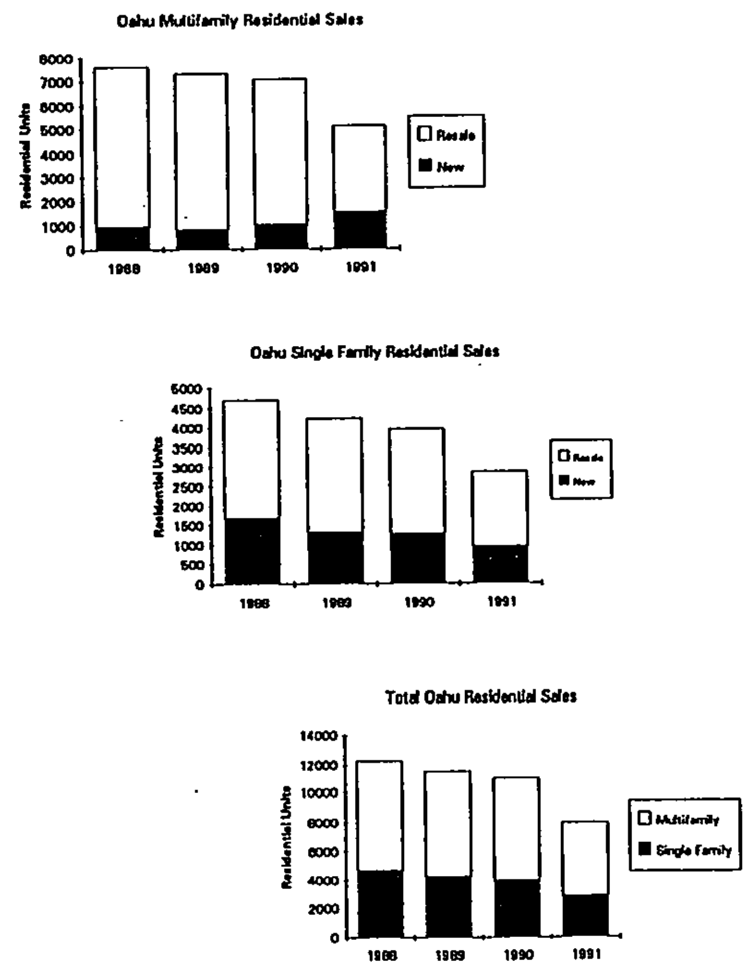
Source: Locations, Inc.

Proportion of Single Family versus Multifamily Residential Resales. Exhibit IV-7, *Comparison of Single Family to Multifamily Housing 1988 - 1991*, shows that the proportion of single family detached to total residential units has steadily decreased over time. This has resulted from a number of factors, including:

- The limited supply of urban-zoned land for development;
- Increase in the number of single parent families;
- Decline in housing affordability as growth in housing prices outpaced growth in income for many Oahu residents, forcing them into more affordable attached units; and
- The developers' response to affordable housing requirements by taking advantage of the lower per unit construction costs associated with multifamily units.

Exhibit IV-7
Wahiawa Lands

Comparison of Single Family to Multifamily Housing 1988 - 1991



COMMERCIAL INDICATORS

The following factors appear to support demand for further development of commercial space on Oahu:

- Growth in Gross State Product
- Wage and salary employment
- Trends in Oahu's office market
- Trends in Oahu's industrial market
- Consumer prices
- Retail sales
- Visitation and tourist expenditures

Growth in Gross State Product

The Gross State Product (GSP) is an indicator of economic prosperity in a region, and its associated manufacturing activity. Strong growth in the area's GSP may be indicative of a healthy and growing industrial market.

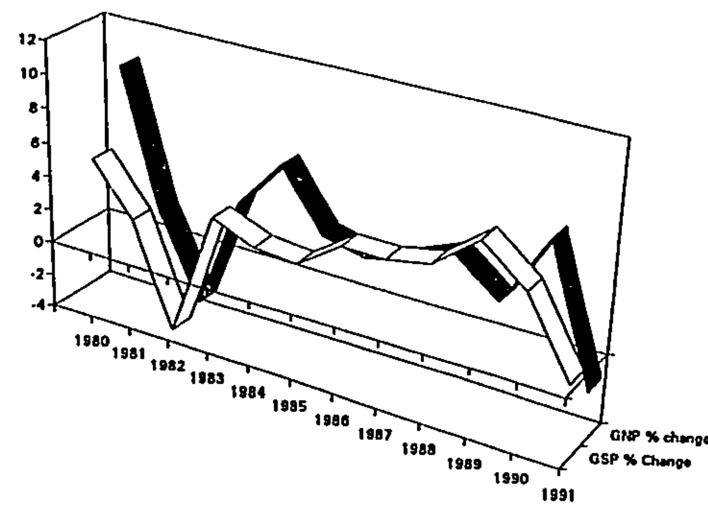
During the last half of the 1980s, Hawaii consistently experienced over five percent real annual growth in its Gross State Product (GSP). On the following page, Exhibit IV-8, *Trends: Gross State Product Versus Gross National Product*, illustrates the following:

Growth continues to be positive, however the 1991 figures indicate that it has begun to subside from the overheated growth rate of the 1980s.

Hawaii's business cycles tend to lag in time behind the Mainland's macroeconomic trends.

Exhibit IV-8
Wahiawa Lands

Comparison of Gross State and Gross National Products, 1980 - 1991



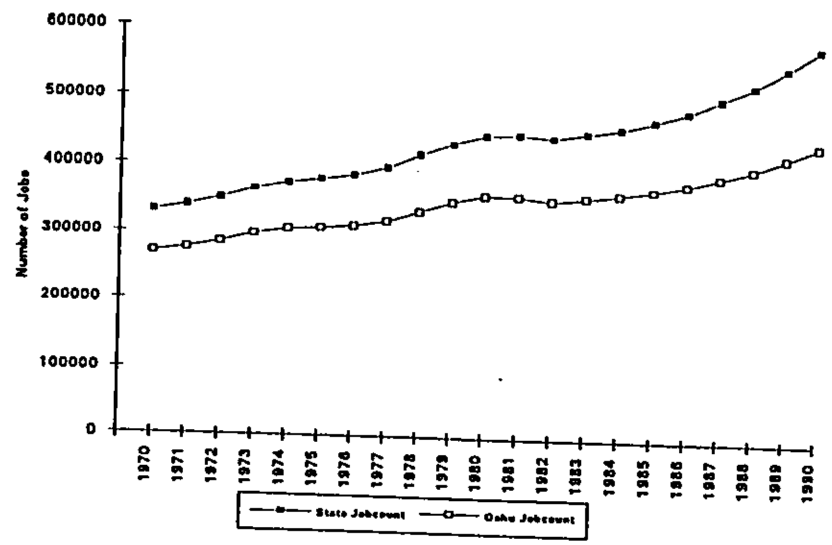
Sources: Gross State Product: Bank of Hawaii
Gross National Product: 1980-1989 - Statistical Abstract of the U.S.; 1990-1991 - Survey of Current Business, August 1992

Wage and Salary Employment

Jobs. Hawaii's employment indicators show a basically healthy state economy, although one not immune to corrections such as the recessions in 1982 and 1992. As stated earlier, on a statistical basis as Oahu goes, so goes Hawaii. The close correlation that exists between shifts in economic performance on Oahu and the State as a whole is illustrated in the employment trend lines shown in Exhibit IV-9, *Trends in Wage and Salary Employment for the State of Hawaii and County of Honolulu, 1970-1990.*

Exhibit IV-9
Wahiawa Lands

Trends in Wage and Salary Employment for the State of Hawaii and County of Honolulu, 1970-1990



Source: State of Hawaii Data Book, 1991, Table 338

Employment Composition. Equally as important as the level of overall employment to Oahu's economy is the type of employment. An analysis of predicted job growth on Oahu and its composition is presented below in Exhibit IV-10, *Composition of Employment on Oahu, 1985 - 2010.*

Exhibit IV-10
Wahiawa Lands

Composition of Employment on Oahu, 1985-2010

Employment Island of Oahu (in thousands)	1985	1990	% Chg	1995	% Chg	2000	% Chg	2005	% Chg	2010	% Chg
Manufacturing	5.7	6.7	18%	7.1	6%	7.7	8%	8.2	6%	8.7	6%
Transp. commun, utilities	27	29.7	10%	31.2	5%	32.3	4%	32.8	2%	33	1%
Trade (exc. e&d)	60.4	70.3	16%	76	8%	77.6	2%	83.7	8%	86.7	4%
Eating and drinking	31.5	36.6	16%	38.5	5%	40.1	4%	41.1	2%	42.2	3%
Banking and finance	26.9	29.4	9%	32.1	9%	33.4	4%	34	2%	34.8	2%
Services, other	71.1	86.8	22%	100	15%	111	11%	119.8	8%	129	7%
Government											
State/local	47.8	50.1	5%	52.6	5%	54.8	4%	55.8	2%	56	0%
Federal	31.4	31.3	0%	31.7	1%	32.1	1%	32.5	1%	32.9	1%
Total	79.2	81.4	3%	84.3	4%	86.9	3%	88.3	2%	88.9	1%
Self-employed	24.7	26.3	6%	31.2	19%	33.7	8%	35.7	6%	37.7	6%

Source: Series M-K

As shown in the previous table, the greatest increases are expected in service, manufacturing and retail trade jobs. These trends will support the planned commercial office, light industrial and retail land uses on the subject property.

White Collar Employment. Office demand can be related to increases in white collar employment categories. The primary white collar employment category is the finance, insurance and real estate sector. Additionally, a portion of the service sector is typically housed in office space. The growth in these categories should support a moderate level of continued office development.

Manufacturing. The manufacturing sector growth is expected to be one of the largest in the Oahu employment market. This strong growth, combined with decreases in the supply of industrial space, should sustain demand for light industrial land on Oahu.

Wholesale and retail employment. Wholesale and retail employment growth has the greatest effect on the demand for retail space. This sector is projected to have a roller coaster future. A stabilizing force may be the additional demand which comes from growth in the service sector, restaurant employment and banking and financial services. Often these businesses choose retail locations in order serve the public.

Unemployment

According to Bank of Hawaii economists, throughout the 1980s and into the 1990s, Hawaii's employment trends have exhibited strength relative to Mainland performance.

The highest unemployment rate in Hawaii in the years 1987 to 1992 was equal to the lowest mainland unemployment rate.

Similarly, mainland employment decreased 2 percent from 1990 to 1992, whereas Hawaii's employment continued to grow with temporary dips. In 1989, Hawaii ranked 49th in the nation for business failures.

Oahu Office Market

Vacancy Rate. The subject property stands to gain from the strength of the Oahu commercial office market which over the past three years has experienced the extremely low vacancy rate of under five percent over the period, as shown in Exhibit IV-11, *Trends in Oahu Office Supply and Vacancy*. The low vacancy rates shown have served to push up rental rates to a point at or above the threshold of many firms.

Exhibit IV-11
Wahiawa Lands

Trends in Oahu Office Supply and Vacancy

Period	Total Square Feet	Vacancy	Occupied Square Feet	Annual Change	% Change
4th 89	9,677,000	5.00%	9,193,150		
2nd 90	9,797,000	3.90%	9,414,917		
4th 90	9,914,000	3.40%	9,576,924	383,774	4.17%
2nd 91	10,134,000	4.20%	9,708,372		
4th 91	10,195,000	4.50%	9,736,225	159,301	1.66%
					2.91%

Source: Coldwell Banker-Torto Wheaton Services

Recent developments and the addition of the planned First Hawaiian Bank Tower will likely increase short-term vacancy rates and help to alleviate the rental rate impact on many firms. However, as with other types of development, a limited supply of suitable lands should cause occupancy rates to return to their historic strength and further increase rental rates. As these rates exceed the thresholds of office tenants, the firms will have to seek other, cheaper options. These options include back office/suburban locations or leaving the market area.

Growth in Commercial Office Space on Oahu. Exhibit IV-12, *Summary of Office Space Locations on Oahu*, illustrates the growth in total square feet of commercial office space on Oahu. Of particular note is the slight decline already seen in the proportion of commercial office space in the downtown area. This trend is expected to accelerate as major Oahu businesses move to locate some of their administrative offices into more cost-effective suburban locations.

Exhibit IV-12
Wahiawa Lands

Summary of Office Space Locations on Oahu

Period	Total	Downtown	Honolulu County	Honolulu Proper
4th 89	9,677,000	5,315,000	546,000	3,816,000
2nd 90	9,797,000	5,319,000	546,000	3,932,000
4th 90	9,914,000	5,279,000	542,000	4,093,000
2nd 91	10,134,000	5,279,000	547,000	4,308,000
4th 91	10,195,000	5,304,000	547,000	4,344,000
% of Total		52.03%	5.37%	42.61%

Source: Coldwell Banker-Torto Wheaton Services

Central Oahu Commercial Office Supply. A 1992 analysis of the office supply in the subject property's Central Oahu region reveals that there is an existing supply of approximately 350,000 square feet of office space. 42,000 or twelve percent of the space is available. As shown in Exhibit IV-13, *Central Oahu Office Supply - 1992*, the greatest vacancies exist in the newer speculative multi-tenant buildings.

Exhibit IV-13, Wahiawa Lands, Central Oahu Office Supply - 1992

Building	Location	Year Open	Gross Square Footage	Net Square Footage	Available Square Ft.	Rental Range ($)
Honfed Bank	Waipahu	1977	30,635	20,315	0	$1.70
Intelect	Mililani	1990	32,000		0	N/A
Lee Towne Center	Waipahu	1992	20,000	18,000	14,400	$1.20 - $2.25
Leilehua Building	Mililani	1988	25,000	20,000	1,180	$1.75
Mililani Town Center Office Building	Mililani	1992	21,000		11,500	$2.25 - $2.50
New Town Office Building	New Town	1975	61,058	59,375	5,184	$1.75 - $2.40
Oceanic Cablevision Building	Mililani	1992				N/A
Pearl City Business Plaza	Pearl City	1981		53,400	1,200	$1.75 - $2.25
Pearl City Plaza	Pearl City	1988	30,939	26,139	8,172	$1.60 - $2.15
Pearl Ridge Office Center	Pearl Ridge	1976	85,000	77,291	0	$2.00 - $2.33
Verifone Building	Mililani	1989	32,000		0	N/A
Waipahu Shopping Plaza Office Building	Waipahu	1978	13,773	12,065	440	$0.95 - $2.25
TOTAL			351,405	286,585	42,076	

Source: Hawaii Business Magazine

Back Office Market. The subject property is positioned to benefit from the trend among major businesses on Oahu to relocate certain operations to suburban locations. These companies feel that lower land cost and reduced commuting time for employees will help reduce their operating costs. Offices in suburban locations, including back office activities, will have increased market appeal as pressures on the transportation system and rising Honolulu land prices create demand for jobs closer to Central and West Oahu's growing residential populations.

Industrial Market

Market Size. As shown below, CB Commercial has estimated a total of 30 million square feet of industrial space on Oahu with an additional 4.5 million expected by year end 1992. This is illustrated in Exhibit IV-14, *Growth in Oahu Industrial Space*.

Exhibit IV-14
Wahiawa Lands

Growth in Oahu Industrial Space

Date/Project	Expected Year	Square Footage	Acres	Comments
Oahu Industrial Supply as of 1Q 92		30,126,000		
Future Additions				
Campbell Industrial Park	1992	150,000 105,000		Jackson Development Yett Partners
Kenai Industrial Park	1992		65	Approx. 1,150,000 SF @ 40% coverage
Kapolei Business Park	1992		132	Approx. 2,300,000 SF @ 40% coverage
Halawa Center	1992	88,000		
Airport Industrial Park	1992	415,000		
Waipahu	1992	150,000		Two parks
TOTAL		31,034,000	197	

Sources: CB Commercial Real Estate Group of Hawaii, Inc.
Grubb & Ellis/Loc
News Articles

Distribution of Industrial Space. The distribution of industrial space on Oahu is heavily weighted in the Kalihi/Sand Island and Airport/Aiea areas, as seen in the chart below, with almost two-thirds of space relegated to those locations. Central Oahu (Pearl City/Waipahu and Mililani account for about 12% currently, but this share is expected to grow with the addition to supply expected in 1992, as shown in Exhibit IV-15, *Geographic Distribution of Oahu Industrial Space.*

Of additional importance, will be the future reduction in the supply of industrial space in the Kakaako and Airport/Aiea areas. These reductions will be brought about by the conversion to mixed use in the Kakaako area and expansion of the airport in the Airport/Aiea area. Combined, these two areas account for over 40% of the island's industrial supply.

Exhibit IV-15
Wahiawa Lands

Geographic Distribution
of Oahu Industrial Space

Period	Total	Airport/Aiea	Ewa	Kakaako	Kalihi/Sand Island	Kaneohe/Kailua	Mililani	Pearl City/Waipahu
1st 89	24,470,000	6,486,000	2,177,000	3,698,000	8,866,000	301,000	0	2,942,000
3rd 89	25,747,000	6,964,000	2,276,000	3,803,000	9,095,000	321,000	0	3,288,000
1st 90	26,650,000	7,219,000	2,362,000	3,846,000	9,531,000	331,000	0	3,381,000
3rd 90	28,917,000	8,059,000	2,489,000	4,013,000	10,271,000	479,000	30,000	3,576,000
1st 91	29,232,000	8,209,000	2,671,000	3,983,000	10,271,000	492,000	30,000	3,576,000
3rd 91	29,865,000	8,322,000	3,118,000	3,983,000	10,271,000	502,000	30,000	3,639,000
1st 92	30,126,000	8,499,000	3,175,000	3,995,000	10,271,000	502,000	30,000	3,654,000
% of Total	100.00%	28.21%	10.54%	13.26%	34.09%	1.67%	0.10%	12.13%
Growth		9.43%	13.40%	2.61%	5.03%	18.59%	N/A	7.49%

Source: Coldwell Banker-Torto Wheaton Services

Industrial Supply and Demand Factors. Industrial vacancy trends can be related to several supply and demand factors:

Island Location. Hawaii's island location creates a need for large amounts of warehouse space. As both the main distribution and largest population center, Oahu benefits the most from this need. As shown in Exhibit IV-16, *Distribution of Industrial Space by Sectors*, almost three-quarters of the industrial space on Oahu in 1989 to 1992 was warehouse or light industrial space.

Exhibit IV-16
Wahiawa Lands

Distribution of Industrial Space by Sectors

Period	Industrial	Manufacturing	Warehouse	R&D	Other	Occupied Space	Annual Change	% Change
1st 89	24,470,000	3,517,000	16,990,000	806,000	3,157,000	23,980,600		
3rd 89	25,747,000	3,333,000	19,592,000	193,000	2,629,000	25,257,807		
1st 90	26,650,000	3,444,000	20,462,000	280,000	2,464,000	25,930,450	1,949,850	8.13%
3rd 90	28,917,000	3,472,000	21,938,000	303,000	3,204,000	28,107,324		
1st 91	29,232,000	3,354,000	21,786,000	250,000	3,842,000	28,384,272	2,453,822	9.46%
3rd 91	29,865,000	4,179,000	21,724,000	188,000	3,774,000	28,431,480		
1st 92	30,126,000	3,995,000	22,045,000	188,000	3,898,000	28,438,944	54,672	0.19%
% of Total		13.26%	73.18%	0.62%	12.94%	94.40%		5.85%

Source: Coldwell Banker-Torto Wheaton Services

Reductions in Supply due to Redevelopment. Continuing reductions in the supply of industrial space due to the expansion of Honolulu International Airport and the redevelopment of the Kakaako district have put further upward pressures on the occupancy levels of existing facilities.

Low Vacancy Rates. Despite recent additions to supply, over the past several years the Oahu industrial market has experienced strong occupancy levels. CB Commercial estimated that four percent of Hawaii's industrial supply of 32 million square feet was available for occupancy, which is equivalent to an occupancy level of approximately 30,750,000 square feet. The national vacancy factor is closer to seven percent, indicating a healthy island market.

Introduction of Non-Industrial Uses. Costco and similar no frills retailers can afford to pay higher rents than typical industrial uses and are utilizing an increasingly large proportion of available industrial space.

All of these factors have contributed to upward pressures on occupancy and rents for light industrial purposes.

Consumer Prices

Consumer prices on Oahu have exceeded national trends in the recent past, although the trend is still one of low inflation. For example, Oahu experienced a 4.84% change in consumer prices between mid 1991 and mid 1992.

Retail Trends

Retail Sales Performance. Hawaii's retail sales performance has been consistent with other positive economic trends in both real terms and when compared to Mainland markets. For example, Mainland retail sales fell dramatically in 1990 while Hawaii's sales continued to be robust but at a slightly lower level.

Hawaii's healthier retail climate is the result of a number of factors:

- Limited supply of retail space in the islands compared to relatively overbuilt areas of the Mainland
- Limited supply creates higher per square foot retail expenditures.
- Tourism bolsters the local retail trade by increasing the retail market significantly beyond demand generated by residents as indicated by relatively high per capita retail expenditures.

It has long been stated that Oahu is underserved with regard to retail space. This is illustrated both by square feet per resident estimates and sales per square foot of retail space indicators. This continuing demand will support anticipated commercial retail operations on the subject property well into the future.

Retail Supply. Exhibit IV-17, *Retail Supply Summary*, shows the current and expected additions to retail supply on Oahu. As noted, many of the additions are retail associated with major master planned communities coming on line in Central Oahu and Ewa.

Exhibit IV-17
Wahiawa Lands

Retail Supply Summary

Date/Project	Expected Year	Square Footage	Comments
Historical Supply (Oahu)			
1989 Supply		9,850,460	
1990 Additions		279,000	
1991 Additions		N/A	
Future Additions			
Waikiki Landmark Retail	1992	49,422	
Aiea Shopping Center	1992	45,000	
Mililani Town Center Phase Two	1992	50,000	Woolworth's (30,000 SF) Boutiques, etc. (20,000 SF)
Ala Moana Expansion	1993	256,000	
Hawaii Kai Town Center	1993	201,000	
Hawaii Power Center	1993	420,000	Costco now out but were to lease 170,000 SF (compared to 120K SF in Salt Lake; 108K in Hawaii Kai); also 25-30 apparel, appliance and electronics tenants
Waikele Power Center	1993	430,000	Phase one only - outlets. Will include 50 national manufacturers (120,000 SF KMart; 155,000 SF Eagle Hardware at outset)
Kapolei Shopping Center Phase One	1993	140,000	Safeway, Longs; 70% national retailers; 30% local
Royal Kunia	Unknown	200,000	
TOTAL		11,920,882	

Sources: CB Commercial Real Estate Group of Hawaii; Grubb & Ellis; Locations, Inc.; News Articles

Visitation and Tourism Expenditures

The Economic Impact of Tourism. The Hawaii economy benefits greatly from its role as a major tourist destination. Tourists support local employment directly through employment in service industries and indirectly in construction and other job categories. Continuing demand for tourism on Oahu is significant to the subject property in several ways:

Oahu has been able to provide a more steady source of employment for its tourism workforce than other islands and will therefore continue to support the demand for residential development.

Oahu visitors make purchases which will continue to sustain retail demand throughout the island. The subject property is located on a popular around-the-island route favored by Oahu tourists. Thus from a retail perspective it stands to gain from the continued vitality of tourism.

Potential employment generators on the site's commercial or light industrial uses could produce goods for sale to tourists.

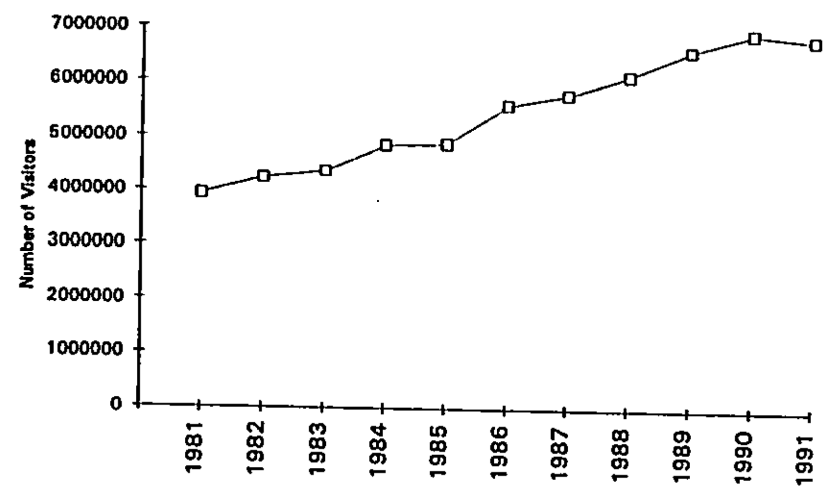
Hotel occupancy. In 1990 the State of Hawaii ranked first in the nation in hotel occupancy rates. Although the rate of growth in tourism slowed during 1991 and 1992, Oahu's Waikiki visitor destination continued to lead the other islands with a sustained occupancy rate of 80%.

Hurricane Iniki created a temporary boon for Oahu and other major islands when it virtually destroyed tourism facilities throughout Kauai in September 1992. During Kauai's rebuilding period Oahu may benefit by absorbing a portion of the tourism that would have gone to Kauai. However, to maintain hotel occupancy rates, advertising funds will have to be committed to overcome the image that all of the islands were damaged by the hurricane.

Visitor arrivals. Since 1980, eastbound and westbound visitor arrivals show an upward trend. According to the Hawaii Visitors Bureau, despite of the effects of the Gulf War and U.S. recession, Hawaii received more than 6.8 million visitors in 1991. Exhibit IV-18, *Total Visitors*, shows the upward trendline since 1981.

Exhibit IV-18
Wahiawa Lands

Total Visitors



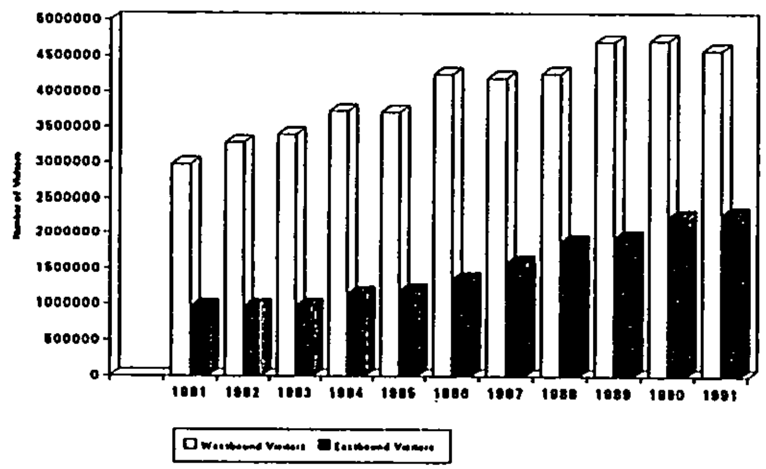
Source: Hawaii Visitors Bureau, Annual Report 1991

1992 Results. Visitor counts for the first half of 1992 are less than one percent below 1991 levels, reflecting a stable tourism climate.

Distribution of Arrivals. Over time the distribution between Mainland U.S. (westbound) and Japanese and Asian (eastbound) visitors has changed dramatically. Exhibit IV-19, Hawaii Visitor Arrivals, illustrates the increasingly greater proportion of eastbound visitors, who now account for over one-third of all visitors to Hawaii. This is an increase from about one-fourth in the early 1980s. The greater proportion of eastbound visitors has increased overall expenditures because of their propensity for spending while in Hawaii.

Exhibit IV-19
Wahlawa Lands

Hawaii Visitor Arrivals



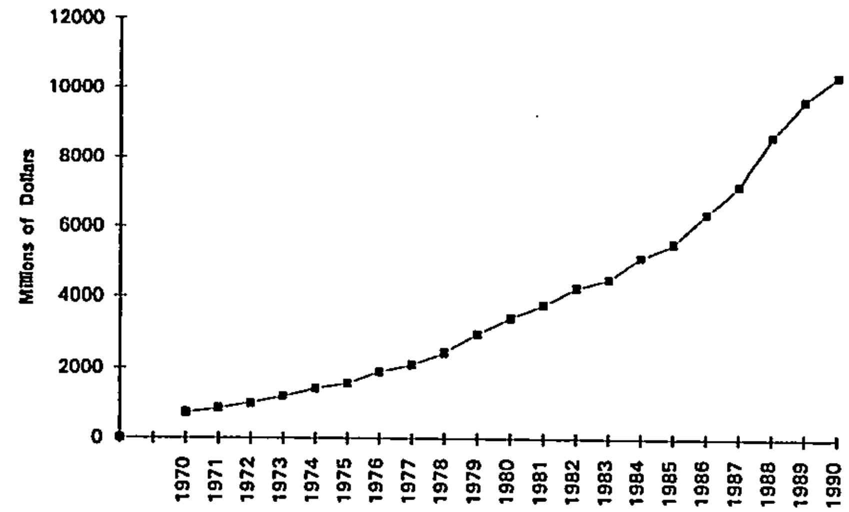
Source: Hawaii Visitors Bureau, Annual Report 1991

1992 Results. Figures released by the Hawaii Visitors Bureau for the first half of 1992 indicate a 24% surge in eastbound visitors, somewhat offset by a 12% drop in westbound visitors which reflects continuation of the U.S. recession. As of June 1992 no decrease in total visitors was seen over 1991 despite worldwide economic challenges.

Total Visitor Expenditures. The trend in visitor related expenditures shown in Exhibit IV-19 below illustrates the steady tourism growth Hawaii has experienced over the past twenty years. Total visitor expenditures grew from $715 million in 1970 to over $10 billion in 1990. This represents a compound annual growth rate of 14.3 percent, which is healthy by any standards. Between 1980 and 1990 alone, expenditures nearly tripled as shown in Exhibit IV-20, Total Visitor Expenditures, on the following page.

Exhibit IV-20
Wahlawa Lands

Total Visitor Expenditures

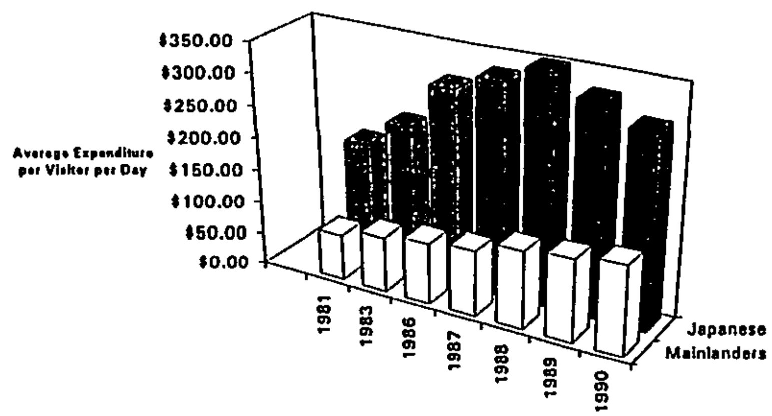


Source: State of Hawaii Data Book, 1991, Table 201

Distribution in Visitor Expenditures. Another significant upward trend in Hawaii tourism is seen in average daily expenditures per visitor. As shown below, while Mainland visitors have gradually increased their expenditures over time, Japanese have typically outspent them by at least two to one. See Exhibit IV-21, *Average Expenditures by Origin of Visitors* on the following page.

Exhibit IV-21
Wahlawa Lands

Average Expenditures by
Origin of Visitors



Source: State of Hawaii Data Book, 1991, Table 195

CONCLUSION

The State of Hawaii, especially the island of Oahu, has demonstrated substantial growth in all sectors of the economy. Based on current and past economic trends, such growth is expected to continue for the foreseeable future, and should support development of the site.

Section V

RESIDENTIAL

Section V

RESIDENTIAL

OVERVIEW

The subject property's Wahiawa location is in the Central Oahu residential market area. The Oahu housing market provides a variety of residential products ranging from high rise luxury condominiums and ocean front homes in Honolulu's primary urban center to older plantation homes on small ranches in the rural areas of Leeward, Windward and North Shore areas. This dramatic variety in residential products also contributes to great diversity in the price of housing.

While housing and its associated pricing vary greatly on the island of Oahu, one thing is universally known: Honolulu's housing ranks as the most expensive the nation. Relatively low wages, high costs of living, a limited supply of land and high construction costs all lead to a shortage of affordable housing for Honolulu's existing and future population. The demand for affordable housing is further illustrated by a relatively high ratio of renters to owners and a significant number of "doubling up" households.

This section presents the existing and future estimates of supply and demand for housing on Oahu. Included throughout this analysis are discussions regarding the Central Oahu market area's relationship to the overall housing market. The section concludes with a description of the proposed property's development concept (which includes a large residential component of approximately 3,100 units) and an estimate of the property's market position.

SUPPLY

Our analysis of Oahu's housing supply begins with an overview of the existing housing stock. This analysis also includes a definition of the primary and secondary competitive residential market areas and a discussion of recent activity in the Central Oahu market. The review of existing conditions is followed by an analysis of the planned and proposed projects for the Central Oahu market area.

Existing Supply

The most recent information regarding the supply of housing on the island of Oahu is derived from the "Development Plan Status Review; Status: Fiscal Year 1992," September 2, 1992, published by the City and County of Honolulu's Department of General Planning. The information from this report is for the period ending June 30, 1991, and is summarized in the following table, Exhibit V-1, *Distribution of Oahu's Housing Stock, June 30, 1991*.

Exhibit V-1
Wahiawa Lands

Distribution of Oahu's Housing Stock
June 30, 1991

Development Plan Area	Existing Stock as of (6/30/91)	Share of Market
Primary Urban Center	166,823	58.2%
Ewa	12,143	4.2%
Central Oahu	36,728	12.7%
East Honolulu	15,629	5.5%
Koolaupoko	34,946	12.2%
Koolauloa	3,928	1.4%
North Shore	5,606	2.0%
Waianae	10,863	3.8%
Total	286,666	100.0%

Source: Development Plan Status Review; Status: Fiscal Year 1992, September 1, 1992

Primary Urban Center

As illustrated in Exhibit V-1, *Distribution of Oahu's Housing Stock, June 30, 1992*, the vast majority of the island's population is located in the Primary Urban Center (PUC). The PUC is a 65,380 acre sector and is the third largest in terms of geographic area of the eight planning regions.

Approximately 30 percent of the PUC is designated for urban uses. The majority of the developed area within this district consists of higher density housing structures. This region will continue to be popular with island residents due to its proximity to Honolulu's central business district. However, housing in the region continues to be pushed out of reach of more and more Oahu residents. This is a function of rapidly increasing land and housing prices and building costs associated with developing the PUC.

Central Oahu

The subject property is located in the Central Oahu planning area. This region is the second largest planning district based on geographic area and concentration of housing units. It should be noted, however, that the Central Oahu area contains less than 25 percent of the supply of the PUC's housing stock with the following characteristics:

- Housing in the Central Oahu area tends to have a greater concentration of lower density single family homes and smaller multi-family structures.
- Of the 69,105 acres in this planning district, approximately 5,100 acres are designated for residential uses or 7.4% of the overall land area.
- The majority of the district's lands are in preservation, agricultural and military uses.

The plentiful supply of easily developable land, desirable local climate, existing infrastructure and an established residential reputation should continue to support an increasing supply of residential units in the Central Oahu area.

Ewa

A final region of interest is the Ewa area. This area only accounts for approximately four percent of Oahu's housing stock. However, the continued development of master planned communities such as West Loch, Ewa by Gentry and Kapolei, which offer affordable and moderately priced housing, have and will continue to position this as an area of rapid growth. In an attempt to provide affordable housing, the area is following a relatively dense development pattern.

Existing Supply Conclusions

- **Primary Competitive Supply.** Based on our survey of actively selling subdivisions it is the consultants' opinion that the primary competitive supply for the subject property will come from developments in the Central Oahu market. The most competitive projects will be those located in master planned communities. These communities include developments such as Mililani Mauka, Melemanu Woodlands and Waikele. Additionally, Central Oahu competition will come from stand-alone subdivisions in the area.
- **Secondary Competitive Supply.** Secondary competition is also expected from the final phases of some of the master planned communities in the Ewa area. The most competitive of these communities will be Ewa by Gentry. To a lesser extent, The City of Kapolei can be considered to be in the secondary competitive market. However, it must by noted that this project has established a unique identity, and that most buyers in The City of Kapolei probably will not shop the subject property. Due to an upscale orientation of the existing and planned subdivisions in the Makakilo development, this project is deemed to provide limited if any competition for the proposed development on the subject property.

The development of the planned employment facilities in the Kapolei second city should position Central Oahu as an ideal location for dual income households with one downtown worker and one second city worker.

Additions to Supply

Turnover of tenancy in single family residential units tends to be lower than that of multi-family uses and certain commercial uses. As such, communities which will be actively selling residential projects at the time that the subject property is developed must be considered in the analysis of supply and demand. With regard to additions to supply, this report focusses on only projects which are in the primary competitive area. These projects are presented in the following table, Exhibit V-3, *Additions to Residential Central Oahu Supply, 1992-2010.* Also provided in the table is a summary of the "build-out" schedule which the developers have provided to the Department of General Planning. A descriptive summary of each of the major developments follows:

Exhibit V-2
Wahiawa Lands

Additions to Residential Central Oahu Supply
1992 - 2010

	1992	1993	1994	1995-1999	2000-2004	2005-2010	Total Constr.	Additions
ADDITIONS								
CRESTVIEW	24	24	24	119			191	
CROWN ELDERLY		111	111	222			444	
MANAGER'S DRIVE DEV.			470				470	
MELEMANU WOODLANDS	12	170	150	949			1,281	
MILILANI	4	4	4	19			31	
MILILANI MAUKA (PH I)	910	691	510	125	500	500	3,236	
MILILANI MAUKA (PH II)				995			995	
ROYAL KUNIA PH I (Note 1)			300	860	859		2,019	
ROYAL KUNIA PH II (Note 2)					500	500	1,000	
SCHOFIELD BARRACKS			202				202	
SUMMITT			200	400			600	
WAHIAWA	60	60	60	296			476	
WAIAWA GENTRY PH1 (Note 3)			300	1,375	0		1,675	
WAIAWA GENTRY PH 2 (Note 4)					1,000	0	1,000	
WAIKELE	446	527	463	1,046			2,482	
WAIPAHU	77	77	77	387			618	
WHITMORE	1	1	1	5			8	
WILIKINA ELDERLY		64					64	
MISC	46	46	46	227			365	
ADDITIONS TOTAL	1,580	1,775	2,918	7,025	2,859	1,000	17,157	17,157

Notes 1 through 4: Consultant estimate of timing

Caveats. It should be noted that the development schedule presented in the previous table is only a general indicator of the timing of these planned projects. In practice many of the projects may not follow these schedules. For example:

- The potential for delay was illustrated in the Department of General Planning's "Development Plan Status Review, Fiscal Year 1992," which indicated that a number of projects including Ewa by Gentry, Ewa Marina, Ko Olina, Royal Kunia and Waiawa have experienced slippage between the long term development schedules presented for 1991 and those presented for 1992.
- Recent turmoil in the financial markets and an anticipated cyclical downturn in the residential market may have accounted for some of these delays. However, in 1991, with a growing number of developments showing a lack of reasonable progress the City Council considered the adoption of a policy which would penalize projects with protracted development delays. In June 1992, the City Council adopted Resolution 92-138 which would provide for a "use it or review it" policy. This resolution is currently in the public and agency review stage.

The following projects have been included in our analysis of the future additions to the subject property's competitive residential supply:

Melemanu Woodlands - This project is being developed in the Melemanu Woods area along Waikakalaua Stream. The development is accessible via H-2 at the Mililani Technological Park exit and then south on Wikao Road and Waikalani Drive. At build-out the development is estimated to include 1,281 units on 70 acres.

The development plan for the Melemanu Woodlands project was approved in 1984 and zoning approvals were granted in 1986. As part of the project's approvals, the City and County of Honolulu required that 15 percent of the development be priced below 80 percent of the median income bracket. First phase infrastructure improvements have been completed and currently two multifamily developments are actively selling products in the project. The project's primary amenity will be open space. As illustrated in the build-out table presented previously, Exhibit V-2, *Additions to Residential Central Oahu Supply, 1992-2010*, the majority of the project will be completed or "winding down" by the time units will be available for sale on the subject property.

Mililani Mauka - This extension of Castle & Cooke Properties' Mililani Town project is currently envisioned to include approximately 4,500 units on a total of 1,200 acres. The project is located to the east of H-2 and is accessible via Exit 5.

Phase 1. The first phase of the project was approved with a ceiling of 3,500 units. At the time of the publication of the 1992 Development Plan Status Review, 264 units were reported to have been completed.

Phase I is intended to be offered in two increments. As a stipulation of the approval process, 50% of the units must meet "affordable" criteria:

- 30 percent of the project's units are required to be priced within 80 to 120 percent of the median income.
- An additional 20 percent of the first phase's units are required to be priced within 120 to 140 percent of the median income.

Phase 2. The second phase of Mililani Mauka (995 units) received development plan approvals during the fiscal year of 1992. Zoning approvals are still pending from the City.

Phase II will be located in the upper northeastern portion of Mililani Mauka. The plan for this phase is to include a mix of single family housing and low density apartments. The same 50 percent affordable requirement was imposed. Additionally, a stipulation requiring no loss of pineapple production has been imposed. Development of this project is expected to continue through the end of the decade.

Several single family and multi-family developments are currently actively selling, under construction or recently completed in the development's first phase. These subdivisions are discussed in the *Market Position* section below.

In addition to the completed units, 915 units were reported to be under construction. The majority of the development is planned to consist of residential units with only a limited level of support commercial and recreational services when compared to the company's Mililani Town development.

Royal Kunia - This project is expected to be developed on 670 acres north of the Village Park community on lands currently planted in sugar cane. The project will be a golf-oriented community accessible from H-1 via Kunia Road.

The first phase is reported to consist of 1,750 to 2,019 units. A total of 152 units were indicated to have been completed previously. Several stipulations were imposed on this phase of the development. Provisions were made for 150 units for the under 80 percent of median income bracket; 20 percent of these units are to be reserved for the elderly. Of the project's total units, 50 percent are to be in the affordable range. The 50 percent affordable component consists of:

- 10 percent at 80 percent of median income housing;
- 20 percent at 80 to 120 percent of median income; and
- 20 percent at the 120 to 140 percent of median income range.

The first phase of the project received its Development Plan Amendment approvals in 1989 and received zoning approvals in 1991. During the

fiscal year 1992 an additional 1,000 units received development plan approvals. Also in 1992 an additional application for 505 acres was submitted. While a decision has not yet been made on this application, the Department of General Planning strongly opposes the development.

Infrastructure improvements are scheduled for the period of 1992 to 1997, with construction of residential units scheduled between 1994 and 1999. The development is to include a mix of single family and multifamily units. The construction schedule for the second phase of the development has yet to be developed.

Summitt - This project, to be developed by Robert Maxwell & Company, is planned for slightly fewer than 600 units. The development will be located on an approximately 50 acre parcel northeast of Mililani Mauka. Sixty percent of the units are planned to be affordable with the remainder for gap group and market buyers. Pending zoning approvals, the units would be on the market in the 1994-96 time frame.

Waiawa Ridge (Gentry) - This project has received its Development Plan Amendment approval. However, it is still waiting for city zoning approvals. According to the developer, the project will require higher densities than other Central Oahu projects due to its location closer to the downtown area and an attempt to offer upscale product at a reasonable price. As part of the approval process the State has imposed a 60 percent affordable requirement including:

- 30 percent of the total units to be provided for the 80 to 120 percent of median income range; and
- 30 percent of the total units to be provided for the 120 to 140 percent of median income range.

Previously submitted in 1991, the project received its Development Plan Amendment approval in 1992. The Department of Land Utilization is currently reviewing zoning of both phases of the project. A Development Plan Amendment for an additional 1,000 units was adopted in fiscal year 1992. It should be noted that the developer is also trying to gain approvals for adjacent lands.

Pending zoning approvals, off-site improvements are expected to begin in 1993 with housing construction continuing through the 1994 to 1999 period. Discussions with the developer indicate that the project's schedule will likely be delayed one year.

Waikele - This master planned community is being developed north of H-1 between its nearly-completed Waikele exit and Kamehameha Highway. Development of Waikele includes:

- One sold out and completed subdivision;
- One sold out affordable subdivision with construction in progress;
- Three actively selling subdivisions;

- One seeded golf course; and
- One recently opened freeway off and on ramp.

An additional amenity to the community will be the Waikele Power Center, a large commercial retail development. Substantial stipulations on the pricing of the products to be offered at Waikele were imposed. These stipulations include the following:

- Ten percent of units for 80 percent of median income or below bracket;
- Eight percent of the units are to be priced below $120,000, reserved for six months for those earning less than 120 percent of median income level;
- Seven percent of the units are to be priced below $140,000, reserved similarly for the less than 140 percent bracket;
- Ten percent of the units are to be priced below $150,000, reserved similarly for the less than 150 percent bracket; and
- Fifteen percent are to be priced below $170,000, reserved similarly for the less than 185 percent level. All prices are allowed to rise with the Consumer Price Index.

Waikele received Development Plan Amendment approvals in 1985 and zoning approval in 1986. At the time of the publication of the 1992 Development Plan Status Review, 298 of the 2,780 planned units had been completed and an additional 446 units were under construction. This development is expected to be built-out over the remainder of the decade.

The infrastructure for the first two phases has been completed and the Phase III improvements are in the design stage. These improvements are to consist of an H-1 overpass at Manager's Drive, water reservoir, roadways and utilities.

Existing Neighborhoods - In addition to the master planned communities, the Department of General Planning prepares estimates of the future capacity of neighborhoods. These estimates are based on past experience with the specific neighborhood. No timetable has been prepared for these developments. As such, the consultants have assumed that these communities would be built out pro rata over the next eight years. The communities included are: Crestview, Mililani, Wahiawa, Waipahu, Whitmore, Village Park and a provision for Miscellaneous areas.

Government Projects - In the calculation of capacity, the Department of General Planning excludes government developments. For the Central Oahu area, government projects include two elderly projects (Crown Elderly and Wilikina Elderly), a City and County housing project (Manager's Drive Development) and one military

development at Schofield Barracks. The estimated build-out of these projects has been based on the proposed schedules presented in the 1992 Development Plan Status Review.

Land Use Commission Projects - In addition to reviewing the projects included in the 1992 Development Plan Status Review report, the consultants have reviewed the files of projects which have been submitted to the State Land Use Commission (LUC). An interview with department staff indicated that many of the large projects are presented to the land use commission before they go to the Department of General Planning (DGP). The representative felt that this procedure aided projects in obtaining DGP approvals. However, this could not be stated as fact.

Additionally, the interview indicated that the LUC was primarily focused on the land use intended as part of the application. While the LUC would prefer that these projects develop in a manner consistent with their application, it was indicated that variances often occur. As such it appears that the LUC deals with projects at a higher level focusing on use rather than specific unit counts. The more detailed analysis and product specific levels are addressed to a greater degree by DGP.

Based on these observations, it would appear that the projects which have been submitted to the LUC, but are not included in the DGP Status Review, are too preliminary to be counted as definite additions. Due to the preliminary status of these projects, it would not be fair to exclude the development potential of the subject property. As such, we have included a listing of projects which are maintaining a level of contact with the LUC. However, these projects have not been included in the final analysis of shortfall/(overbuilt) conditions. The projects which appear to be actively exploring increasing their allowable units include: Mililani Mauka, Waiawa Gentry and Royal Kunia.

Supply Summary

The consultants' research indicates that affordable projects draw demand from the entire Oahu population. It is necessary to understand the supply in the overall market area as a tool for defining the level of available demand. However, the most important segment of supply is that which exists in the primary market area, in this case Central Oahu. The following table, Exhibit V-3, *Supply Summary, 1992 - 2010,* summarizes the existing and future supply of housing for the Central Oahu area during the scope of the study.

Exhibit V-3
Wahiawa Lands

Supply Summary
1992 - 2010

	1991	1992	1993	1994	1995-1999	2000-2004	2005-2010	Total Constr.	Exist + Add
EXISTING HOUSING STOCK	36,728								36,728
ADDITIONS									
CRESTVIEW		24	24	24	119			191	
CROWN ELDERLY			111	111	222			444	
MANAGER'S DRIVE DEV.				470				470	
MELEMANU WOODLANDS		12	170	150	949			1,281	
MILILANI		4	4	4	19			31	
MILILANI MAUKA (PH I)		910	691	510	125	500	500	3,236	
MILILANI MAUKA (PH II)					995			995	
ROYAL KUNIA PH I (Note 1)				300	860	859		2,019	
ROYAL KUNIA PH II (Note 2)						500	500	1,000	
SCHOFIELD BARRACKS				202				202	
SUMMITT				200	400			600	
WAHIAWA		60	60	60	296			476	
WAIAWA GENTRY PH1 (Note 3)				300	1,375	0		1,675	
WAIAWA GENTRY PH 2 (Note 4)						1,000	0	1,000	
WAIKELE		446	527	463	1,046			2,482	
WAIPAHU		77	77	77	387			618	
WHITMORE		1	1	1	5			8	
WILIKINA ELDERLY			64					64	
MISC		46	46	46	227			365	
ADDITIONS SUB TOTAL	0	1,580	1,775	2,918	7,025	2,859	1,000	17,157	17,157
EXISTING & PROJECTED SUPPLY									53,885

Notes 1 through 4:
Consultant estimate of timing

DEMAND

The demand for housing can be closely associated with the increase in an area's population base. More specifically, the formation of new households increases the demand for new housing. In an undersupplied market area the direction of demand is typically affected by the location of the supply. Furthermore, the restricted availability of housing in these undersupplied market areas puts pressure on housing costs. This pressure leads to a condition where housing prices increase faster than the population's ability to pay these costs which in turn creates a situation with pent up demand for affordable and reasonably priced housing. This pent up demand is evidenced by relatively higher levels of renters compared to owners in the Honolulu market area and a significant level of doubling up of families.

Population

As illustrated in the Area Review section, over the past decade population increases in Honolulu have increased at a compounded annual growth rate of 0.93 percent or approximately 7,367 persons annually. While the projections through 2010 anticipate a lower growth percentage, annual absolute increases are expected to increase to a level of 8,163 persons annually. By the year 2010, Honolulu's population is expected to stand at 999,500.

The following sections discuss the expected sources of demand for additional residential units.

Households and Household Size

Estimated Increase in Occupied Housing Units by 2010: *76,789 units*

Rationale

As of June 30, 1991 the Oahu housing stock was estimated to be 286,666 units. It is common knowledge that on Oahu many households are "doubling up." Interviews in the subject property's immediate market area indicated that these households may consist of two or three adult family members, often grown children with families of their own living with parents. This situation helps to contribute to a larger than average household size. Additionally, a national trend to smaller family sizes is expected to continue to decrease the average household size in the future.

We have utilized a household size of 2.75 persons for our calculation of the future demand for housing. This household size is consistent with the figure used by the Department of General Planning. However, based on decreasing family sizes and the alleviation of some of the need for doubling up by an increase in the supply of affordable housing, the 2.75 average household size appears to be conservative. Assuming the

household size of 2.75 persons and a population of 999,500 by the year 2010, the number of occupied households in 2010 is estimated to be 363,455. This would indicate a need for an additional 76,789 units between June 30, 1991 and 2010.

Vacancy Rate

Estimated Number of Vacant Units as of December 31, 2010: *4,507 units*

Rationale

A certain level of vacancy in the market area is deemed to be healthy. This vacancy level allows the free movement of the population in and out of a community and within the community. According to the 1990 U.S. Census, the vacancy factor in the Honolulu residential market area was 5.87 percent. This factor included both owned and rental units. The 1990 census figure appears to be at a reasonable level. Applying this vacancy rate to the estimated demand for housing of 76,789 between 1991 and 2010, an additional 4,507 vacant units should be introduced into the market.

Total Oahu Housing Demand

Expected Total Demand for Oahu by December 30, 2010: *370,000 units*

Rationale

Based on the above discussion the total demand for new housing units on the island of Oahu, including a provision for vacancy, is estimated to be 81,296 units. When added to the existing housing stock total demand for housing for the entire Honolulu housing market is estimated to be 367,962 (or approximately 370,000) units by the end of 2010.

Central Oahu Allocation

Expected Demand between June 30, 1991 and December 31, 2010: *55,000 to 61,000 units*

Rationale

The Department of General Planning allocated 14.9 to 16.5 percent of the island of Oahu's population to the Central Oahu area. The Department reported that between 1980 and 1990 the area's capture rate of the island population increased from 13.3 percent to 15.6 percent (representing a 28.6 percent change in population).

The Central Oahu area benefits from a number of factors which promote successful development. Existing infrastructure, new infrastructure under construction and other improvements are planned as part of the future projects (as described in the *Supply* section). The climate of the Central Oahu area is considered to be very attractive as compared to that of some of the lower lying areas of Oahu. Physically, the area's gently sloping terrain and soil conditions lend themselves to ease of development. Land in this area is available in large parcels which are owned either individually, corporately or by a limited number of land owners.

The Department of General Planning's estimates appear to be conservative based on Central Oahu's attributes. Only at the upper end of their estimates do the area's very positive attributes appear to be accounted for. In addition to the locational, climatic, affordability and infrastructure attributes of the Central Oahu area, the consultants also believe that a lower household size should be used in the calculation of future demand. It would appear that the Department of General Planning's estimates do not completely address decreasing family sizes, a reduction in "doubling-up" and the ability of affordable housing to attract population from other areas at significant levels. Application of the Department of General Planning's capture rates of 14.9 to 16.5 percent to the estimated island-wide demand of approximately 370,000 units by the year 2010, indicates demand in the Central Oahu area of approximately 55,000 to 61,000 units.

Demand Summary

Exhibit V-4, *Calculation of Demand, 1990 - 2010*, summarizes the above discussion through the presentation of the calculation of demand. A range of demand levels for the Central Oahu is presented. This range is comprised of three divisions. Included in the range are the Department of General Planning's low and high-end allocation estimates. These levels are compared to the third division which assumes a consistent capture rate at the 1990 level of 15.6 percent.

Exhibit V-4
Wahiawa Lands

Calculation of Demand
1990 - 2010

Assumptions				Notes
Oahu Population 2010	999,500			
Persons per Household	2.75			DGP Estimate for Oahu
Vacancy Rate	5.87%			Per 1990 Census
Demand Calculations				
Population/Households	363,455			999,500/2.75
Existing Housing Supply	286,666			DGP DPSR, 1992
Demand for New Housing	76,789			DGP DPSR, 1992
Vacancy Provision	4,507			Based on vacancy assumption
Total Demand by Year 2010	367,962	367,962	367,962	
Central Oahu Allocation Factor	14.90 Low End	16.50 Hi End	15.60 Existing	DGP and Consultant Estimate
Central Oahu Demand	54,826	60,714	57,402	

SUPPLY AND DEMAND CALCULATION

Exhibit V-5, *Supply and Demand Summary*, presents the estimated supply and demand relationship based on the discussion presented in the prior sections. An additional adjustment to the supply side of the analysis has been made. The adjustment attempts to account for the slippage in development schedules which is occurring in the market area.

The subject property will likely be active through at least one real estate cycle of approximately nine years. As such it is likely that many of the proposed properties may experience delays in product delivery due to financing, design or the possible introduction in the future of a "use it or review it" policy.

Based on these calculations it would appear that adequate demand would exist for residential development on the subject property. These conclusions were confirmed by interviews in the local community and with developers and real estate agents active in the Oahu residential market.

Exhibit V-5
Wahiawa Lands, Supply and Demand Summary

Assumptions				Notes
Oahu Population 2010	999,500			
Persons per Household	2.75			DGP Estimate for Oahu
Vacancy Rate	5.87%			Per 1990 Census
Demand Calculations				
Population/Households	363,455			999,500/2.75
Existing Housing Supply	286,666			DGP DPSR, 1992
Demand for New Housing	76,789			DGP DPSR, 1992
Vacancy Provision	4,507			Based on vacancy assumption
Total Demand by Year 2010	367,962	367,962	367,962	
Central Oahu Allocation Factor	14.90 Low End	16.50 Hi End	15.60 Existing	DGP and Consultant Estimate
Central Oahu Demand	54,826	60,714	57,402	
Supply Calculations				
Existing Inventory - Central Oahu	36,728	36,728	36,728	DGP DPSR 1992
Housing Capacity	17,157	17,157	17,157	Expected Additions
Unadjusted Supply	53,885	53,885	53,885	
Deduction for Timing (10%)	-5,389	-5,389	-5,389	Consultant Estimate
Adjusted Supply by Year 2010	48,497	48,497	48,497	
Conclusions				
Estimated Demand	54,826	60,714	57,402	
Adjusted Supply	48,497	48,497	48,497	
= Estimated (Oversupply)/ Shortfall by 2010	6,330	12,217	8,906	

MARKET POSITION

Methodology

Product Survey. The first step in determining the potential market performance of the subject property was to survey products offered for sale in the primary competitive and the surrounding Ewa and Waianae market areas. The projects were surveyed as a guideline for determining product sizing, pricing and absorption. Product pricing and absorption rates were later adjusted for locational attributes. As the results of this market assessment are stated in current dollars, no inflation adjustment has been made. Once the existing products were identified and surveyed, a list of comparable products was prepared for each of the individual villages within the proposed Wahiawa Lands development. These comparables served as guidelines for potential products which could be developed in the subject project's subdivisions and their potential performance.

Estimate of Absorption. Once the product types were identified for each of the neighborhood areas, a potential absorption schedule was prepared. Key assumptions include:

- The absorption schedule assumes that three to four different product types would be active at a time.
- It is further assumed that as any of these product types are built out they would be replaced with a similar product.
- Additionally, as identified in the area review section, the Honolulu residential market area appears to follow an approximately nine year cycle. To the extent possible, but recognizing that the future cannot be exactly predicted, the product absorption schedule attempts to follow these trends with regards to product offerings.
- The timing for delivery of the first finished lots and general schedule for phasing has been provided by the client.

It must be noted that this hypothetical absorption schedule is only one of many potential schedules, and that the actual schedule may differ significantly based on enforceable market or financial conditions. Additionally, should the approval process accelerate or be delayed, the absorption schedule may vary in the type of product or the location of the subdivision initially offered. Finally it must be noted that the hypothetical absorption schedule reflects only market-related factors and does not account for soil conditions, financial optimization or engineering factors.

Cross Checks. As a final step in our analysis, we have compared the hypothetical absorption schedule with the performance of other master planned communities. This comparison was prepared as a cross check for overall absorption levels. An attempt has been made to reflect the

typical build up and decline of a master planned community's sales velocity.

Development Concept: "Country"

The Wahiawa community considers itself, and is generally recognized, as a part of Oahu's so-called "country." In order to blend in with this atmosphere the consultants' believe that the project should provide a feeling of openness. This could be accomplished with community open spaces and a generally lower density level for each type of product than found in recently developed Central Oahu communities. Additionally, it is the consultants' belief that the country concept would be incorporated in the product design of each product type. This concept has been reviewed with active developers in the local market area and appears to be consistent with their view of the site's development potential.

Inventory of Existing Products

Exhibit V-6, *Existing Residential Products, 1992* on the following page provides an overview of subdivisions which are currently active or have recently been completed in the Central Oahu, Ewa and Waianae residential market areas. The Makakilo project also offers a custom lot program. These custom lot subdivisions have not been included as they are not deemed to be competitive with any of the proposed developments within the subject property. Whenever possible weighted averages have been used.

Exhibit V-6
Wahiawa Lands, Existing Residential Products, 1992

Subdivision	Area	Type	#	Mo. Absp	Size(SF)			$(000's)		
					Min	Max	Avg	Min	Max	Avg
Evergreen Terrace	Ctl.	SFA	130	8	934	1289	1112	205	244	225
The Ridge	Ctl.	SFA	44	**	703	875	793	170	209	190
Na Lei	Ctl.	SFD	171	20	1075	1456	1299	280	360	320
Na Pua	Ctl.	SFD	109	N/A	1033	1572	1279	280	360	320
Kumelewai Court	Ctl.	SFA	152	16	855	1634	1076	178	280	229
Kumelewai Gardens	Ctl.	SFA	160	Lottery	501	777	639	89	132	111
Hampton Court	Ctl.	SFA	100	N/A	874	1725	1373	250	360	305
Fairway Village	Ctl.	SFA	208	N/A	796	1387	1022	215	320	268
Parkview	Ctl.	SFA	80	Lottery*	650	N/A	N/A	82	N/A	N/A
Sunset Point	Ctl.	SFA	280	11	1342	1477	1396	337	361	349
Golf Club Estates	Ctl.	SFD	82	N/A	1600	2016	1771	477	500	489
Fairway Signature	Ewa	SFD	144	144	1635	1828	1757	285	330	308
Fairway Paradise	Ewa	SFD	**	**	1812	2210	2018	319	424	372
Fairway Homes	Ewa	SFD	**	**	2220	2744	2483	400	578	489
Parkway Homes	Ewa	SFA	**	**	1798	2568	2245	276	345	311
Parkway Signature	Ewa	SFA	451	**	1798	2568	2245	259	309	284
Sun Terra	Ewa	SFD	451	48	945	1671	1268	252	305	279
The Arbors	Ewa	SFA	289	31	1009	1526	1141	217	295	256
Sun Rise	Ewa	SFA	408	70	407	830	600	124	188	156
Kumu Iki	Ewa	SFD	367	30	966	1924	1369	280	350	315
Malanai	Ewa	SFD	625	4	1721	2246	1985	335	365	350
West Cliff	Ewa	SFD	28	28	1436	2370	1903	315	350	333
Lokelani	Wai.	SFA	288	5	954	1309	1121	177	208	193
Village at Pokai Bay	Wai.	SFD	447	13	800	1915	1167	189	290	240

* This project was the impetus for the lottery system.
** Information not available at the time of publication.
Source: Developers, real estate agents, Gail W. Atwater James W. Stanney Consultants.

Absorption

The sales rates used in our hypothetical absorption schedule tend to be lower than those indicated by the above survey summary. These variances are related to an annualizing of absorption. The annualizing addresses down periods between the availability of product and the associated construction periods. Based on the consultants' research into products which have been on the market for extended periods and the overall sales rates for individual projects obtained from Locations Inc., these more conservative figures appear to be in line with actual conditions in the market place.

Additionally, absorption rates shown in the hypothetical absorption schedule take into consideration the potential type of product to be offered on the specific parcel, surrounding land uses and the qualitative factors presented in Exhibit V-7, *Qualitative Evaluation Criteria*.

Exhibit V-7
Wahiawa Lands

Qualitative Evaluation Criteria

Master Planned Community	Access	Views	Neighborhood	Amenities	Overall Ranking
Ewa by Gentry	Equal	Inferior	Slightly Superior	Inferior	Similar
Kapolei	Equal	Inferior	Slightly Superior*	Similar	Slightly Inferior
Mililani Mauka	Superior	Slightly Inferior	Superior	Inferior	Slightly Superior
Royal Kunia	Superior	Slightly Inferior	Similar	Superior	Slightly Superior
Waikele	Far Superior	Superior	Superior	Superior	Superior
West Loch	Superior	Slightly Superior	Similar	Similar	Slightly Superior

* Kapolei has a developing identity which is positive; Wahiawa's identity is undefined

Pricing

The proposed community is anticipated to be developed along the general guidelines of the State of Hawaii, Department of Budget and Finance's Housing Finance and Development Corporation. These guidelines provide for the development of 60 percent of the development's housing component to be affordable and the remainder of the development to be offered at market rates.

Affordable Product

Two equal divisions have typically been made within the affordable product:

- Typically, 30 percent of the development's product will be priced at 80 to 120 percent of the median household income.
- An additional 30 percent of the product will be priced in the 120 to 140 percent of median income brackets.

For a family of four the median annual income is assumed to be $46,000. The State further assumes that qualifying residents would make a down payment of five percent and that housing payments on a 30-year mortgage would represent 33 percent of the families' income. Additionally, the State estimates monthly tax, insurance and maintenance fees of $130 for single family developments and $255 for multifamily developments. The following table, Exhibit V-8, *Affordable Housing Pricing Guidelines, 1992*, summarizes the State's recommended pricing for single and multifamily developments financed at 9.5 percent interest rates.

Exhibit V-8
Wahiawa Lands

Affordable Housing Pricing Guidelines
1992

	Percent of Median Income						
	80%	90%	100%	110%	120%	130%	140%
Single Family	$110,400	$126,300	$142,100	$157,900	$173,800	$189,600	$205,400
Multi-Family	$94,800	$110,600	$126,400	$142,300	$158,300	$173,900	$189,800

Source: State of Hawaii, Department of Budget and Finance's Housing Finance and Development Corporation

Market-Priced Product

With regard to market housing, locational adjustments were made to the comparables indicated in the previous table. The information in Exhibit V-9, *Locational Adjustment*, was derived from the 1990 U.S. Census and was used in the consultants' neighborhood adjustments of the comparable projects.

Exhibit V-9
Wahlawa Lands

Locational Adjustment

Location	Census Tract	Value of Owner Occ. Unit	Adjustment	Rent $	Adjustment
West Loch	83.01	$125,000	141.36%	$731	69.22%
Ewa Gentry	84.00	$238,800	73.99%	$680	74.41%
Kapolei	86.98	$147,000	120.20%	$99	511.11%
Mililani	89.05	$282,900	62.46%	$1,000 +	50.60%
Waplo/Waikele	89.01	$212,300	83.23%	$640	79.06%
Makakilo	86.04	$234,800	75.26%	$962	52.60%
Lokelani	96.01	$90,000	196.33%	$636	79.56%
Village at Pokai Bay	97.02	$158,900	111.20%	$516	98.06%
Wahlawa	91.00	$176,700	100.00%	$506	100.00%

Product	Adjustment	Adjusted Price	Square Feet	$/S.F. Base	$/S.F. Adjusted
Na Lei	62.46%		1,289	$246.34	$153.86
Na Pua	62.46%		1,279	$254.47	$158.94
Sunset Point	83.23%		1,396	$251.20	$209.07
Sun Terra	73.99%		1,268	$217.98	$161.28
Village Pokai Bay	111.20%		1,167	$201.19	$223.72
		$256,360	1,282		$200.00
Estimated		$250,000	1,300		$192.31

Product	Adjustment	Adjusted Price	Square Feet	$/S.F. Base	$/S.F. Adjusted
Fairway Paradise	141.36%		2,018	$184.09	$260.23
Malanai	120.20%		1,985	$199.24	$239.49
Golf Club Estates	83.23%		1,771	$274.65	$228.59
		$433,050	1,925		$225.00
Estimated		$375,000	1800		$208.33
		$322,581	1600		$201.61
		325000	1600		$203.13

Potential Product Types

The following is a brief description of the subdivisions included in the Draft Site Plan and comparable products which have been developed in other communities with similar attributes. It must be noted that these products are only included for illustrative purposes and that the actual products developed in any or all of the proposed subdivisions could vary significantly. These variances could be caused by the style preferences of the selected developer and/or unforeseeable changes in the economic, market and financial conditions in the market area. It must also be noted that the timing discussed below for sales of various products is hypothetical and the actual schedule may vary. The map on the following page, Exhibit V-10, *Wahlawa Lands Neighborhoods*, delineates the proposed neighborhood locations and boundaries within the subject property.

Single Family - Market-Priced

Parcel No. 1 - is located in the northeastern portion of the property. The parcel should be largely surrounded by the proposed golf course. The anticipated zoning for the proposed 34 acre parcel would provide for the development of single family detached units. Based on its location, surrounding amenities and the intended development density, this parcel is believed to be one of the more attractive subdivisions within the community. The preliminary phasing schedule and estimated market conditions would indicate that this subdivision could come on line during 1999. After reviewing the comparables the consultants have assumed that the average product to be developed on parcel one would be an approximately 1,600 square foot single family home priced around $325,000 and absorbing at eight units per month.

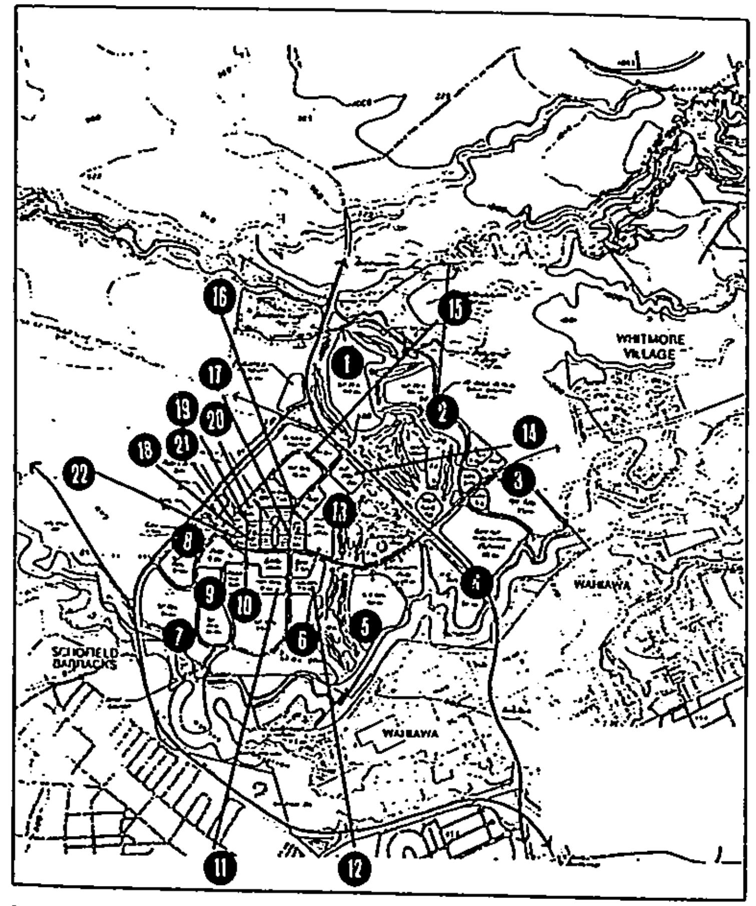
Parcel No. 2 - is located to the north of Whitmore Avenue and along the property's eastern boundary. To the west the proposed subdivision should front golf-related facilities. To the south will be a small commercial center, park and an elementary school. The subdivision's eastern boundary will abut Castle & Cooke's property which is currently in pineapple production. The planners have proposed a product density of 6.0 dwelling units per acre for this 28-acre parcel.

This development has been estimated to be the first single family subdivision to be started with in the proposed community. Potential comparable developments for a product on this site may include Na Lei, Na Pua, Sunset Point Sun Terra and Village at Pokai Bay. Based on these comparables and taking into consideration the property's surrounding land uses (including the uncertain future of the adjacent Castle & Cooke holdings), the consultants have estimated that an average housing unit on parcel two would be approximately 1,300 square feet and priced around $250,000. Absorption for this type of product is estimated at approximately 12 units per month.

Parcel No. 5 - is located in what is considered to be the most desirable location in the proposed development. This 30-acre subdivision is currently envisioned as completely surrounded by parks, the golf course and lake frontage.

Exhibit V-10
Wahiawa Lands

Wahiawa Lands Neighborhoods



Conceptual Plan | Figure: 4

WAHIAWA LANDS MASTER PLAN
Prepared For: Galbraith Trust Estate, Hawaiian Trust Company, Ltd., Trustee
Prepared By: Helber Hastert & Fee, Planners
Not to Scale

As this development is expected to be the most expensive housing project in the community (average units priced at approximately $375,000), its absorption rate is anticipated to be the lowest of the single family products at four units per month. The development of this type of product would coincide with the peak of the market which is anticipated to be approximately 2007. Comparable subdivisions for this site are believed to be Fairway Paradise, Malanai and Golf Club Estates. Based on these comparables we would anticipate that a product averaging approximately 1,800 square feet could be developed on this site. This sizing is somewhat smaller than the average of these projects to avoid the following situation: real estate professionals in the market area indicated that the slower absorption rates in comparable developments were associated with the sizing of the units, placing the houses out of the affordability level of most shoppers.

Parcel No. 6 - is located to the west of parcel number five along Lake Wilson. The two parcels are separated by the proposed golf course. Along the western frontage of the subdivision single family developments are anticipated. To the immediate north of the subject 47 acre parcel is a proposed medium density subdivision. The site is believed to exhibit similar characteristics to those of parcel number one. As such, this subdivision is anticipated to follow similar pricing, sizing and absorption rates. The estimated timing of sales on this site is 2004, with absorption of about 8 units per month.

Parcels No. 7 & 10 - are located to the north and west of parcel six. Parcel seven has preliminarily been sized at 34 acres and parcel number ten has been sized at 34 acres. While these sites may include some affordable units, for ease of analysis these subdivisions have been assumed to include only market units. The products for these sites are anticipated to be similar to those proposed for parcel two. These similarities include sizing (1,300 square feet), pricing ($250,000) and absorption rates (12 units per month). Sales of units in these two subdivisions are anticipated to occur between 2004 and 2006.

Single Family - Affordable

Parcels No. 8 & 9 - have been assumed to be affordable single family developments for ease of analysis. However, as with parcels seven and ten, the actual development of these subdivisions may include market units. Parcel eight fronts Kamananui Road to the south of the proposed road bisecting the development. Parcel nine is located southeast of parcel eight and is largely surrounded by residential parcels six, seven, and ten, a park and an elementary school.

Comparables for these projects could include Kumu Iki, the affordable units at Sunset Point, Lokelani and Fairway Signature. Due to a limited supply of lower density single family affordable units, absorption of these units is expected to be strong at 16 units per month. Our analysis of absorption has assumed that sales in parcel eight would begin in 1999 and sales at parcel nine would begin in 2003.

Pricing of the development's affordable single family units has been estimated at the 120 to 140 percent of median income bracket or $173,800 to $205,400 based on State guidelines.

Medium Density - Affordable

Parcels No. 3 & 4 - are located to the east and west of the proposed 33 acre commercial/industrial park, south of Whitmore Avenue and north of Lake Wilson. Parcel three is a 25 acre parcel east of the commercial/industrial park and the 26 acre parcel four is located west of the commercial/industrial park and Kamehameha Highway. Potential comparables for these subdivisions could include The Arbors, Kumelewai Court and Fairway Villas. Pricing for these projects is anticipated to average in the lower range of the 120 to 140 percent of the median income bracket. Absorption of these units has been assumed at 12 units per month.

Parcels No. 11 & 12 - are located in the central portion of the proposed development south of the community's Town Center. Parcel 11 is an eight acre site and parcel 12 is an 7.5 acre site. In addition to the comparables listed for parcels three and four, other developments could include Evergreen Terrace and Kumelewai Gardens. While absorption levels are expected to be the same as parcels three and four, the average pricing for parcels 11 and 12 is expected to be at the upper end of 120 to 140 percent bracket.

Multifamily - Affordable

The Town Center area is anticipated to include affordable multifamily units. If these units were to be offered for sale it is estimated that they would be priced at the lower end of the 80 to 120 percent of median income bracket. As the exact product type for this area of the community has yet to be defined, a conservative six unit per month absorption rate has been assumed based on the consultants' experiences. The development of the Town Center is estimated to occur during the middle of the community's "build-out" period with sales of the area's units starting in 2002.

Parcels No. 13 & 14 - are located to the east of the town center and adjacent to the golf course. Parcel 14 is located north of parcel 13. Should the units on these sites be offered for sale, comparables may include Parkview, Kumelewai Gardens, Kumelewai Court, Evergreen Terrace and Fairway villas. The pricing of these units is estimated to be in the upper end of the 80 to 120 percent range due to the golf course frontage of the subdivisions. Sales on the seven acre parcel 14 are anticipated to begin in the year 2000 with the development of the 19 acre parcel 13 following the "build-out" of parcel 14. Absorption of these units is estimated to be strong at 12 units per month due to the locational attributes of the subdivisions.

Parcel No. 15 - is located north of the Town Center and to the south of the proposed 31 acre business center. Due to the uncertainty of timing of the land use to the north of this 12 acre site, sales for this subdivision are estimated to begin in 2007.

An absorption rate of eight units per month was assumed due to the density of the development, location within the community and a lack of view amenities. Average pricing for this subdivision is anticipated to be at the lower end of the 80 to 120 percent of median income bracket.

Parcels No. 16 - 22 - are located around the town center. Should the units in this portion of the community be offered for sale it is anticipated that prices of these units would average in the low to mid point of the 80 to 120 percent bracket. The units in subdivisions 16 through 19 are anticipated to average higher prices than those in units 20 through 22, due to their location away from Kamananui Road and proximity to community amenities. Absorption of these units is estimated at eight units per month.

Rental Potential

It should be noted that the developer has indicated that an unspecified number of the multifamily units described above may be offered as rentals. Based on a limited survey of multifamily rentals in the Central and Ewa markets we have estimated that rental units could include studio, one, two or three bedroom units. Current market rates for these units are shown below in Exhibit V-11, *Market Rates for Rental Units*:

Exhibit V-11
Wahiawa Lands

Market Rates for Rental Units

Type	Market Prices	Affordable Prices
Studio	$645 - $750	$640
One Bedroom	$735 - $850	$740
Two Bedrooms	$850 - $975	$895
Three Bedrooms	$950	N/A

Source: Real Estate Agents and Rental Agents

It should be noted that the affordable rental rates stated in the previous table are derived from our interviews. These rates cannot directly be compared to the State's guidelines. The difference relates to the fact that the State's guidelines are based on family size rather than unit type.

Additionally, the State's guidelines cover a broad range of income levels and potential development credits. At the current status of planning the consultants are unable to calculate the mix of rental versus "for sale" units. As such, the type of units offered and their pricing cannot be determined.

Tenant Turnover. Our interviews and recent media reports indicate that some projects in the Oahu market are experiencing increases in vacancy rates. It has been represented by one rental agent that vacancies increase when the State raises the rates that projects can charge affordable tenants. Additionally, the recent addition of military housing developments has reduced some of the demand for rental units in the market area. High turnover rates are prevalent in the market area as many tenants struggle to pay the existing rental rates. As rates rise many families are forced to move out. These tenants often return to doubling-up situations or leave the island. Based on the normally high level of tenant turnover and waiting lists which are still present at many projects, the increase in vacancy rates in the market area is not expected to be long term.

HYPOTHETICAL ABSORPTION SCHEDULE

Exhibit V-12, *Hypothetical Absorption Table*, summarizes the timing and absorption discussions presented in the prior section. Again it must be noted that the hypothetical absorption schedule only represents one of many potential scenarios which could actual occur. The schedule which follows is intended to reflect the bell shaped curve of build up and decline of absorption which has been experienced in other master planned communities.

Exhibit V-12
Wahiawa Lands

Hypothetical Absorption Table

SF-Mkt.	#	Ac.	Du/Ac	Units/$	Units	Abs Mo.	Abs Ann.	Start Date	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
				1,236																		
	1	34.0	6	$325,000	204	8	96	1999			96	96	12	0								
	2	26.0	6	$250,000	158	12	144	1998		144	12	0										
	5	30.0	6	$375,000	180	4	48	2007											48	48	48	36
	6	47.0	6	$325,000	282	8	96	2004								96	96	90	0			
	7	34.0	6	$250,000	216	12	144	2005									144	72	0			
	10	33.0	6	$250,000	198	12	144	2004								144	54	0				
				$297,694	1,238				0	144	108	96	12	0	0	240	294	182	48	48	48	36
SF-Afford.				248																		
	8	21.0	6	$189,600	126	16	192	1999			126	0										
	9	20.0	6	$189,600	120	16	192	2003							120	0						
				$189,600	246				0	0	126	0	0	0	120	0	0	0	0	0	0	0
Med.				660																		
	3	25.0	10	$158,100	250	12	144	2000				144	106	0								
	4	26.0	10	$158,100	260	12	144	2002						144	116	0						
	11	8.0	10	$173,900	80	12	144	1999			80	0										
	12	7.5	10	$173,900	70	12	144	2001					70	0								
				$161,891	660				0	0	80	144	176	144	116	0	0	0	0	0	0	0
Multi.				958																		
	Cmr.	9.9	15	$110,600	148	6	72	2002						72	72	4	0					
	13	19.0	15	$158,100	285	12	144	2001					144	141	0							
	14	7.0	15	$142,300	106	12	144	2000				106	0									
	15	12.0	15	$110,600	188	8	96	2007											96	92	0	
	16	2.5	15	$126,400	38	8	96	1998		38	0											
	17	2.0	15	$126,400	30	8	96	1999			30	0										
	18	2.0	15	$126,400	30	8	96	1997	30	0												
	19	2.0	15	$126,400	30	8	96	1997	30	0												
	20	3.0	15	$110,600	45	8	96	1997	45	0												
	21	2.0	15	$110,600	30	8	96	1997	30	0												
	22	2.0	15	$110,600	30	8	96	1998		30	0											
				$130,306	958				135	68	30	106	144	213	72	4	0	0	96	92	0	0
					3100				135	212	344	346	332	357	308	244	294	182	144	140	48	36

CONCLUSION

Based on the estimated 13-year sell out of the 3,100 residential units in the proposed development, an average annual absorption rate of between 225 and 250 units appears to compare favorably with the experiences of other communities. We have analyzed the capture rates of the following communities which ranged from approximately 5.5 percent of new home sales to approximately 28 percent:

- West Loch;
- Mililani/Mililani Mauka;
- Kapolei; and
- Ewa by Gentry.

Based on the capture rates of these developments the subject property's estimated capture rates, which range between approximately three and 8.5 percent per year, appear to be conservative.

Section VI

RETAIL

Section VI

RETAIL

INTRODUCTION

It has been the consultants' experience that projects of the size of that proposed for the subject property often require a retail component. The current draft site plan for the subject property provides for the location of several different retail uses within the proposed community. The following section defines the retail trade area for potential retail services located on the subject property. Further, the section reviews current and future supply and demand conditions and outlines possible retail tenants which could be located in retail facilities should they be developed on the subject property.

TRADE AREA DEFINITION

In order to define a trade area for the subject property, interviews were conducted with merchants in the Wahiawa market area and with the corporate offices of selected local retailers. The Wahiawa merchants were interviewed because the project intends to be an extension of this community. These interviews were instrumental in defining the geographic boundaries of the existing trade area and the current retail climate in the site's immediate area.

Additionally, a limited number of chain operators was interviewed. These interviews provided further insight into the establishment of a trade area for the subject development. As potential tenants, they aided the analysis by identifying demographic requirements, "no compete" zones and store sizing requirements.

A relatively consistent trade area was defined based on the Wahiawa merchant and local tenant interviews. A relatively consistent trade area was defined. Residents of the immediate Wahiawa market apparently account for approximately 75 percent of retail sales in the existing Wahiawa stores. An additional 20 percent of the retail sales in the Wahiawa market area is estimated to come from the North Shore. Merchants in Wahiawa felt that they drew residents from the North Shore communities of Mokuleia and Waialua to the west and Haleiwa, Waimea, Sunset Beach and Pupukea to the east. An additional five percent of sales came from the entire Oahu market. Only a minimal about of sales are generated by residents living to the south of Wahiawa. This is accounted for by the level of retail development which has occurred in these mature communities and a natural tendency for shoppers to travel towards town rather than away from town for their shopping needs.

While residential developers tend to evaluate their markets based on Census tracts, retailers typically relate to zip codes for their market information. As such we have defined the primary and secondary markets as including the following zip codes:

Exhibit VI-1
Wahiawa Lands

Definition of Trade Areas

Trade Area	Zip Code
Primary	96786
Secondary	96791, 96712

SUPPLY

Current Wahiawa Retail Supply

The supply of retail space in the Wahiawa community primarily consists of small retail buildings and strip shopping centers located along Kamehameha Highway, California Avenue and Kilani Avenue. According to members of the Wahiawa business and finance community, the retail developments along Kamehameha Highway are in a declining state. The businesses along Kilani Avenue appear to have a secondary location relative to those located on California Avenue. While causing additional traffic concerns in the local community, the expansion of the neighborhood shopping center on California Avenue has shifted the community's emphasis towards this area of the town. It should be noted that some typical shopping center anchors have stand-alone stores in Wahiawa. These retailers include Cornet, an independent supermarket and a large hardware store.

Current North Shore Retail Supply

The retail supply on the North Shore primarily consists of a limited number of businesses operating out of small retail buildings and three larger grocery stores. The community of Haleiwa has the greatest retail concentration including several mid-sized strip centers and a neighborhood shopping center.

Retail Sales and Composition

Exhibit VI-2, *Retail Sales and Competition Report*, was prepared by Urban Decision Systems, Inc.(UDS). UDS is a recognized demographic data source for retail tenants nationally. The table illustrates the existing level of retail sales and the number of establishments in certain retail categories for the primary, secondary and metropolitan trade areas. It should be noted that the retail sales section of the report represents the sales level within the *primary* market, including the effects from the secondary market areas.

The retail sales section of the table in Exhibit VI-2 indicates the dominance of the Wahiawa area within the primary and secondary trade areas. This section also provides some insight into the spending habits in the local market area. For example:

- The primary trade area demonstrates a higher percentage of expenditures (larger than the secondary and metropolitan areas) in the areas of lumber, automotive dealers and drug stores. This expenditure level on nonessential items is indicative of a trade center. This factor is further illustrated by the direct relationship of sales in the primary market to those in the secondary market.
- The majority of the categories in the table indicate that the primary market area accounts for more than 50 percent of the combined primary and secondary trade areas' sales. Particularly dominant categories include lumber (100%), drug stores (100%), automotive dealers (96.4%) and home furnishing stores.
- Indicative of the North Shore's tourism influence and the relative inconvenience of the neighborhood center located on California Avenue, the Wahiawa market appears to capture less than its fair share of the food store, apparel store and gasoline station categories.

The *Total Retail Establishments* section further illustrates the Wahiawa market's areas of dominance and weakness. Additionally, this section of the table provides insight into retail categories which are currently not being served in the market area.

- For example, the table clearly indicates a lack of department stores, men's and women's apparel stores, appliance stores, jewelry stores and book stores.
- As illustrated in the *Demand* section, certain categories are obviously unfeasible.
- Additionally, the recent opening of a jewelry store, which according to our interviews is performing well, may have adequately served this need.
- Further, the need for some of these categories may be covered by establishments offering a variety of merchandise.

Exhibit VI-2
Wahiawa Lands

Retail Sales and Competition Report

RETAIL SALES & COMPETITION
WAHIAWA

URBAN DECISION SYSTEMS, INC.
10/20/92

	PRIMARY AREA	SECONDARY AREA	HONOLULU COUNTY,HI
RETAIL SALES ($000)	115585	186485	9585913
GAF stores	12.7%	14.4%	46.3%
Durable goods	34.9%	23.4%	27.1%
Lumber, bldg mat, mtr home	4750	4750	194182
General merchandise stores	8923	15571	2991099
Food stores	23650	55127	1349919
Automotive dealers	31301	32467	1425676
Gasoline stations	9790	20556	365398
Apparel stores	1921	6023	627383
Home furnishings stores	3288	4037	299451
Eating & drinking places	21475	35408	1222652
Drug stores	8402	8402	330401
Misc retail stores	2085	4144	779895
TOTAL RETAIL ESTABLISEMENTS	96	164	5161
Lumber, bldg mat, mtr home	1	1	90
General merchandise stores	3	5	87
Department stores	0	0	18
Food stores	14	31	596
Grocery stores	9	23	373
Automotive dealers	10	11	195
Auto & home supply	4	5	95
Gasoline stations	4	13	212
Apparel stores	3	9	604
Men's wear stores	0	0	54
Women's wear stores	0	1	218
Shoe stores	1	1	66
Home furnishings stores	8	10	278
Furniture stores	2	3	61
Appliance stores	0	1	28
Radio TV stores	2	2	79
Eating & drinking places	36	58	1688
Restaurants & lunchrooms	22	37	1120
Bars	4	5	178
Drug stores	3	3	82
Misc retail stores	14	23	1329
Sporting goods stores	2	3	86
Jewelry stores	0	1	37
Book stores	0	0	232

Source: Jan. 1,1992 UDS Estimates
1990 County Business Patterns
124433 (XRC)

Urban Decision Systems/PO Box 25953/Los Angeles, CA 90025/(800) 633-9568

Even considering these weaknesses, this portion of Exhibit VI-2 provides a starting point for identifying potential tenants for a retail development on the subject property.

ADDITIONS TO SUPPLY

Wahiawa

Future supply of retail space in the primary and secondary market areas was determined by utilizing Table N of the Appendix to the Development Plan Status Review; Status: Fiscal Year 1992, dated September 1, 1992, prepared by the City and County of Honolulu's Department of General Planning. Analysis also included a review of recent articles related to retail development. With the exception of the 46,000 square foot expansion of the Wahiawa Town Center neighborhood center, which has already been completed, no other retail developments are proposed in the primary trade area.

Additions to Central Oahu Retail Supply

Two other proposed retail developments in the Central Oahu area are located to the south of the subject: Mililani Town Center expansion and the Waikele Center. These developments are expected to have little effect on the primary market area. The lack of impact is related to the intended regional draw of the Waikele development and the expansion of merchandise categories which are not offered in the subject's trade areas.

North Shore Additions

No additional retail developments have been formally proposed for the North Shore trade area. Considered to be in the Koolauloa planning area, the proposed developments at the Kuilima Resort could have some impact on the subject property's secondary trade area. However, the development of the proposed shopping center at the resort appears to be on hold. Should this project be developed its presence may serve to reduce the amount of demand that the Wahiawa area is able to capture from the eastern portions of its North Shore trade area.

DEMAND

Demand for retail services on the subject property will be a function of the existing population to the extent that tenants in the proposed development can serve needs which are not currently being met by the existing Wahiawa merchants. Additionally, demand will be generated by the natural growth in population, the induced demand brought into the market area by the residential population of the subject property and growth in the population of the secondary trade area.

Existing Demand

The base demand is illustrated by the first portion of the table presented in Exhibit VI-2. The UDS numbers assume the primary trade area's population to be 41,404. The secondary trade area's population was estimated to account for an additional 15,788 persons. Based on these figures and the current expenditures illustrated in the prior table, per capita expenditures are estimated to be $2,792 in the primary trade area and $3,261 in the secondary trade area. The higher level of per capita sales in the secondary market is a function of the area's tourist and visitor orientation and lower population base.

The following tables have also been prepared by UDS. The tables illustrate the demand potential for various types of goods and services in each of the subject's primary and secondary trade areas. UDS calculates retail potential based on an eight tier regional and sub regional model. Per capita expenditures are determined by dividing the population into the retail potential. These figures are than translated into retail square footages based on surveys of retail trade organizations.

From these tables, potential demand was grouped into categories similar to those included in the previous supply table (Exhibit VI-2). Based on the existing and potential additions to supply an indication of the market draw was estimated for each of the retail categories.

These retail draw factors take into account the following:

- Type of service;
- The closest provider of these services; and
- Level of need by the population for the type of service.

Exhibit VI-3
Wahiawa Lands

Primary Trade Area's Retail Potential

RETAIL POTENTIAL: STORE SUMMARY — URBAN DECISION SYSTEMS, INC.
WAHIAWA PRIMARY AREA — 10/20/92
AREA SUMMARY

STORE SUMMARY:
ANNUAL SALES POTENTIAL, 1990

	AGGREGATE ($000)	PER CAPITA	MARKET INDEX*	GLA [1]
DEPARTMENT STORES	20760	501.38	86	135
VARIETY STORES	1346	32.50	85	22
CATALOG SHOWROOMS	1411	34.07	82	5
GROCERY STORES	41862	1011.01	87	139
CONVENIENCE STORES	2512	60.66	87	11
APPAREL STORES	9023	217.92	84	65
SHOE STORES	1722	41.58	89	11
JEWELRY STORES	1497	36.15	78	5
FURNITURE STORES	3506	84.68	84	27
APPLIANCE STORES	1372	33.15	89	6
RESTAURANTS [1]	13494	325.90	67	2374
DRUG STORES	6431	155.30	77	36
LIQUOR STORES	3082	74.44	97	16
HARDWARE STORES	1272	30.73	63	9
LUMBER STORES	5351	129.24	58	31
LAWN & GARDEN STORES	439	10.60	64	4
PAINT STORES	545	13.17	59	2
FLOORING STORES	1224	29.57	81	8

NOTE:
[1] GLA: Supportable floor space (gross leasable area, thou sqft), except for restaurants: total supportable seats

*Market Index Reference Area:
UNITED STATES

Source: Apr. 1,1990 UDS Estimates — 124433 (RP)

Urban Decision Systems/PO Box 25953/Los Angeles, CA 90025/(800) 633-9568

Exhibit VI-4
Wahiawa Lands

Secondary Trade Area's Retail Potential

RETAIL POTENTIAL: STORE SUMMARY — URBAN DECISION SYSTEMS, INC.
WAHIAWA SECONDARY AREA — 10/20/92
AREA SUMMARY

STORE SUMMARY:
ANNUAL SALES POTENTIAL, 1990

	AGGREGATE ($000)	PER CAPITA	MARKET INDEX*	GLA [1]
DEPARTMENT STORES	29310	512.49	88	194
VARIETY STORES	1907	33.34	87	32
CATALOG SHOWROOMS	2013	35.19	84	7
GROCERY STORES	57985	1013.86	87	199
CONVENIENCE STORES	3498	61.16	88	15
APPAREL STORES	12806	223.91	86	96
SHOE STORES	2422	42.35	91	16
JEWELRY STORES	2155	37.68	81	7
FURNITURE STORES	4975	86.99	86	39
APPLIANCE STORES	1922	33.61	90	8
RESTAURANTS [1]	18850	329.58	68	3551
DRUG STORES	9116	159.38	79	52
LIQUOR STORES	4325	75.62	99	23
HARDWARE STORES	1813	31.69	65	14
LUMBER STORES	7647	133.70	60	46
LAWN & GARDEN STORES	624	10.91	66	6
PAINT STORES	779	13.63	61	3
FLOORING STORES	1741	30.44	83	12

NOTE:
[1] GLA: Supportable floor space (gross leasable area, thou sqft), except for restaurants: total supportable seats

*Market Index Reference Area:
. UNITED STATES

Source: Apr. 1,1990 UDS Estimates — 124433 (RP)

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Categories which tend to draw from large trade areas or those which are not served by the existing or the proposed supply are assumed to draw demand from both the primary and secondary trade areas. Services which are sensitive to drive times or face a large supply of competitors are assumed to only draw from the primary trade area.

These groupings are summarized in the following table, Exhibit VI-5, *Wahiawa Lands Retail Groupings.*

Exhibit VI-5
Wahiawa Lands

Wahiawa Lands Retail Groupings

Category	Subcategory	Draw
General Merchandise Stores	Department Stores	Primary and Secondary
	Variety Stores	Primary
	Catalog Showrooms	Primary and Secondary
Food Stores	Grocery Stores	Primary
	Convenience Stores	Primary
Apparel Stores	Apparel Stores	Primary
	Shoe Stores	Primary and Secondary
Home Furnishing Stores	Furniture Stores	Primary
	Appliance Stores	Primary
Restaurants	Restaurants	Primary
Drug Stores	Drug Stores	Primary & Secondary
Lumber, Building Materials, Mfr. Home	Hardware Stores	Primary & Secondary
	Lumber Stores	Primary & Secondary
	Lawn and Garden Stores	Primary & Secondary
	Paint Stores	Primary & Secondary
	Flooring Stores	Primary & Secondary
Jewelry Stores	Jewelry Stores	Primary & Secondary
Liquor Stores		Primary

Source: Gail W. Atwater James W. Stanney Consultants

Growth In Demand

Population. In addition to the existing demand, further demand will be created by increases in the primary and secondary trade areas. The State's Series M-K population projections were not prepared for the census tract or zip code levels. However, the City and County of Honolulu has prepared planning area level projections. These estimates compare favorably for the North Shore area (17,000 in 2010), however, some interpolation is required to estimate the primary trade area's population.

Central Oahu Market Share. Comparing the UDS estimate of primary trade area population to the 1990 Central Oahu population level, a market share of 31.7 percent is indicated. We have applied this market share figure to the midpoint of the 2010 population calculation presented in the *Residential* section of the report, which is 158,000. The result of this calculation is a future primary market area of approximately 50,000 which would primarily consist of the existing population and future residents of the subject property.

Calculation of Growth. The population increases are then converted in to retail sales based on the per capita expenditure figures indicated in the UDS tables. The calculation of the growth in demand is summarized in the following table:

Exhibit VI-6
Wahiawa Lands

Retail Demand

RETAIL DEMAND SUMMARY SUB-CATEGORIES	DRAW	BASE DEMAND ($000)	GROWTH IN DEMAND ($000)	TOTAL POTENTIAL DEMAND ($000)	CATEGORY	POTENTIAL DEMAND ($000)
Department Stores	Primary & Secondary	$29,310	$5,027	$34,337	General Merchandise Stores	$38,320
Variety Stores	Primary	$1,346	$279	$1,625		
Catalog Show Rooms	Primary & Secondary	$2,013	$345	$2,358		
Grocery Stores	Primary	$41,862	$8,691	$50,553	Food Stores	$53,586
Convenience Stores	Primary	$2,512	$521	$3,033		
Apparel Stores	Primary	$9,023	$1,873	$10,896	Apparel Stores	$13,734
Shoe Stores	Primary & Secondary	$2,422	$415	$2,837		
Furniture Stores	Primary	$3,506	$728	$4,234	Home Furn. Stores	$5,891
Appliance Stores	Primary	$1,372	$285	$1,657		
Restaurants	Primary	$13,494	$2,801	$16,295	Restaurants	$16,295
Drug Stores	Primary & Secondary	$9,116	$1,563	$10,679	Drug Stores	$10,679
Hardware Stores	Primary & Secondary	$1,813	$311	$2,124	Lumber, Bldg. Mat., Mtr. Home	$14,765
Lumber Stores	Primary & Secondary	$7,647	$1,311	$8,958		
Lawn & Garden Stores	Primary & Secondary	$624	$107	$731		
Paint Stores	Primary & Secondary	$779	$134	$913		
Flooring Stores	Primary & Secondary	$1,741	$299	$2,040		

Source: UDS, Inc.; Gail W. Atwater James W. Stanney Consultants

SUPPLY AND DEMAND SUMMARY

By comparing the summary of existing retail sales (shown in the retail supply section), with the retail potential (discussed in the demand section) an indication of unsatisfied retail demand is indicated. This unsatisfied demand can consist of two forms:

- Residents in the subject property's competitive trade areas may purchase these goods and services in other market areas (including catalog sales); or
- Residents may go without satisfying these wants and needs.

Should adequate unsatisfied demand exist to attract retailers who provide these goods and services, it is assumed that residents would chose purchase these items closer to home.

Determining adequate levels of demand is a function of local spending habits, existing and planned additions to supply, typical sales levels for a particular retail category and normal facility sizes. Exhibit VI-7, *Future Retail Potential*, compares the existing retail sales levels for the primary trade area with the retail potential for various retail categories. This comparison also considers the retail categories' geographic drawing potential.

Demand Calculation. Where the retail potential exceeds the existing retail spending levels, unsatisfied retail potential exists. To calculate demand, this unsatisfied spending potential was then converted into an estimation of needed square feet of retail space by major retail category. The conversion was made based on a *weighted average typical per square foot sales rate* for each of the major retail categories.

Exhibit VI-7
Wahlawa Lands

Future Retail Potential

Category	Retail Potential ($000'S)	Existing Sales ($000'S)	Unsatisfied Demand ($)	Potential S.F.
Lumber, Bldg. Mat., Mtr. Home	$14,765	$4,750	$10,015,389	53,192
General Merchandise Stores	$38,320	$8,923	$29,397,015	161,117
Food Stores	$53,586	$23,650	$29,936,075	83,455
Automotive Dealers		$31,301	N/A	
Gasoline Stations		$9,790	N/A	
Apparel Stores	$13,734	$1,921	$11,812,609	69,634
Home Furnishing Stores	$5,891	$3,288	$2,602,867	13,672
Restaurants	$16,295	$21,475	N/A	
Drug Stores	$10,679	$8,402	$2,277,199	11,088

Source: UDS, Inc.; Gail W. Atwater James W. Stanney Consultants

Finally, the estimated need for additional square footage calculations was compared to the typical store size of retail tenants servicing the various retail categories.

- Typical store sizes for tenants can vary greatly based on the merchandise carried and whether a tenant is a local, regional or national chain or independent.
- Additionally, many retailers are repositioning and redesigning their stores. For example, in the grocery industry, the introduction of "superstores" has greatly increased the average size of the typical grocery store.
- In contrast, many department stores have focused their product lines, discontinuing unprofitable items and downsizing newer stores.

The figures used in the following table, Exhibit VI-8, *Need for Additional Retail Space in the Primary Trade Area by 2010*, were derived from the most current edition of the Urban Land Institute's publication Dollars and Cents of Shopping Centers.

Exhibit VI-8
Wahiawa Lands

Need for Additional Retail Space in the Primary Trade Area by 2010

Category	Potential Sq. Ft.	Estimated Store Size		
Lumber, Bldg. Mat., Mtr. Home	53,192	14,500	-	35,500
General Merchandise Stores	161,117	16,500	-	62,000
Food Stores	83,455	25,000	-	50,000
Apparel Stores	69,634	1,200	-	10,000
Home Furnishing Stores	13,672	2,200	-	35,000
Drug Stores	11,088	7,500	-	14,500

Source: UDS, Inc.; Gail W. Atwater James W. Stanney Consultants

MARKET POSITION

Retail Options

The design of the subject property provides for a variety of retail options.

- Small convenience goods and services will be mixed throughout the community,
- A walking mall will be near the Town Center and
- Small to mid-sized shopping center could be developed in the Commercial/Industrial Center.

Design Attributes

The proposed community is surrounded by major arterials and its development design is intended to facilitate pedestrian traffic. These attributes should provide potential retail tenants with excellent visibility and vehicular and pedestrian traffic counts. It should also be noted that the development will be part of the Wahiawa community, which is already established as a trade center for residents of north Central Oahu and the North Shore.

Additionally, as demonstrated by the preceding supply and demand analysis, by the year 2010 there appears to be a significant level of potential demand for a variety of retail goods and services. These needs appear to support a wide range of tenants, including smaller stand-alone or in-line tenants and larger anchor tenants. For example:

- While most categories appear to be under served, a definite need for apparel retailers is indicated.
- Our interviews in the market area indicated that, while the restaurant segment appears to be adequately served, these facilities tend to be concentrated in the fast food and limited service operations. As such, their may exist a need for additional "sit down-table service" restaurants in the Wahiawa area.

CONCLUSION

The proposed development appears to be well positioned to serve a variety of community retail needs. The variety of sites offered within the development can serve small to large tenants. Tenants drawn to the subject property will primarily provide goods and services for its residents. Additionally, by complementing the merchandise offered for sale by the existing Wahiawa merchants, the retail facilities in the proposed community will also help to anchor Wahiawa's position as trade center for the north Central Oahu and North Shore areas.

Section VII

EMPLOYMENT GENERATORS

EMPLOYMENT GENERATORS

INTRODUCTION

In addition to the residential and commercial analyses that form the core of the Market Assessment, the consultants were asked to investigate the possibility of locating employment generating uses on the subject property.

- Commercial employment generating uses would primarily be located in the proposed 38-acre business center adjacent to the planned town center.

- Light industrial uses would be sited in an area designated for commercial/industrial mixed use, which is south of Whitmore Avenue and east of Kamehameha Highway.

This section provides an overview of the methodology utilized in this analysis and additional details relating to the market potential of selected employment generators.

METHODOLOGY

The preliminary step in this analysis was to evaluate the subject parcel's strengths and weaknesses relative to potential employment generating land uses. Evaluation criteria included the property's physical location and characteristics based on site inspection, existing and projected market conditions and market perceptions.

Based on an evaluation of local, regional and national trends in the development of large parcels of land and the consultants' experience, a preliminary land use list was established. The preliminary list of potential employment generators included: suburban office or administrative "back office" park, light industrial park, retail outlet center, health care facilities, distribution/warehousing, heavy industrial and research and development uses.

Through additional market research, interviews and brainstorming sessions a "short list" of land uses was established. This list included:

- Suburban office and/or back office;
- Light industrial (primarily store front warehouse facilities);
- An outlet retail center; and
- Health care related services.

The remaining uses on the preliminary list were considered to have overriding obstacles to their market success.

SUBURBAN OFFICE AND/OR BACK OFFICE

Overview

There is currently a trend among major businesses on Oahu to relocate certain operations to suburban locations. These companies feel that lower land cost and shorter commuting times for employees will help reduce their operating costs. The operations being relocated tend to be divisions not requiring face to face customer contact such as computer facilities and administrative support functions. They are known collectively as *back office* operations.

It is believed that back office operations have the flexibility to be located outside the urban core without loss of efficiency or image. This trend has created demand for commercial office space in outlying suburban areas not previously associated with such traditionally main-office activities.

Potential Market Positioning

According to our research, a labor pool, which exhibits the characteristics typically associated with back office employees, appears to exist in the Central Oahu area. With location of administrative or back office facilities on the subject property, employees would be able to live and work in the Central Oahu area. In addition to the larger employers, some multi-tenant buildings could be developed. These buildings could further serve the community by providing office space for small business operators or self-employed persons.

All back office operations -- including those proposed for Kapolei in Ewa and Mililani Technological Park's industrial mixed use development -- will have to compete with the Central Business District which remains the center of commerce on the island. However, it is expected that over time this resistance will diminish as Central Oahu and Ewa more fully develop as urban communities.

Early signs of this trend were indicated in the Office subsection of the base report's Area Review section. In this section a table showing the changes in the supply of office space on Oahu between 1989 and 1991 indicated that the downtown share of the island's office market had decreased slightly from 55 percent to 52 percent.

Supply

An analysis of the Central Oahu office supply in 1992 reveals that there is an existing supply of approximately 350,000 square feet of office space. A total of 42,000 or twelve percent of the space is available. As noted and illustrated in the *Area Review* of the Market Assessment, the greatest vacancies exist in the newer speculative multi-tenant buildings.

The presence of large scale single-user facilities such as Oceanic Cablevision indicates a willingness on the part of large back office type tenants to locate in the Central Oahu region. Competition for these tenants will come from other business parks such as Gentry Waipio Center. Examples of larger firms which have already committed to back office facilities outside downtown Honolulu include two major banks.

Bank of Hawaii. Hawaii's largest bank has planned a major 250,000 square foot back office operation in Kapolei. Plans are complete but construction has not yet commenced. Bank of Hawaii contemplates a phasing-in of these operations over a period of several years with perhaps subleasing in the interim.

First Hawaiian Bank. The bank has constructed major back office facility located on 3.1 acres near Honolulu International Airport. The facility should be operational in Fall 1992. Approximately 600 employees engaged in information processing, warehousing and printing will be located at the facility.

Demand

An analysis of future growth of Oahu's employment sectors is also presented in the *Area Review*. Expected increases in the service sector and banking and finance areas are particularly significant to the back office market. These two employment segments, which drive the demand for commercial office space, are expected to show strong growth into the future.

We encountered a variety of potential demand sources for back office facilities on the Wahiawa Lands. These include financial institutions, health care providers and hotel operators. The larger financial institutions generally did not view the site as a good location for branches, as they are already committed in Wahiawa and Haleiwa (additionally these facilities are typically considered to be retail outlets).

As noted in the above discussion of supply, some larger firms have already committed to back office space. However, a number of second-tier companies are still not committed and exhibit a significant level of interest in the project site for back office purposes. Types of organizations interviewed that would seriously consider back office facilities on the Wahiawa Lands include:

Several major savings and loan institutions. One of Hawaii's largest savings and loan institutions will have to relocate back office operations currently in leased space on the fringe of downtown Honolulu in 1999.

On a long term basis, management of this firm would consider the project site viable for both back office operations and a regional branch serving both Wahiawa and the North Shore.

Another major savings and loan institution has been analyzing employee demographics with the objective of quantifying the proportion of back office-type workers who reside in Central Oahu. The results are expected to indicate a high ratio of Central Oahu residents. Wahiawa Lands would be considered a suitable location for such operations.

Wahiawa General Hospital. This medical facility would favor commercial space for back office-type operations near Wahiawa. The subject property provides an ideal location for such activities.

A Major Hawaii Hotel Chain. One of the major hotel chains expressed interest in the site as a location for back office operations. Their decision would hinge on the pricing of the proposed facilities. The location was considered favorable.

It must be noted that the listed companies are only a sampling of potential "back office" users. Further, interviewee comments reflected a clear expression of interest only, not a commitment of any kind.

Conclusions

There appears to be favorable market support among financial and health care institutions for locating back office facilities on Wahiawa Lands. This is based on a combination of the existing and projected labor pools, place of residency, location, expected market conditions and further retreat into the suburbs of activities that do not require a high-priced, downtown location.

LIGHT INDUSTRIAL

Overview

Over the past several years, the Oahu industrial market has experienced strong occupancy levels. As discussed in more detail in the *Area Review*, this can be related to supply and demand factors such as the need for warehouse space, continuing reductions in the supply of industrial space on Oahu, a relatively long government entitlement process and the control of industrial land by a relatively small number of owners. Another factor has been the recent introduction of large non-industrial uses such as Costco and similar no frills retailers who can afford to pay higher rents than typical industrial uses.

All of these factors have contributed to upward pressures on occupancy and rents for light industrial purposes.

Potential Market Positioning

As lands within the Primary Urban Center are redeveloped, many industrially-oriented businesses will be displaced. These companies will have to make decisions regarding whether to close their businesses, relocate within Hawaii or relocate out of state. With a limited supply of affordable industrial lands, these firms may not be able to find reasonably priced replacement facilities. As such, the subject property is in a position to offer industrial lands close to a large population base of potential employees.

Supply

In 1992, Hawaii's industrial supply stood at 32 million square feet of space, with a vacancy rate of only four percent according to Coldwell Banker-Torto Wheaton Services. This figure appears favorable compared to a seven percent national vacancy rate published by the same source.

While the Oahu industrial market has remained extremely strong in recent years, changes may be in the wind. Since 1990 certain indicators have started to appear which could mean slowing demand and higher industrial vacancy rates in the future. Some of these factors include:

- The current United States recession and economic problems in Japan;
- The credit crunch brought about by regulatory responses to the Savings and Loan crisis; and
- Most importantly, the rising costs of doing business in Hawaii.

While Hawaii is most definitely impacted by the national recession, this issue, like the credit crunch, is cyclical in nature. However, the rising cost of doing business in Hawaii has far reaching implications. While the development community may have only a limited ability to impact taxation issues, it *can* control certain factors causing business to leave the market. The most significant of these will be the provision of reasonably priced lands to replace those being transitioned into higher uses. Also required will be the segmentation of developments to provide for a variety of industrial and related uses within the development.

Demand

Existing Conditions. Coldwell Banker-Torto Wheaton Services estimated that as of the first quarter of 1992 Oahu had an industrial occupancy level of approximately 28,450,000 square feet.

Absorption. Based on Coldwell Banker-Torto Wheaton's data, the market appears to have absorbed approximately 4,500,000 square feet of industrial space since the first quarter of 1989 or 1,500,000 square feet per year. Between 1991 and 1992 absorption declined from approximately 2,500,000 square feet to only 54,672 square feet. As the full effects of the displacement of airport and Kakaako tenants has yet to be experienced, these absorption rates should recover to their previous levels if not even stronger in the future.

At an average absorption rate of 1,500,000 square feet annually, the approximately 4,250,000 of planned, under construction, and opening projects (indicated by the 1992 CB Commercial report), would take approximately three years to absorb. This figure does not include any increases brought about by the relocation of Kakaako and airport tenants. [Note that figures for planned projects were provided in both acreage and square feet requiring some interpretation by the consultants. Acreage figures were converted at a 40% lot coverage ratio.]

Conclusions

It is believed that the industrial portion of the Wahiawa Lands master plan will provide an affordable alternative for business being displaced by redevelopment of established industrial parks and the introduction of non-industrial tenants who are able to pay higher rents. While Wahiawa is further removed from Oahu's existing population centers than the current location of many of these potential tenants, the westward shift in the population base over time should help to offset this.

Through a combination of natural features and prudent planning efforts, the subject property is expected to offer a mix of attractive and affordable industrial products largely buffered from existing and planned population centers.

Assuming that one or two buildings per year were constructed and occupied on the subject site (at an average size of 50,000 square feet) the property would experience a 3.3 to 6.7 percent capture rate at the three-year average absorption level. This level of capture would not be out of the norm experienced by other projects on Oahu.

RETAIL OUTLET CENTER

Overview

A recent success in the retail industry has been the emergence of outlet centers. From meager beginnings the industry was estimated to have grown into an eight billion dollar industry in the United States by 1990. Oahu is a community which has yet to have benefited from this type of retailing. However, the market exhibits many of the necessary ingredients for the successful development and operation of an outlet center. In fact, recent articles have highlighted the interests of developers and tenants of these centers in the Hawaii market.

Outlet centers have evolved from back rooms in factories and low rent retail shops offering merchandise (primarily seconds and out of production products) displayed on pipe racks and folding tables to a form

of high profile retailing presented in a style equal to that of full priced retailers. More and more often current fashion are offered by the tenants and the percentage of seconds continues to decline.

Critical success factors for retail outlet centers include:

- Higher quality tenants offering consistent merchandise at good values;
- Physical separation from off-price centers and normal retail distribution centers (i.e. department stores);
- A high tourist base;
- Excellent access;
- Tour bus availability (it is estimated that one third of the shoppers will come from the immediate local community, one third will come from the region and one third tend to be tourist); and
- A market containing educated and employed women, who have long been the primary shoppers at outlet centers.

Potential Market Positioning

The subject property has a favorable location for an outlet retail center because it is removed from more traditional product distributors, and because it is able to take advantage of both tourist (around-the-island) and local retail customers.

Waikele Center, the only other proposed outlet center on Oahu, is further ahead in tenant contact with manufacturers' outlets. However, Waikele Center is proceeding with a mixed concept including outlet stores and an off-price anchor. The center will include a KMart store which is often considered to be an off-price tenant. Outlet tenants typically carry only their own brands and view off-price tenants (which may carry the same lines of merchandise) as competitors. A pure outlet center on the subject parcel would fill a unique niche not filled by the power center or mixed concepts.

Supply

No outlet centers currently exist in the Hawaii market area. As noted above, one development has been formally proposed at Waikele. This development, however, appears to have some design and market plans which conflict with current trends in the industry.

Demand

Exhibit VII-1, *Retail Outlet Demand Analysis*, illustrates the potential demand for outlet centers in Hawaii.

Exhibit VII-1, Wahiawa Lands
Retail Outlet Demand Analysis

	(1)	(2)	(3)
All Store Retail Sales	$9,737,000	$11,608,000	$12,172,700
LESS:			
Automotive Dealers (000)	$1,458,000		
Eating and Drinking Establishments (000)	$1,691,000		
Gasoline Service Stations (000)	$523,000		
Building Materials, Hardware Dealers (000)	$295,000		
Applicable Retail Sales (1989) (000) (4)	$5,770,000	$6,878,770	$7,213,542
Inflation Factor to 1990 (138.1/128.7)	1.073	1.073	1.073
1990 Applicable Retail Sales (000)	$6,191,000	$7,381,000	$7,740,131
Outlet Capture Rate (5)	1%	1%	1%
Outlet Sales Capture	$61,910,000	$73,810,000	$77,401,306
Outlet Center $ Per Square Foot (6)	$235	$235	$235
Supportable Sq. Ft. of Outlet Space	263,447	314,085	329,367
Number of Retail Centers Needed 150,000 square feet per center (7)	1 or 2 Centers	1 or 2 Centers	1 or 2 Centers

(1) State of Hawaii Data Book, 1991
Table 653 "Retail Sales by Type of Store"
(2) State of Hawaii Data Book 1991
Table 283 "General Excise and Use Tax Base Collections"
(3) Bank of Hawaii's "Hawaii 1991" Annual Economic Report Vol. 41
(4) Retail sales less non-applicable items (based on relationship established in the first column)
(5) Consultant Estimate
(6) ULI's Outlet and Off-Price Retailing Selected References, ULI Info Packet No. 343, "Ten Reasons Outlet Centers are Solid Investments", February 1991, "Value Retail News
(7) ULI's Outlet and Off-Price Retailing Selected References, ULI Info Packet No. 343, "Outlets are Out and About", June 1989 "Monitor"

The base data sources used in developing the chart above vary greatly in their estimates of retail sales. Because of this we have included three sources believed to be reasonably reliable and made the following assumptions:

- Retail Sales by Type of Store (presented in the first column) provided the greatest detail as to the composition of retail sales. The ratio between shopping center type tenants (Applicable Retail Sales) and total retail sales established from this data source was then utilized to adjust the other total sales figures.
- A conservative step was taken in the analysis by removing all eating and drinking establishment sales from the total.
- Because base figures were for 1989, these figures were adjusted for inflation.
- An outlet capture rate was determined based on the industry's size relative to total retail sales on a national level.

Conclusions

It has long been stated that Oahu is underserved with regard to retail space. This is illustrated both by square feet per resident estimates and sales per square foot of retail space indicators. Our data sources indicated the minimum critical mass necessary for an outlet mall was approximately 150,000 square feet. As such, it appears that the market could support one to two outlet centers.

The Wahiawa site offers numerous potential attributes in order to attract a unique type of retail service to a market which, as discussed previously, is already underserved.

- The subject benefits from the access of two major arterials, which will have their traffic flow capabilities enhanced as a part of the development.
- The Wahiawa location will be well removed from any of Oahu's department stores. Additionally, the site is located on a popular tourist route around the island.
- Finally, the subject would be planned as a pure outlet center and would not mix off-price tenants (for example, KMart, Target, or Walmart) which are not attractive to typical outlet center tenants for competitive reasons.

HEALTH CARE

Overview

As Oahu's population continues to shift to the Central and Leeward communities' and many of the North Shore's population age, an increased interest by medical facilities has been indicated in Leeward and Central Oahu locations. The need for new facilities in the Wahiawa area is further evidenced by the physical constraints on the existing Wahiawa General Hospital and a single medical arts building serving the community.

Potential Market Positioning

The subject property will have sufficient land to attract a large facility. For example, Wahiawa General Hospital may in the future seek an alternate site which is close to its present location. Highway improvements to Wilikina Drive would be necessary to ensure needed access to such a major health care facility.

An additional benefit of attracting a major health care facility to the site would be the from other supportive land uses such as office, limited retail and rental housing for health care personnel.

Supply

The following major health care facilities serve Central Oahu and the North Shore.

- *Wahiawa General Hospital* is an 162-bed, full-service hospital facility serving Wahiawa, Mililani, Waipahu, and the North Shore.
- *Kahuku Hospital* is a small regional general hospital of 26 beds located in the town of Kahuku on the North Shore of Oahu.
- *St. Francis Medical Center - West* is an extension of the medical facility in Central Honolulu serving Leeward and Central Oahu. The facility contains 56 beds and an accompanying physicians' office building.
- *Pali Momi Hospital* is an 116-bed hospital located in Pearl Ridge. It provides a full range of hospital services and is associated with an office complex accommodating 70 physicians.

While the supply of hospital beds is tightly controlled by the State of Hawaii, many facilities have expressed interest in providing outpatient facilities on the Galbraith Trust Lands site.

Demand

Expected demand for health services located on Galbraith Trust Lands is a function of both current circumstances and future growth patterns.

- **Current circumstances.** Wahiawa General Hospital is planning to relocate its facility in the future. The relocation will be necessary due to physical constraints of its current site and access difficulties. In addition, interviews with health care executives indicate a general consensus that the North Shore area is currently underserved by health care services. The Galbraith Trust Lands could help anchor the existing services and strengthen the area as the health service gateway to the North Shore.
- **Future growth patterns.** The planned population growth in western and central Oahu will create increased demand for health care services. The major health care providers interviewed are engaged in long-range planning to position themselves in this expanding market. In general, the highest level of interest is in locating family practice clinic facilities on the project site to serve the projected population and Wahiawa.

While not willing to commit at this time, the following health care providers expressed interest in the subject property:

Wahiawa General Hospital. Given its fully-occupied site and severe parking problems, it is likely that this facility will seek a new location in the future. As with any emergency health care facility, location and access are important site selection factors. The future site must be accessible to Wahiawa General Hospital's major markets: Wahiawa, Mililani, Waipahu and the North Shore. Depending on highway improvements, the Wahiawa Lands could be a suitable site for relocation of Wahiawa General Hospital. A hospital of that size would require 10-12 acres. It is also likely that the hospital would prefer to stay in the greater Wahiawa area to continue to serve its immediate community.

Other Oahu Health Facilities. Interest was expressed by several major Oahu health care providers in locating a 4-5 acre regional family practice clinic on the Wahiawa Lands, with the potential to tap demand from the North Shore being cited as particularly attractive from a marketing perspective. Such a facility would provide doctors' offices plus x-ray and limited laboratory capabilities.

Conclusions

The Galbraith Trust Lands appear to be attractive to health care operators as a potential location for clinic operations and possibly support facilities, such as pharmacies and medical supply stores. The location of the subject parcel would enhance Wahiawa's current position as primary health care provider to Wahiawa town as well as the North Shore. In addition to the potential of locating either Wahiawa General Hospital or a family clinic on the subject property, demand may also exist for an elderly housing (long-term care) facility at the site.

Section VIII

GOLF COURSE ANALYSIS

Section VIII

GOLF COURSE ANALYSIS

OVERVIEW

Our additional analyses also included an assessment of the demand for the development of a public play golf course, with an emphasis on municipal golf courses. As with the prior section, these analyses were performed at a reduced scope. The planners have expressed an interest in developing a golf course for physical reasons such as drainage. Further, if included in the plan, a golf course will serve as an amenity for local residents and the public at large. Similar to the retail needs of Oahu, the island's insufficient supply of reasonably-priced golf facilities is well documented. In addition to support from local residents, golf courses derive significant play from the visitor industry, particularly Asian travelers.

SUPPLY

Existing Supply. The 1991 *State of Hawaii Data Book* identifies 30 golf courses on Oahu. Of these courses nine are military, five are municipal and 16 are private. This source includes both privately owned courses open to the public and membership clubs as being private courses. Our analysis, on the other hand, separates these courses into the following categories: private (membership clubs), public (daily fee courses) and resort courses. Of the five municipal courses one course has nine holes; the remaining four are 18 hole courses. A description of Oahu's golf courses is provided in the following Exhibit 8-1, *Oahu Golf Course Existing Supply - 1992*. The information was obtained from the Hawaii golf course publications as well as golf course operators and verified by the consultants.

Additions to Supply. The undersupply of golf facilities has not gone unnoticed by the development community. By the end of 1991 an equal number of courses to that of the existing supply were actively being planned or developed. Additionally, several courses had been rejected or rumored as of the publication of the Department of General Planning's Development Plan Status Review, Fiscal 1992, the number of proposed courses had decreased to twenty-one. Of these courses three have since opened. A number of developments may have been removed when the Mayor of Honolulu reported that an impact fee of $100 million might be levied on all new golf courses.

Exhibit VIII-1
Wahiawa Lands

Oahu Golf Course Existing Supply - 1992

Course	# of Holes	Yds.		Rating	Par	Golf Cart Mandatory	Cart Fees	Club Rental
Ala Wai Golf Course	18	Ch:	6,020	66.8	70	No	$11	Yes
		M :	5,817	67.2	70			
		W :	5,011	72.1	70			
Bayview Golf Center	18	M :	2,231	N/A	54	no	$3	Yes
		W :	2,113		54		Hand	
Ewa Beach International Golf Club	18	Ch:	6,768	71.7	72	Yes	Yes	Yes
		M :	6,407	69.4	72			
		W :	5,992	63.5	72			
Hawaii Country Club	18	M :	5,916	67.1	72	Weekends	Inc.	Yes
		W :	5,301	64.3	72			
Hawaii Kai Executive	18	M :	2,386	N/A	55	no	$8	Yes
		W :	2,094		55			
Hawaii Kai Champion	18	Ch:	6,686	72.8	72	Yes	Inc.	Yes
		M :	6,350	70.3	72			
		W :	5,719	72.6	74			
Hawaii Prince Golf Course	27	Varies			72	N/A	N/A	N/A
Honolulu International Country Club	18	Ch:	6,624	72.4	71	Yes	Inc.	Yes
		M :	5,995	70.2	71			
		W :	5,470	70.8	73			
Kahuku Golf Course	9	M :	2,699	65.2	35	No	N/A	Yes
		W :	2,699	69.0	36			
Ko Olina Resort	18	Ch:	6,867	72.1	72	Yes	Inc.	Yes
		M :	6,252	69.3	72			
		W :	5,358	69.9	72			
The Links at Kuilima	18	Ch:	7,199	N/A	72	Yes	Inc.	Yes
		M :	6,795	N/A	72			
		W :	6,225	N/A	72			
Makaha Valley Country Club	18	Ch:	6,369	69.2	71	Yes	Inc.	Yes
		M :	6,091	67.6	71			
		W :	5,720	72.7	71			
Ted Makalena Golf Course	18	M :	5,946	67.9	71	No	$11	Yes
		W :	5,651	71.2	73			
Mid Pacific Country Club	18	Ch:	6,793	71.6	71	Yes	Inc.	Yes
		M :	6,240	70.1	71			
		W :	6,087	74.3	71			
Mililani Golf Course	18	Ch:	6,815			Yes	Inc.	Yes
		M :	6,360	70.4	72			
		W :	5,888	72.8	72			
Moanalua Golf Course	9	M :	5,944	67.8	36	No	$9	Yes
		W :	5,788	72.9	36			
Oahu Country Club	18	M :	5,820	68.6	71	No	$7	Yes
		W :	5,454	70.8	73		Inc.	
Olomana Golf Links	18	Ch:	6,326	70.3	72	Yes	Inc.	Yes
		M :	5,887	68.2	72			
		W :	5,561	66.6	73			

Course	# of Holes	Yds.		Rating	Par	Golf Cart Mandatory	Cart Fees	Club Rental
Pali Golf Course	18	Ch:	6,754	70.0	72	No	$11	Yes
		M :	6,494	70.4	72			
		W :	6,080	74.5	74			
Pearl Country Club	18	Ch:	6,750	72.5		Yes	Inc.	Yes
		W :	5,489	70.2	73			
		H :	N/A	70	72			
Sheraton Makaha Resort & Country Club	18	Ch:	7,091	73.2	72	Yes	Inc.	Yes
		M :	6,398	70.6	72			
		W :	6,041	73.3	72			
Turtle Bay Hilton & Country Club	9 w/ Double Tees	Ch:	N/A	N/A	70	Yes	Inc.	Yes
		M :	6,050	N/A	70			
		W :	5,165	N/A	70			
Waialae Country Club	18	Ch:	7,012	72.7	72	Yes	Inc.	Yes
		M :	6,651	70.2	72			
		W :	6,114	74.0	72			
West Loch	18	Ch:	6,479	70.3	72	Yes	$11	No
		M :	5,849	67.8	72			
		W :	5,298	68.8	72			

Course	Pro Shop	Driving Range	Night Lights	Rest.	Cock-tails	Green Fees (1992) Time	Local	Tour.	Course Type
Ala Wai Golf Course	Yes	Yes	Yes	Yes	Yes	Wkdey	$8	$18	Muni.
						Wkend	$12	$20	
Bayview Golf Center	Yes	Yes	Yes	No	No	Day	$10	$21	Public
						Eve.	$5	$10	
Ewa Beach International Golf Club	Yes	No	No	Yes	Yes	Wkdey	$60		Private
						Wkend	$70		
Hawaii Country Club	Yes	Yes	No	Yes	Yes	Wkdey	$25	$60	Public
						Wkend	$37	$65	
Hawaii Kai Executive	Yes	Yes	Yes	Yes	Yes	Wkdey	$22	$35	Public
						Wkend	$23	$35	
Hawaii Kai Champion	Yes	Yes	Yes	Yes	Yes	Wkdey	$37	$80	Public
						Wkend	$41	$80	
Hawaii Prince Golf Course	Yes	N/A	N/A	Yes	Yes	Day	$80	$135	Public
						Eve.	$55	$135	
Honolulu International Country Club	Yes	No	Yes	Yes	Yes	Wkdey	$50		Private
						Wkend	$65		
Kahuku Golf Course	No	Yes	No	No	No	Wkdey	$6	$19	Muni.
						Wkend	$8	$19	
Ko Olina Resort	Yes	Yes	No	Yes	Yes	Wkdey	$55	$130	Resort
						Wkdey	$65		
						Wkend	$85		
The Links at Kuilima	Yes	No	No	Yes	No	Wkdey	$55	$115	Resort
						Wkend	$75	$125	
						Resort		$75	
Makaha Valley Country Club	Yes	Yes	No	Yes	Yes	Wkdey	$30	$80	Public
						Wkend	$37	N/A	
Ted Makalena Golf Course	Yes	No	N/A	Yes	Yes	Wkdey	$8	$18	Muni.
						Wkend	$12	$20	
Mid Pacific Country Club	Yes	Yes	No	Yes	Yes	Guest	$40	$158	Private
Mililani Golf Course	Yes	Yes	Yes	Yes	Yes	Wkdey	$35	$80	Public
						Wkend	$40	$85	
Moanalua Golf Course	Yes	No	N/A	Yes	Yes	Wkdey	$20		Private
						Wkend	$25		
Oahu Country Club	Yes	Yes	No	Yes	Yes	Guest	$68		Private
						W/Mbr.	$19		
Olomana Golf Links	Yes	Yes	Yes	Yes	Yes	Wkdey	$29	$75	Public
						Wkend	$35	$75	
Pali Golf Course	Yes	Yes	Yes	Yes	Yes	Wkdey	$8	$18	Muni.
						Wkend	$12	$20	
Pearl Country Club	Yes	Yes	Yes	Yes	Yes	Wkdey	$37	$80	Public
						Wkend	$41	$85	

Course	Pro Shop	Driving Range	Night Lights	Rest.	Cock-tails	Green Fees (1992) Time	Local	Tour.	Course Type
Sheraton Makaha Resort & Country Club	Yes	Yes	No	Yes	Yes	Resort		$75	Resort
						Sheraton		$130	
						Public	$65	$140	
Turtle Bay Hilton & Country Club	Yes	No	No	Yes	No	Wkdey	$35	$55	Resort
						Wkend	$55	$65	
						Resort		$50	
Waialae Country Club	Yes	Yes	No	Yes	Yes	Guest		$40	Private
West Loch	Yes	Yes	Yes	Yes	Yes	Wkdey	$8	$18	Muni.
						Wkend	$12	$20	

Sources: 1992 Aloha Section PGA Annual (Hawaii); Golf Hawaii, the Complete Guide; Pro Shops; Score Cards; Gail W. Atwater James W. Stanney Consultants

The majority of new courses have been planned as privately owned courses which would be open to public play. Only three municipal courses were in these list of proposed courses. One of the courses had been rejected, a second is being blocked by a landowner and the final course is in the planning stage. Additionally, a municipal course is currently in the planning and design phase for the Ewa market area. A summary of the courses with a high probability of being developed is included as Exhibit VIII-2, *Additions to Oahu's Golf Course Supply.*

Exhibit VIII-2
Wahiawa Lands

Additions to Oahu's Golf Course Supply

DP Area	Development	# of Holes	Acres	Estimated Year of Opening	Approval Status	Development Status	Type
Ewa	Ewa Gentry Golf Course	18	190	N/A	Rezoning Needed	Master Grading Complete	Public
Ewa	Ewa Marina Golf Course	27	272	N/A	Rezoning Needed	N/A	Public
Ewa	Ko Olina Phase II Golf Course	18	156	1996	Rezoning Needed	Expected to Begin in 1994	Resort
Ewa	Makakilo Golf Course	18	290	1993	Approved	Under Construction	Public
Ewa	Villages of Kapolei Golf Course	18	195	N/A	Exempted	Under Construction	Muni.
Co	Royal Kunia Golf Course #1	18	172	1997	PRU Required	N/A	Public
Co	Royal Kunia Golf Course #2	18	163	N/A	PRU Required	N/A	Private
Co	Waiawa Golf Course #1	18	198	1995	Rezoning Needed	Begin in 1993 w/ Approval	N/A
Co	Waiawa Golf Course #2	18	167	1995	Rezoning Needed	Begin in 1993 w/ Approval	N/A
Co	Waikele Golf Course	18	140	N/A	Approved	Under Construction	Public
Kp	Bayview Golf Course Redevelopment	18	220	1994	PRU	Begin in 1993 w/ Approval	Public
Kp	Heeia-Maluluni Sports Center	18	103	On Hold	Denied Rezoning Needed CDUA Required	Planning	Public
Kp	Minami Golf Course	18	240	1992	Approved	Under Construction	Public
Kp	Royal Hawaiian Country Club #1	18	175	1992	Approved	Under Construction	Public
Kp	Royal Hawaiian Country Club #2	18	175	1995	Approved	Begin in 1993	Public
Kp	Waikane Golf Course	18	300	N/A	Rezoning Needed SMP May Be Required	N/A	Public
Wai	Makaha Valley Country Club Exp.	9	85	1995	PRU	N/A	N/A
Wai	Waianae Kai	27	252	N/A	Pending Rezoning Needed	N/A	Public

Source: Table O of the Appendix to the Department of General Planning's Development Status Review, Fiscal Year 1992; Gail W. Atwater James W. Stanney Consultants

DEMAND

Existing Demand. Exhibit VIII-3, *Level of Play on Oahu's Municipal Golf Courses* on the following page, provides insight into the current usage levels for municipal courses on Oahu. The only course which was not reported to be operating at capacity is the West Loch course. The capacity for this course is currently being controlled by the City and County of Honolulu until the course can further mature. The Golf Administrator for the City and County of Honolulu, indicated that with the exception of the West Loch course and the nine hole Kahuku course, desired capacities at each course would be approximately 150,000 rounds annually.

Exhibit VIII-3
Wahiawa Lands

Level of Play on Oahu's Municipal Golf Courses

Level of Play on Oahu's Municipal Golf Courses
Fiscal Year 9991/1992

Golf Course	# of Holes	Annual Rounds Played	Daily Cart Rentals
Ala Wai	18	188,000	145
Pali	18	145,000	140
Ted Makalena	18	167,000	110
Kahuku	9	60,000	NA
West Loch	18	100,000	110
TOTAL	81	660,000	505

Source: David Mills, Golf Administrator for the City and County of Honolulu

Numerous local and national studies have assessed the need for golf facilities. The most common rules of thumb indicate that for every 25,000 to 50,000 persons one 18 hole golf course is required. Due to the wide discrepancy in these indicators, we have calculated the need for additional facilities based on each of the extremes and have indicated a range of potential need. An additional indicator was provided by the City and County's Golf Administrator, who stated that one municipal course was required per 100,000 persons.

Supply/Demand Analysis

Exhibit VIII-4, *1990 Oahu Golf Demand Analysis*, illustrates the base 1990 supply and demand for golf courses on Oahu. As existing municipal courses are reported to be operating at capacity, and often exceed desired capacity levels, the ratio of one course per 50,000 persons is inappropriate for the local market. While still representing numbers that may be slightly conservative, the ratio of one course to 25,000 residents appears more appropriate for Oahu. Under both the one course per 25,000 persons and the Golf Administrator's municipal test, adequate demand appears to exist in the near future for the development of an additional municipal course on Oahu.

With regards to non-municipal daily fee courses, a special uniqueness would be required to differentiate the subject project from the numerous others proposed. As the subject will not be able to offer the ocean amenities that contribute to the attractiveness and desirability of many of the proposed courses, another form of differentiation would be required. This could be the offering of reduced rates and special preferences regarding tee times for local residents. These rates could be indexed to the rates charged by municipal courses.

While this fee structure would definitely create a uniqueness for the subject, it may not be financially feasible. The analysis of financial feasibility, however, was not part of the consultants' scope of work.

Exhibit VIII-4
Wahiawa Lands

1990 Oahu Golf Demand Analysis

	At One Course Per 25,000	At One Course Per 50,000	At One Course Per 100,000
Base (1)	913,000	913,000	913,000
Military and Dependent Population (2)	<113190>	<113190>	<113190>
Adjusted Non-Military Population	799,910	799,910	799,910
Supportable Non-Military Courses	32	16	8
Existing Non-Military Courses (3)	20	20	4
Need for Additional Courses as of June 1990	12	<4>	4
Supportable Number of Municipal Courses (based on national percentage)			
Total Supportable Courses	32	16	8
% Municipal courses	16%	16%	100%
Supportable Municipal Courses on Oahu	5	3	8
Existing Municipal Courses as of July 1990	4	4	4
Supply and Demand Balance	1	<1>	4

(1) 1990 De Facto Population, by County Table 6, State of Hawaii Data Book ,1990

(2) Military Personnel, Dependents and Families, by Service and Island Table 342, Data Book

(3) Golf courses, by Number of Holes, Ownership, and Islands: Table 233 State of Hawaii Data Book, 1990

Design

The City and County of Honolulu recommends that the minimum size of a course should be 150 acres. Driving ranges for municipal courses have typically occupied approximately 10 acres. The recently completed West Loch course reportedly cost the City $18 million of which $3 million was allocated to land acquisition. Mr. Mills indicated that the actual costs to the developer may have exceeded $18 million. The course currently under design is budgeted for $21 million including land. An actual land allocation was unattainable.

CONCLUSIONS

Based on the preceding analysis there appears to be adequate demand for the development of additional municipal courses, and a limited number of daily fee courses, on Oahu. Future population growth will increase this existing demand. Further, the analysis does not account for the reports of national sources which indicate that the percentage of golf participants is increasing. With a shortage of land in the Honolulu area, increasingly golfers will have to travel further in order to play.

Central Oahu and Ewa appear to have the largest concentrations of reasonably priced land which can be readily developed into golf courses. These factors combined with the increased population expected in the Leeward and central areas and the excess capacity on existing municipal facilities indicate that these areas of Oahu will most likely capture the majority of the future additions to the island's golf course supply.

The City and County's Golf Director indicated that if an affordable course were developed on the subject property, there would be no problems in filling the course. Additionally as the city has been unable to expand the Kahuku facility, pent-up demand is believed to exist on the North Shore. The subject would be well positioned to capture this demand either with a municipal course or a daily fee course which would be indexed to the municipal course rates.

Appendix A

LIMITING CONDITIONS

Appendix A
LIMITING CONDITIONS

- The words "project," "projection" and forecast are not meant to follow the definition of any professional organizations.
- The consultants assume no responsibility for economic, market or physical factors occurring after our last day of field work in October 1992, which may affect the opinions stated herein.
- No opinion is intended to be expressed for legal matters or that would require specialized investigation or knowledge beyond that ordinarily employed by a market consultant.
- No opinion as to title is rendered.
- No engineering reports or surveys have been prepared by or made available to the consultants.
- Maps and exhibits included herein are for illustration only, as an aid in visualizing matters discussed within the report. They should not be considered as surveys or relied upon for any other purpose.
- No opinion is expressed as to the value of subsurface oil, gas, or mineral rights and the property is not subject to surface entry for the exploration or removal of such materials.
- The estimates included in this report are utilized to assist in the market assessment of the property based on current market conditions, anticipated short term supply and demand factors and a continued stable economy. Therefore, estimates are subject to changes in future conditions that cannot be accurately predicted by the consultant.
- Selected portions of this report shall not be given to third parties without the prior written consent of the consultants.
- The consultants are not qualified to detect the existence of potentially hazardous material which may or may not be present on or near the property. We urge the client to retain an expert in the field before making a business decision regarding the property.

Appendix B
PROFESSIONAL QUALIFICATIONS

GAIL W. ATWATER

Ms. Atwater is experienced in development of market feasibility studies and competitive analyses for industrial, commercial and residential real estate development. She has been a land use consultant for the past seven years, both as an independent and as an associate of Deloitte & Touche Management Consulting. She also has six years of corporate managerial experience at GTE Hawaiian Tel.

EDUCATION

Master of Business Administration, Marketing, University of Hawaii
Master of Education, Guidance and Counseling, Florida Atlantic University
Bachelor of Arts, Literature, Wheaton College
Pursuing a Certificate in Urban and Regional Planning, University of Hawaii (will conclude in May 1993)

HIGHLIGHTS OF RELEVANT EXPERIENCE

Analyzed the supply and demand of industrial land on Oahu in a market assessment which supported development of a business-industrial park on Oahu.

For the State of Hawaii, Department of Land and Natural Resources, managed completion of a project involving development and application of a strategic land management methodology for 200,000 acres of leased agricultural land.

Analyzed market feasibility for an executive conference center on an Oahu site for a Hawaii planning firm.

Assisted in preparing an economic impact study for the developer of Ko Olina Resort in West Oahu, including analysis of market opportunities and potential revenues, for State and county governments, from proposed golf course and commercial development.

Developed three consecutive Five-Year Strategic Plans for GTE Hawaiian Tel. Analyzed market opportunities for worldwide operations of GTE, including market analysis, product selection, and implementation planning.

Developed or facilitated top management in development of strategic plans for diverse private and public sector clients, such as the Chamber of Commerce of Hawaii and Hawaii Strategic Development Corporation.

PROFESSIONAL AFFILIATIONS

American Planning Association, Hawaii Chapter, Vice President
Hawaii Society of Corporate Planners, Past President and current Vice President - Communications

JAMES W. STANNEY

Mr. Stanney is experienced in market analysis of commercial, industrial and residential portfolios and master planned communities. He has ten years of experience analyzing Hawaii, Mainland and international real estate assets. Most recently an independent consultant and real estate appraiser, he was formerly a Manager in the Management Advisor Services of Kenneth Levanthal & Company and consultant with Mountain West Research and Pannell Kerr Forster.

EDUCATION

B.S., California State Polytechnic University, Pomona, Hotel Restaurant Management.
B.S., California State Polytechnic University, Pomona, Finance, Insurance and Real Estate.
Additional studies at the University of Denver.

HIGHLIGHTS OF RELEVANT EXPERIENCE

Analyzed the market and financial performance of two Westin hotels in Hawaii. The analysis was then used in evaluating purchase offers and debt restructuring.

Valued the office, industrial and commercial land assets and helped develop orderly dissolution strategies for the real estate portfolio of non-developer entities.

Prepared market feasibility studies, assessed the interdependencies of land uses and appraised mixed use projects including office, lodging, residential and retail components.

Analyzed the market and financial factors impacting the residential and commercial portfolios for the development companies of two savings and loans.

Performed market due diligence and prepared the marketing package for the sale of commercial and residential parcels of a 4,000 acre master-planned community in southwest Phoenix, Arizona. Later, a market analysis and financial analysis was prepared for the sale of approximately one third of the property to a single builder.

Appraised a 1,120 acre master-planned community currently under construction in San Diego, California. Land uses included in the development were single family detached units, for sale multifamily units, multifamily rental units, industrial, commercial, parks, public facilities, and churches.

Provided input into the sizing and pricing of residential products to be offered as part of a proposed master planned community located in the northern portion of San Diego, California.

APPENDIX J

Agricultural Impact Report
Decision Analysts Hawaii, Inc.

WAHIAWA LANDS MASTER PLAN: *Impact on Agriculture*

WAHIAWA LANDS MASTER PLAN: *Impact on Agriculture*

PREPARED FOR:
Helber Hastert & Fee, Planners

PREPARED BY:
Decision Analysts Hawaii, Inc.

January 1993

CONTENTS

TABLES

FIGURES

Acronyms

Companies and Estates

- Amfac/JMB .... Amfac/JMB Hawaii
- Campbell Estate .... The Estate of James Campbell
- C&C .... Castle & Cooke, Inc.

Plantations

- Del Monte .... Del Monte Fresh Produce (Hawaii), Inc.
- Dole .... Dole Foods Company
- ML&P .... Maui Land and Pineapple
- OSCo .... Oahu Sugar Company, Ltd.
- WSCo .... Waialua Sugar Co., Inc.

Government Agencies

- DLNR .... (State) Department of Land and Natural Resources
- DOA .... (State) Department of Agriculture
- FDA .... (Federal) Food and Drug Administration

Trade Agreements

- GATT .... General Agreement on Tariffs and Trade
- NAFTA .... North American Free Trade Agreement

Executive Summary

The Wahiawa Lands Master Plan project ("the Project") is proposed for development by Hawaiian Trust Co., Ltd. on behalf of the George Galbraith Trust which owns the property. The Project will encompass an area of approximately 876 acres located north of Wahiawa in the Poamoho area. The property is now leased to Del Monte Fresh Produce (Hawaii), Inc. (Del Monte), with about 800 acres used for growing pineapple.

Agronomic Conditions

The agronomic conditions at the Project site are favorable for cultivating pineapple. The property has deep well-drained soils that are easy to work, a large expanse of flat fields which favor use of mechanized equipment, moderate rainfall which eliminates the need for expensive drip irrigation and reduces pumping costs, and temperatures which favor summer crops. Seasonal cloud cover and cool temperatures limit productivity during the winter months.

The agronomic conditions are *not* favorable for cultivating most other crops because of relatively low sunshine and expensive irrigation water, particularly since most crops require far more water than pineapple.

Impact on Del Monte Fresh Produce (Hawaii), Inc.

Of the two pineapple and two sugar plantations on Oahu, Del Monte is economically the healthiest and provides the most employment, while using the least amount of land and comparatively little water. Del Monte sells fresh pineapple on the mainland, and is developing the market for high-value fresh-chilled pineapple—that is, pineapple that is pre-cut, chilled and packaged in plastic bags. If possible, Del Monte plans to expand production and acreage.

However, the plantation is particularly vulnerable to a loss of land because: it is small, with few land reserves; the nature of the fresh pineapple market is such that steady production must be maintained in order to deliver fresh fruit to customers; and flexibility to rearrange production is limited because pineapple has a long crop cycle in Hawaii—typically it takes about 5 years to produce three crops, including a customary fallow period before planting in order to control pests and enrich the soil.

If a large field is not available when it is time to plant a new crop, then about a 4-month planting period would be missed, during which time the planting crew would be idle. Approximately 18 months after the missed planting, the output from the plantation as a whole would decline by about 40% for a period lasting about 4 months. This would be followed by a second decline in production of about 35% a year later, and a third decline of about 26% the next year. During each of the three 4-month declines, a portion of the harvesting crew would be idle. Also, orders would not be filled and customers would be lost.

Since lands are not immediately available to replace those proposed for development by Galbraith Trust, various adjustments in Del Monte's operations, and possibly the Project development schedule, are necessary in order for Del Monte to maintain production and deliveries, and to allow the Project to proceed as quickly as possible. As a result of discussions between Del Monte and Galbraith Trust, Del Monte plans to harvest its last crop on Field #203 in late summer 1994 (see Figure ES-1). This harvesting schedule will allow development to proceed on Phase I of the Project soon after all permits are received, with land clearing beginning as early as January 1996. Del Monte will adjust its chemical spraying practices on the surrounding fields to safeguard the health of construction workers. Phase I will also result in the loss of 4 acres of Field #202 as a site for a sewage treatment plant.

On Field #206, Del Monte will shorten the crop cycle by a year by omitting the normal fallow period between crops (i.e., it will "quick cycle" the field), harvesting its last crop in the late summer of 1998. Del Monte will also quick-cycle Field #204, harvesting its last crop in the late summer of 1999.

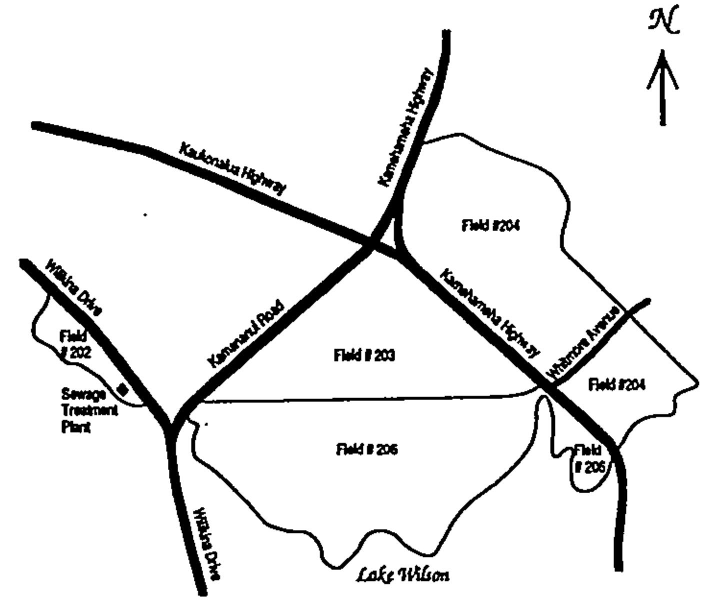

Figure ES-1.
Affected Del Monte Fields

After the last fruiting cycles on these three fields are completed, the plants will be left in the fields and slips will be harvested to use as planting stock on other fields. This will continue until the land must be cleared for development.

In order to increase production from the remainder of the plantation, Del Monte will quick-cycle other fields, and plant poor-quality fields in the foothills which are now fallow.

With these adjustments, the first 400-acres of replacement land will not be needed until early 1999, and the second 400 acres will not be needed until 2000, or 2001 if other fields are quick-cycled.

Assuming that replacement lands are made available to accommodate this schedule, then the impact of the Project on Del Monte will be small, with no loss in production, revenues, or employment. The major change would be that Del Monte eventually would farm different lands. Replacement lands are most likely to come from upper Kunia fields now being farmed by Oahu Sugar Co., Ltd. (OSCo). If so, then the major agricultural impact of the Project will fall on OSCo rather than on Del Monte—assuming that OSCo survives beyond the year 2000.

If replacement lands are not made available by the time Del Monte needs them, then Del Monte would probably be forced to close its Oahu plantation, and replace it with a larger one in Mexico or Guatemala. Del Monte would take this action in order to maintain production and deliveries, and to retain its customers. A phase-out of Hawaii operations would likely occur over a period of about 4 years starting around the year 2000. The total loss in direct and indirect employment supported by Del Monte would amount to about 1,500 jobs.

IMPACT ON DOLE FOOD COMPANY, INC.

Around the year 2000 or even later, the Project will probably cause Dole Food Company, Inc. (Dole) to fallow the pineapple lands that will be sandwiched between the Project and Whitmore Village, thereby releasing approximately 60 acres of land for a housing development. Also, since the Whitmore Village baseyard would be near some of the homes in the Project, Dole may choose to take advantage of market

opportunities and relocate the baseyard to the Dole packing plant area on Kamehameha Highway. Even though such a move would be costly, Dole would profit from developing the site since it will be suitable for homes or a neighborhood shopping center.

If the Project causes the demise of Del Monte's Oahu plantation because it is unable to secure replacement lands, then Dole may benefit in two ways. First, it could lease about 1,200+ acres from the Galbraith Trust—land which is now being leased to Del Monte. This would consolidate Dole's pineapple operations and add good-quality fields near its packing plant.

Second, Dole would gain a marketing advantage if Del Monte were to close its Hawaii operations, since it could advertise itself as the only major supplier of premium fresh pineapple from Hawaii, while Del Monte's identification with Hawaii would be lost. It is not anticipated, however, that Dole would be able to make significant inroads into Del Monte's market, since Del Monte is likely to counter by underselling Dole with pineapple from Mexico or Guatemala. This pineapple would be of the same type and quality as that grown in Hawaii.

In any case, the Project is not expected to significantly affect Dole's pineapple production or employment.

IMPACT ON OAHU SUGAR CO., LTD.

Impact if OSCo Loses Lands to Del Monte

If replacement lands for Del Monte are made available at the expense of OSCo—possibly with 400 acres of upper Kunia land in 1999 and 400 acres in 2000 or 2001—then the resulting loss of OSCo acreage would weaken this plantation. However, the survival of OSCo will depend largely on the future level of U.S. sugar prices—prices which will be affected by competition from new sweeteners, and by international trade agreements which may expose the U.S. market to low-cost foreign sugar. OSCo's survival will also depend upon its success in renewing all of its major leases with terms which are sufficiently favorable to allow profitable operations. All the lands farmed by OSCo are leased, and the leases expire in 1995 and 1996.

The impact on OSCo of losing 800 acres of sugarcane land may fall more heavily on the major landowners than on OSCo because the major landowners may have to make greater concessions to OSCo in order to make it attractive for them to stay in operation.

Assuming that the leases are renegotiated and that sugar prices still favor OSCo's remaining in business beyond the year 2000, then the loss of about 800 acres of sugarcane land in upper Kunia translates into a loss in production of about 6,800 tons of raw sugar per year, or about 10% of the 1991 production of 68,265 tons. The associated loss in molasses output would be 2,240 tons, while the loss in energy production would be 7 million kWh of electricity.

Gross export revenues (but not profits) would decline by about $2.6 million per year, based on 1992 prices. However, the impacts on profits would be much less than the loss in export revenues since the cost of farming the land and processing the cane would be eliminated.

Water requirements for sugar would decline by about 6.4 mgd. However, this savings would be partially offset by the water required for growing pineapple in Kunia and for the Project.

Approximately 14 field jobs and 12 factory jobs are associated with 800 acres of cane land. However, in practice, the number of jobs lost would be lower since specialized mill and field employees must be retained. Also, any reduction in employment is likely to occur through attrition.

With regard to how the form of the sugar plantation would be affected, the loss of upper Kunia lands would *not* conform to OSCo's preferred sequence for contracting the plantation, which is from the periphery of the plantation inward. Lands in upper Kunia are a short trucking distance from the mill, soils are superior to those of most other fields, and yields are higher than average.

If OSCo is able to survive for many years while losing land to Del Monte and to various housing projects, then the amount of land under cultivation by OSCo would decline from 10,800 acres in 1992 to about 7,150 acres, more or less, in 2010. At this reduced size, the survival of OSCo is uncertain since profitability will depend heavi-

ly upon: the price of sugar, OSCo's lease rents and other lease terms and conditions, and future improvements in yields and operating efficiencies. The loss of 800 acres to Del Monte would contribute further to the difficulties due to the loss of economies of scale.

However, if OSCo closes, then the loss of direct and indirect employment supported by the plantation would be about 750 jobs. There would also be a significant reduction in greenery in Ewa and Central Oahu.

Impact if Del Monte Closes

If Del Monte is forced to close because it is unable to secure land to replace that lost to the Project, then OSCo would probably benefit—assuming that OSCo survives beyond the year 2000. Depending on water availability and pumping costs, OSCo would be able to cultivate sugarcane on newly leased upper Kunia lands now farmed by Del Monte. It is estimated that pumping costs would limit a pineapple-to-sugarcane land-use shift to about 2,000 acres.

IMPACT ON WAIALUA SUGAR CO., INC.

The Project could benefit WSCo indirectly if it causes Del Monte to close its Oahu plantation—assuming that WSCo survives beyond the year 2000. The closing would free about 1,200 acres of Galbraith Trust lands which could be used by Dole. In turn, Dole could free some of its pineapple land for use by WSco. With more acreage, WSCo would benefit through greater economies of scale.

A similar result could occur if OSCo were to close—possibly as an indirect impact of the Project if Del Monte moves onto replacement lands at the expense of OSCo. The closure of OSCo would free up land in upper Kunia, which could allow Del Monte to move off the Galbraith Trust lands and make them available to Dole. In turn, Dole could free land for use by WSCo. Without OSCo, WSCo would have to absorb the full cost of the sugar terminal at Honolulu Harbor. However, labor savings would be possible by shifting workers between the Harbor and the Aiea refinery, depending on deliveries from WSCo. Overall, WSCo would benefit because it would have more acreage.

IMPACT ON DIVERSIFIED AGRICULTURE

The Project (1) will not adversely affect any existing diversified-agriculture activities because none exist on the site; (2) will not affect the amount of land available for diversified agriculture; and (3) will not limit the growth of diversified agriculture since, in other parts of the State, far more agricultural land has been released from plantation agriculture than has been absorbed by other activities.

WAHIAWA LANDS MASTER PLAN: Impact on Agriculture

INTRODUCTION

The Wahiawa Lands Master Plan project ("the Project") is proposed for development by Hawaiian Trust Co., Ltd. on behalf of the George Galbraith Trust which owns the property. The Project will encompass an area of approximately 876 acres located in the Poamoho area north of Wahiawa. The site straddles Kamehameha Highway, and is bounded on the south by Lake Wilson and on the northwest by Kamananui Road. Wilikina Drive and lands of Schofield Barracks are to the west, and Whitmore Village is to the east. The project will include single-family and medium-density housing; a town center with commercial stores, offices and civic/public facilities; a second commercial area with convenience stores; a commercial/light industrial area, an elementary school; parks; a pineapple museum; and an 18-hole golf course. The property is now leased to Del Monte Fresh Produce (Hawaii), Inc. (Del Monte), with about 800 acres used for growing pineapple.

This report addresses the impact of the Project on agriculture. The analysis covers the agronomic quality of the site; and the impacts of the Project on Del Monte, the other plantations which could be affected, and the potential growth of diversified agriculture.

AGRONOMIC CONDITIONS

Soil Types and Uses

The affected acreage consists of eight soil types:[1]

WaA	Wahiawa silty clay, 0 to 3 percent slopes.
WaB	Wahiawa silty clay, 3 to 8 percent slopes.

KyA	Kunia silty clay loam, 0 to 3 percent slopes.
KuB	Kolekole silty clay loam, 1 to 6 percent slopes.
WaC	Wahiawa silty clay, 8 to 15 percent slopes.
KuD	Kolekole silty clay loam, 12 to 25 percent slopes.
HLMG	Helemano silty clay, 30 to 90 percent slopes.
FL	Fill land, mixed.

For each soil type, Table 1 shows the possible agricultural uses and two soil ratings (explained below). The predominate soil types—WaA and WaB—comprise over 90 percent of the project area. Except for these two soil types and KyA and KuB, the other soil types are located primarily at the edges of the pineapple fields.

Soil Ratings

The soils within the petition area have been rated in terms of four classification systems commonly used in Hawaii: (1) Land Capability Grouping, (2) Agricultural Lands of Importance to the State of Hawaii, (3) Overall Productivity Rating, and (4) Proposed Land Evaluation and Site Assessment. These classification systems are discussed below.

(1) *Land Capability Grouping by the United States Department of Agriculture Soil Conservation Service (SCS).*[1]

This classification system rates soils according to eight levels, ranging from the highest classification level, I, to the lowest level, VIII. Assuming that the land is irrigated, soil types WaA and WaB have land capability ratings of I and IIe, respectively. Capability Class I soils have few limitations that restrict their use, while Class II soils have moderate limitations that reduce the choice of plants that can be grown successfully, or require moderate conservation practices. The subclassification "e" indicates a risk of erosion.

Table 1.— WAHIAWA LANDS MASTER PLAN: SOIL TYPES, AGRICULTURAL USES AND SOIL RATINGS

Soil Type	Agricultural Uses	SCS Rating[1]	LESA Rating
Predominate Soil Types			
WaA	Sugarcane, Pineapple, Pasture	I	96
WaB	Sugarcane, Pineapple, Pasture	IIe	94
Remaining Soil Types			
KyA	Sugarcane, Pineapple	I	95
KuB	Sugarcane, Pineapple, Pasture	IIe	83
WaC	Sugarcane, Pineapple	IIIe	85
KuD	Pineapple, Pasture	IVe	56
HLMG (Gulches)	Pasture	VIIe	17
FL (Fill Land)	—	—	—

1. Assuming that all soils, except HLMG, are irrigated.

Source: United States Department of Agriculture, Soil Conservation Service. *Soil Survey of Islands of Kauai, Oahu, Maui, Molokai, and Lanai, State of Hawaii.* Washington, D.C., August 1972.

(2) *Agricultural Lands of Importance in the State of Hawaii (ALISH), by the SCS, University of Hawaii (UH) College of Tropical Agriculture and Human Resources, and the State of Hawaii, Department of Agriculture.*[2]

This system classifies lands into three categories: (a) "Prime" agricultural land which is land that is best-suited for the production of crops because of its ability to sustain high yields with relatively little input and with the least damage to the environment; (b) "Unique" agricultural land which is non-prime agricultural land that is currently used for the production of specific high-value crops; and (c) "Other" agricultural land which is non-prime and non-unique agricultural land that is of importance to the production of crops. Nearly all of the land in the proposed development is rated as "Unique" agricultural land. It falls into this category because it was not irrigated when it was classified but is considered to be excellent land for cultivating pineapple.

(3) *Overall Productivity Rating, by the UH Land Study Bureau (LSB).*[3]

This classification rates soils according to five levels, with "A" representing the class of highest productivity and "E" the lowest. Nearly all of the soils in the petition area have an Overall Rating of "B." However, the ratings for selective crops are:

— "a" for pineapple;
— "b" for forage and grazing, and
— "c" for vegetable crops, sugarcane, orchards, and timber.

In addition, machine tillability is rated as "good." Also, most of the soils are "nonstony," over 30 inches deep, well-drained, and with slopes of 0 to 10%.

(4) *Proposed Land Evaluation and Site Assessment (LESA) System, by the State of Hawaii Land Evaluation and Site Assessment Commission.*[4]

Based on soil quality, locational attributes, improvements, nearby activities, and land-use plans, this proposed classification system would designate a sufficient amount of the better agricultural lands to meet projected agricultural goals. If the LESA classification approach were applied to the proposed site, all of the designated lands—except fill land and land on side slopes—would be termed "important agricultural lands" (IAL). The majority of the land is rated 94 and 96 out of a possible total of 100. For Oahu, ratings of 66 or above indicate IAL. The ratings for each soil type are shown in Table 1.

In summary, all but the fill land and side slopes on the property are comprised of excellent soils for cultivating crops.

Climatic Conditions

Located in the middle of the island atop the Leilehua (Schofield) Plateau at an elevation of about 900 feet, the property has climatic conditions that are somewhat cooler and rainier than most other agricultural areas on Oahu. Average temperatures range from about 60°F to 75°F in the winter months and from about 65°F to 85°F in the summer months.[5] Sunshine is moderate, averaging less than 400 calories per square centimeter per year versus over 500 for the Ewa Plain.[6] Rainfall averages about 40 to 50 inches per year, with most of the rainfall occurring in the winter months.[5]

Water Availability

Groundwater is available from a well north of Kamananui Road. However, because of the high elevation of the site, pumping cost are relatively high, exceeding 60 cents per 1,000 gallons.[7] But, high pumping costs are less of a problem for pineapple than is the case for most other crops because the plant requires comparatively little water.

Del Monte Assessment of Agronomic Conditions

The subject fields are regarded by Del Monte—who grows pineapple on the site—as among their best pineapple fields on Oahu as well as in Asia and Central America where they also grow pineapple.[7,8] Yields are comparatively high and farming costs low. Conditions favorable for pineapple production include deep well-drained soils that are easy to work, a large expanse of flat fields which favor use of mechanized equipment, moderate rainfall which eliminates the need for expensive drip irrigation and reduces pumping costs (water for these fields is applied by overhead sprinklers), and temperatures which favor summer crops. However, seasonal cloud cover and cool temperatures limit productivity during the winter months.

Although the subject fields have favorable agronomic conditions for growing pineapple, other Oahu fields farmed by Del Monte also produce high yields and similar profits.

Summary

The agronomic conditions at the Project site are favorable for cultivating pineapple. However, the conditions are *not* favorable for cultivating most other crops because of relatively low sunshine and expensive irrigation water.

References

[1] U.S. Department of Agriculture, Soil Conservation Service in cooperation with The University of Hawaii Agricultural Experiment Station. *Soil Survey of Islands of Kauai, Oahu, Maui, Molokai, and Lanai, State of Hawaii.* Washington, D.C. August 1972.

[2] Harold L. Baker. *Agricultural Lands of Importance in the State of Hawaii.* University of Hawaii College of Tropical Agriculture and Human Resources, Honolulu, Hawaii. 1977.

[3] Land Study Bureau. *Detailed Land Classification, Oahu.* Honolulu, Hawaii. 1963.

[4] State of Hawaii Land Evaluation and Site Assessment Commission. *A Report on the State of Hawaii Land Evaluation and Site Assessment System.* Legislative Reference Bureau, Honolulu, Hawaii. February 1986.

[5] Department of Geography, University of Hawaii. *Atlas of Hawaii, Second Edition,* University Press. 1983.

[6] Department of Planning and Economic Development. "A Home-Owner's Guide to Solar Water Heating on Oahu with Oahu Sunshine Map." Honolulu, Hawaii. October 1983.

[7] Del Monte Fresh Produce (Hawaii), Inc.

[8] Kehlor, Robert R. *The History of Del Monte Pineapple in Hawaii.* 1992.

THE PINEAPPLE INDUSTRY

The History of Pineapple in Hawaii

Following earlier commercial attempts in Hawaii and elsewhere, the world pineapple industry had its commercial start at the turn of the century in Central Oahu.[1,2] In 1898, some California farmers purchased 1,300 acres of homestead land in Wahiawa where they experimented with growing pineapple, along with a number of other fruits and vegetables. One of the original homesteaders was A. W. Eames, whose farm would evolve into Del Monte's pineapple operations. In 1900, Jim Dole—a recent arrival from Massachusetts and second cousin of Sanford B. Dole, President of the Republic of Hawaii and then Governor of the Territory of Hawaii—purchased some of the homestead land. His farm evolved into the pineapple operations of Dole Food Co., Inc. (Dole).

The pineapple industry became successful in Hawaii due to a combination of circumstances, but primary among them were the excellent growing conditions in Central Oahu and other areas of Hawaii; the annexation of Hawaii to the United States as a territory, which thereby eliminated the 35% tariff on processed food products shipped to the U.S. market; technological advances which increased yields, reduced farming and canning costs, and extended the shelf-life of the product; and strong marketing of a "new" and exotic fruit.

By 1915, the pineapple industry was Hawaii's second largest industry.[1] By the 1920s, over a dozen plantations were operating on Oahu, Kauai, Maui, Molokai, Lanai and the Big Island.[2] During the 1930s and 1940s, Hawaii supplied 80% of the world's pineapple production, and was known as the "Pineapple Capital of the World."[2]

In the late 1950s, Hawaii's pineapple industry had reached its zenith, with about 76,600 acres farmed by various plantations.[3] In order of production, major producers included Dole; Libby, McNeill & Libby of Honolulu, Ltd. (Libby); Del Monte; and Maui Land & Pineapple Co. (ML&P). But in the early 1960s, the industry began contracting as some producers moved their canning operations to countries where labor and other costs were much lower, while others producers left the industry entirely. By 1990, Hawaii supplied only 10% of the world production of canned pineapple.[4] And by 1993, pineapple acreage in Hawaii had been reduced to less than 28,000 acres.[5] Correspondingly, employment in the pineapple industry declined from about 12,100 jobs in 1960 to less than 2,400 jobs in early 1993.[5,6]

Hawaii's Current Pineapple Industry

Only three pineapple companies remain in Hawaii: Del Monte and Dole which operate plantations on Oahu, and ML&P which operates on Maui. Libby closed its operations in the late 1960s. In addition, Wailuku Agribusiness Co., Inc. (Wailuku Ag) on Maui grows pineapple for ML&P. Even though Hawaii's pineapple industry is much smaller than it once was, the remaining plantations, particularly the two on Oahu, are economically healthy.

DEL MONTE AND DOLE

In terms of their pineapple operations, Del Monte and Dole share many similarities. As mentioned above, both started in Wahiawa at the turn of the century. Both developed major plantations on Oahu, then the Neighbor Islands, then overseas. Both grew so that the two are now the major pineapple companies in the U.S. and world markets. Furthermore, the two grew to be strong competitors, selling pineapple under their own brand names. In the 1980s, Del Monte closed its Honolulu cannery and its Molokai plantation.[2] Similarly, Dole closed its Molokai plantation in the mid-1970s, and is in the final stages of closing its Honolulu cannery and its Lanai plantation, except for about 150 acres which it will retain to provide fresh fruit to the two hotels on the island.

Del Monte and Dole each have only one plantation remaining; both are located on Oahu and are similar in size: Del Monte's plantation is about 7,500 acres, and Dole's is slightly over 8,000 acres.[5] Both of these plantations grow pineapple for the high-value fresh market on the mainland and in Hawaii—markets which cannot be serviced from low-cost Asian producers. Both companies deliver fresh pineapple to the West Coast markets via refrigerated surface transportation. Both companies deliver fresh pineapple to major cities throughout the mainland via air transportation that is made possible as a result of the large visitor industry and the frequent flights from Honolulu to the mainland using wide-bodied jets.

Both companies are developing the high-value fresh-chilled market (cut pineapple that is sold fresh rather than canned).

MAUI LAND & PINEAPPLE CO.

ML&P farms about 10,000 acres split between two locations, one in Central Maui and the other in West Maui.[5] In addition, Wailuku Ag grows pineapple for ML&P on about 2,200 acres in Central Maui.[5]

Most of the pineapple grown on Maui is canned for the private-label market (also called store-brand market, such as Safeway's "Townhouse" brand). Expensive advertising is avoided by placing this Hawaii-grown canned pineapple on shelves next to the products of Del Monte and Dole, and selling the private-label pineapple at a slightly lower price.

ML&P also sells fresh pineapple on the mainland, but the volume is small because of transportation problems. Kahului Harbor is too small for large container ships, Kahului Airport has a runway that is too short to allow fully-loaded wide-bodied jets to take off for direct flights to the mainland, and air or barge shipment of pineapple to Honolulu for transfer to the mainland is too slow and/or too expensive.

The Pineapple Industry Outside Hawaii

DEL MONTE AND DOLE

Outside Hawaii, Del Monte and Dole also share many similarities. Del Monte has a plantation in Central America (Costa Rica) which delivers fresh pineapple to the East-Coast market via surface transportation; Dole has a plantation in Central America (Honduras) and one in the Caribbean (Dominican Republic) which deliver fresh pineapple to the East-Coast, Midwest and European markets via surface transportation.[1,2,5] Dole has a very large plantation in the Philippines where pineapple is grown for the canned market for distribution to the U.S., Europe, and other countries, and for the fresh market in Japan. In addition, Dole grows pineapple in Thailand for the canned pineapple market. In order to supply its mainland market, Del Monte receives canned pineapple from a very large plantation in the Philippines operated by Del Monte Foods, which is a separate company (see page 12).

OTHER PRODUCERS

Although the world pineapple industry is dominated by Del Monte and Dole, a collection of growers in Thailand are a major force in the canned market, supplying about 40% of the world's pineapple market.[2,5] Other areas where pineapple is grown on a commercial scale are Mexico, where the fruit is grown by brokerage companies for the U.S. market; Guatemala which is operated by Chiquita; Puerto Rico; Martinique; Cuba; Brazil; Australia; Malaysia; Indonesia; Taiwan; China; Kenya which supplies fruit to the European market, and which is a former Del Monte plantation; Swaziland; West Africa; and the Azores.[2,5] Pineapple growing regions are generally located in the tropic and subtropic zones—that is, in the area between the Tropic of Cancer north of the equator and the Tropic of Capricorn south of the Equator.[2]

Taiwan was once a major producer for the canned pineapple market, but many plantations closed because, like Hawaii, economic advances on the island led to high labor costs that are not competitive with those of Thailand and the Philippines.[5] A decline also occurred in Malaysia for the same reason.

International Trade Agreements

Imports of fresh pineapple into the United States are not restricted by tariffs or quotas. Consequently, international trade agreements now under negotiation (see page 32) will not affect Hawaii's fresh-pineapple industry.

References

[1] Dole, Richard and Elizabeth Dole Porteus. *The Story of James Dole.* Island Heritage Publishing. Aiea, Hawaii. 1990.
[2] Kehlor, Robert R. *The History of Del Monte Pineapple in Hawaii.* 1992.
[3] Schmitt, Robert C. *Historical Statistics of Hawaii.* The University Press of Honolulu. 1977.
[4] Neil, Christopher. "End of the Line." *Sunday Star-Bulletin & Advertiser.* December 1, 1991. p. C-4.
[5] Derived from information provided by the pineapple companies.
[6] State Department of Land and Industrial Relations. Employment records.

DEL MONTE FRESH PRODUCE (HAWAII), INC.

Background Information[1]

HISTORY[2]

Del Monte Fresh Produce (Hawaii), Inc. ("Del Monte") traces its roots back to 1898 when, for a price of $400, A. W. Eames purchased 100 acres of unimproved homestead land in Wahiawa. Eames was one in a group of pioneering farmers from California who purchased land in the area. Very soon after he purchased his Wahiawa land, Eames planted pineapple and, by 1900, he was selling it locally and in California. Since the market on the mainland for canned pineapple showed promise, Eames founded his Hawaiian Island Packing Company in 1906, and built his first cannery that year in Wahiawa.

In 1912, the company cleared and planted the Poamoho fields (now Galbraith Trust lands) as a new growing area, and built a larger cannery in Wahiawa to replace the one built in 1906.

In 1917, the Hawaiian Island Packing Company joined the newly formed California Packing Corporation (CPC, also called Calpak and Del Monte), which sold under the brand name Del Monte. By 1919, Del Monte farmed 6,600 acres which are nearly the same lands as those currently farmed by Del Monte. The lands were leased from Waialua Agricultural Company (now lands of Galbraith Trust), Oahu Railway and Land Company (now Campbell Estate lands), and The Territory of Hawaii (now State lands). However, the Galbraith fields have not been continuously farmed by Del Monte; Dole also farmed these lands on occasion.

From 1919 to 1927, Del Monte also grew sugarcane in fields in what is now Wahiawa town. From 1919 to the early 1960s, Del Monte also farmed land in Kahuku. Fields in the Ewa Flat area have also been farmed.

In 1920, a new pineapple cannery was built in Iwilei and remained in operation until 1983, closing due to the high labor costs as compared to Asian producers. The cannery processed fruit from Oahu as well as Del Monte's 4,000-acre plantation on Molokai, which operated from 1927 to 1988. The company also had a cannery on Maui from 1926 to 1934; this was sold to what is now ML&P. Also on Maui, Del Monte and ML&P jointly operated a can company from 1966 to 1977 when ML&P purchased full control of the operation.

Fresh-fruit shipments to the mainland began in the late 1950s for surface freight, and in the mid-1970s for airfreight. Since the early 1980s, the principal product of Del Monte's Hawaii operation has been fresh pineapple for the mainland and Hawaii markets. More recently, Del Monte has been flying fresh-chilled pineapple to the mainland.

In 1967 the corporate name was changed to "Del Monte Corporation." In 1979, Del Monte was purchased by R. J. Reynolds which, in turn, merged with Nabisco in 1986 to form RJR Nabisco. Following the largest leveraged buy-out in history, the Del Monte Corporation was split into five separate companies and then sold. One of the resulting companies is Del Monte Foods, headquartered in San Francisco, California. A second is Del Monte Tropical Fruit Company (which includes the Hawaii pineapple plantation), headquartered in Coral Gables, Florida. The remaining three companies are based in Europe (Royal Foods), Japan (Kikoman Foods, Japan) and Canada (Nabisco).

Del Monte Tropical Fruit Company was sold in late 1989 to Polly Peck International, a London-based conglomerate which, in turn, sold it to a Mexican investor group in 1992, when the name was changed to Del Monte Fresh Produce Co. The Hawaii operation is called Del Monte Fresh Produce (Hawaii), Inc.

PRODUCTS, PRODUCTION AND SALES

Del Monte produces four products in Hawaii: fresh-whole pineapple, "fresh-chilled" pineapple, frozen pineapple, and juice concentrate. Fresh-chilled and frozen pineapple—relatively new products with a growing market—are precut and packaged in plastic bags. These two products constitute a high-value use of pineapple which, due to a bruise or a sunburn, may not be suitable for sale as a fresh whole pineapple.

Del Monte's Hawaii operation produced 99,000 tons of pineapple in 1991, and projects an increase to 125,000 tons in 1996.

Sales in 1991 totaled about $62 million, for an average of about $626 per ton of pineapple produced.

DISTRIBUTION

The fresh whole pineapple and the fresh-chilled fruit are marketed primarily on the U.S. mainland, but some is sold locally. Nearly two-thirds of this product is shipped by air and arrives at market within 48 hours of the time it leaves the fields. However, some of the fresh pineapple travels in refrigerated cargo ships arriving on the west coast 10 to 12 days after harvesting.

Juice concentrate is marketed on the mainland and in Japan, and is carried by cargo ship.

COMPETITION AND COMPETITIVE ADVANTAGES

Del Monte continues to grow pineapple in Hawaii for a number of reasons. First, since pineapple is widely associated with Hawaii, the identification of Del Monte with Hawaii offers marketing advantages, even for the Del Monte pineapple grown elsewhere.

Second, Hawaiian pineapple can be sold at a premium price because the American public perceives Hawaiian pineapple to be of higher quality than that produced in other countries. However, prices soften in the summer months when peaches, watermelons and other summer fruits and melons are available.

Third, transportation services from Oahu to the mainland are excellent, thanks largely to Hawaii's visitor industry. Both air and surface transportation are frequent and reliable, and "back-haul" rates are favorable. In contrast, it is not practical to deliver fresh pineapple to the U.S. market from low-cost Asian plantations, nor even from the Neighbor Islands except for a small volume using available air-cargo space. However, fresh pineapple can be delivered from Mexico by truck, and from Central America and the Caribbean on ships which deliver bananas to the U.S. market.

A fourth advantage offered by Hawaii is that it is a politically and economically safe environment since it is part of the United States.

LAND AREA, OWNERSHIP AND USE

Of the two pineapple and two sugar plantations on Oahu, Del Monte farms the least land: about 7,420 acres in 1991 and about 7,500 acres in late 1992. All of the lands farmed by Del Monte are leased. The three major landowners who lease to

Del Monte are The Estate of James Campbell (about 4,790 acres), the George Galbraith Trust (about 2,050 acres), and the State of Hawaii (about 580 acres). All three leases expire on December 31, 1994. The Campbell Estate lands are located south of Wahiawa in the Upper Kunia area and west of Kunia Road. The State lands are also south of Wahiawa in Upper Kunia, but are north of the Hawaii Country Club and east of Kunia Road. The Galbraith lands are just north of Wahiawa in the Poamoho area. As noted above, Del Monte has farmed these lands since as early as 1919, but not continuously.

In 1992, Del Monte entered into leases with Castle & Cooke and Lopez for about 80 acres. These lands are also in the Poamoho area, but are to the west of Wilikina Drive.

In 1991, Del Monte cultivated about 5,690 acres and used an additional 120 acres for the plantation village at Poamoho and its Kunia headquarters and plantation village complex. An additional 1,610 acres were not in cultivation, including (1) high-elevation fields which have been fallowed because they are unsuitable for producing high-quality fresh fruit, (2) roads, and (3) gullies and other lands that are unsuitable for mechanized farming.

At 5,690 acres under cultivation, Del Monte farms all of the land which is suitable for producing high-quality pineapple for the fresh-market.

WATER USAGE AND COSTS

Del Monte relies on rainfall to supply water to its fields, and supplements this with well water. Because the pineapple plant uses water very efficiently, Del Monte uses less than 1 million gallons per day (mgd) over the entire plantation, and most of this is in Kunia. However, for fields in sunny areas having low rainfall, about 1/2 inch of water is applied weekly, which amounts to a daily average of slightly less than 2,000 gallons of water per acre. In comparison, daily per-acre usage of water exceeds 8,000 gallons for sugarcane, and about 3,500 gallons for single-family homes.

Pumping costs to supply water to Del Monte's fields range from between 60 and 90 cents per 1,000 gallons, depending upon whether a diesel or electrical pump is used, and on the maintenance costs incurred.

EMPLOYMENT

Of the four plantations on Oahu, Del Monte provides the most employment. The job count fluctuates with the season, ranging from a low of about 685 workers during the winter months when planting is curtailed because of weather, to a high of about 760 workers in the summer at peak harvest, with an average over the year of about 710 jobs. Summer employment in 1992 totaled 757 workers including: 378 field workers; 194 workers in the Kunia packing plant; 144 workers in the fresh-chilled operations in Waiakamilo; and 41 workers in operations, engineering, research, and sales, most of whom are located at the Kunia headquarters. Seasonal workers include an average of about 35 Mexican nationals who help with harvesting.

The skills required vary from highly skilled (managers, agronomists, engineers, researchers), to skilled (supervisors, technicians, mechanics, equipment operators, journeymen, secretaries, etc.), to semi-skilled (field workers, fruit packers, glove repair workers, clerical help, etc.). Non-management employees are represented by the International Longshoremen's and Warehousemen's Union (ILWU). Hourly wage rates for laborers range from about $8 to over $11, depending on grade level. Salaries are higher for the skilled jobs.

In addition to the direct employment provided by Del Monte, the company indirectly supports about 800 jobs as a result of the purchase of goods and services by the company itself as well as by its employees.[3] Thus, total employment supported by Del Monte amounts to about 1,500 direct and indirect jobs.

CROP CYCLE AND YIELD

Because of good farming practices, Del Monte normally obtains three crops from each planting, for a total yield of about 125 tons per acre.

The first harvest (known as the plant crop) is produced 18 to 22 months after planting, and the second and third harvests (known as the first and second "ratoon" crops) take 12 to 13 months each. After the last crop is harvested, a field is usually fallowed for about a year. During the fallow period, the old plants are burned or left to dry out (to control nematodes and insects), or are turned under (to enrich the soil). Then the soil is tilled and prepared for replanting. For Del Monte, a complete crop cycle typically lasts about 5 years. However, the crop cycle can be shorter or longer, depending upon whether a second ratoon crop is allowed to grow, and on the duration of the fallow period.

The plant crop produces the largest fruit and the largest yield, while the two ratoon crops produce fruit and yields that are progressively smaller. Over a complete crop cycle, the plant crop produces about 40% of the total yield, while the first and second ratoon produce about 34% and 26%, respectively, of the yield.

Normally, about 25 acres are planted each week, while 75 acres are harvested. The weekly harvest normally includes three fields, one of which will be a plant crop, another will be a first ratoon crop, and the other will be a second ratoon crop.

EPA Regulations

The U.S. Environmental Protection Agency (EPA) regulates the use of various chemicals and other chemicals which are regarded by the pineapple industry as critical to controlling pests and to the continued survival of pineapple operations in Hawaii. An ongoing concern of the pineapple companies is that the EPA will withdraw approval of key chemicals, thereby forcing pineapple operations to close.

Economic Health and Expansion Plans

Of the four plantations on Oahu, Del Monte appears to enjoy the strongest economic health. Although Del Monte has been marginally profitable in recent years, the company anticipates profitable future operations based on producing high-value fresh pineapple and pioneering the market for high-value fresh-chilled pineapple.

Provided sufficient land is available and EPA approval continues for key chemicals, Del Monte has a long-term future and plans to expand acreage and production.

Impact of the Project on Del Monte

The impact of the Project on Del Monte will depend upon: (1) whether or not replacement lands become available; (2) the availability of water to irrigate these lands; and (3) the timing with respect to the crop cycle, the dates Del Monte must be

off the Galbraith fields, and the dates replacement lands will be available. The affected fields are discussed first, along with the normal planting and harvesting schedule, the development schedule for the Project, the need for replacement lands, adjustments in operations planned by Del Monte, and the timing for securing replacement lands.

Affected Fields and Crop Schedule

The Project affects three large fields used by Del Monte: Field #203 (called the "Birthing Stone"), Field #204, and Field #206 (see Figure ES-1). Fields #203 and #206, which are farmed as a single unit, lie in a triangle bounded by Lake Wilson on the south, Kamananui Road on the northwest, and Kamehameha Highway on the northeast: Field #203 is the northern top of the triangle, and Field #206 is the southern base of the triangle bordering Lake Wilson. Excluding roads, about 432 acres of Fields #203 and #206 are farmed: about 172 acres in Field #203, and 260 acres in Field #206.

Fields #203 and #206 were last planted in late 1990, and the third harvest is scheduled for the summer of 1994. Normally, these fields would be replanted in late 1995, and harvested in the summers of 1997 through 1999.

Field #204 lies to the east of Kamehameha Highway near Whitmore Village. This field, which has 288 acres in crop, exclusive of roads, was planted in late 1991, and the third harvest is scheduled for the summer of 1995. Normally, it would be replanted in late 1996, and harvested in the summers of 1998 through 2000.

About 4 acres of Field #202, which lies to the west of Wilikina Drive, will be used for a sewage treatment plant. However, this small loss of acreage will not significantly affect Del Monte's operations.

Development Schedule

Phase I of the Project encompasses about 100 acres and includes the commercial center and abutting areas. Most of Phase I, plus additional acreage which must be fallowed to accommodate construction, falls within Field #203. Land clearing for this phase is scheduled to begin as early as January 1996 but as late as December

1997. First occupancy of homes and commercial areas would occur about two years after land is first cleared.

In order to accommodate the needs of Del Monte, land clearing for Field #206 is scheduled for after the summer of 1998. For Field #204, land clearing is scheduled for after the summer of 1999. As explained below, these are the earliest dates Del Monte can vacate these fields without disrupting their production and deliveries.

THE NEED FOR REPLACEMENT LANDS

It is critically important to the economic health of Del Monte that they secure about 800 acres of good-quality lands to replace those lost to the Project because (1) good-quality replacement lands cannot be provided from within the existing plantation, and (2) a significant loss of acreage would be very disruptive to Del Monte's production and delivery.

For example if a 430-acre field is not available when it is time to start a new crop cycle, then a 17-week (about 4-month) planting cycle would be missed (430 acres ÷ 25 acres planted each week). During this 4-month period, the planting crew would be idle. Approximately 18 months after the missed planting, production would fall off for about a 4-month period because there would be no plant crop to harvest. In another 12 to 13 months, production would fall off again for 4 months, because the first ratoon crop would not be produced; the same thing would happen a third time with the second ratoon crop. Because each crop is progressively smaller, the drop in production from the plantation as a whole would amount to about 40% for the plant crop, 34% for the first ratoon, and 26% for the second ratoon. During these periods of lost production, some of the harvest and packing crews would be idle.

Of far greater significance, deliveries to customers would be missed. In turn, some of these customers would likely turn to Dole and other suppliers, resulting in Del Monte suffering a permanent loss of customers and market share even after production is restored. Del Monte would no longer be regarded as a reliable supplier of fresh pineapple or fresh-chilled pineapple.

The loss of two large fields without replacement would exacerbate the problem. The simultaneous loss of a plant crop from one field and a first ratoon crop from another field could result in a plantation-wide production and delivery shortfall of more than 70%.

Of significance, the impact on a pineapple plantation of losing acreage is far greater than it is on a sugar plantation. To retain its customers as well as its economies of production, a pineapple plantation that sells to the fresh market must maintain fairly steady production and deliveries since fresh pineapple cannot be stored. For a sugar plantation, production can vary greatly over time without losing customers because sugar can be stored until it is needed.

ADJUSTMENTS TO THE PLANTATION

As indicated above, the normal crop cycle for Fields #203 and #206 would indicate replanting in late 1995, and harvesting in the summers of 1997, 1998 and 1999. For Field #204, the normal crop cycle would indicate replanting in late 1996, and harvesting in the summers of 1998, 1999 and 2000. However, replacement lands are *not* expected to be available by 1995 and 1996 to maintain this planting schedule. Consequently, another crop cycle will be required on the Galbraith Trust lands if Del Monte is to maintain its production.

Nevertheless, as a result of discussions between Del Monte and Galbraith Trust, Del Monte plans to make a number of adjustments which will allow it to maintain its level of production even though it will lose land to Phase I of the Project. It will also shorten the time Del Monte will require use of the remaining Project lands. The adjustments planned by Del Monte are:

- — harvest the last fruit crop from Field #203 in the late summer of 1994, but leave the plants in the field and continue to harvest slips—to use as planting stock on other fields—until the land must be cleared for development;
- — plant poor-quality fields in the foothills which were fallowed many years ago because they are not economical to farm for the fresh pineapple market, but which can be farmed for one crop cycle in order to maintain production;

- quick-cycle Fields #204 and #206 as well as other fields elsewhere on the plantation in order to shorten the crop cycle by 1 year for Fields #204 and #206, and to increase production (when a field is quick-cycled, it is planted soon after harvest and the normal fallow period before planting is omitted);
- after the fruiting cycles are completed on Fields # 204 and #206, leave the plants in the field and continue to harvest slips—to use as planting stock on other fields—until the land must be cleared for development.

Regarding the quick-cycling of fields, this practice can boost production in the short term, but quick-cycling is not sustainable over the long term because yields would decline eventually as a result of pest and other problems that are normally controlled during the fallow periods. Also, permission will be required from the Department of Health to burn plants in the field since quick-cycling does not allow enough time for the plants to decompose.

With these adjustments, Del Monte could vacate Field #206 after the summer of 1998 and Field #204 after the summer of 1999.

In addition to the above adjustments, Del Monte will need to modify its chemical-spraying practices in order to safeguard the health of construction workers whenever work is occurring downwind of fields that are being farmed. Spraying of chemicals on pineapple fields is quite frequent. The fields are routinely sprayed about 2 or 3 times per month, increasing to once a week during harvest which, for a large field, lasts about 4 months. Modifications to spraying practices will include: use of low-drift nozzles which produce larger and heavier drops, lower rates of application, dilution of chemicals with more water, night spraying, and spraying on Friday evenings before the weekend. These practices will have a minimal impact on Del Monte's operating costs.

TIMING ON PLANTING REPLACEMENT LANDS

With the above adjustments to its operations, Del Monte expects to be able to maintain production through the 1990s. But in order to maintain production beyond the year 2000, about 800 acres of replacement lands will be needed, preferably by 1997. However, steady production can be maintained provided that the first 400-

acre increment of replacement land is available by early 1999; the land would be needed early in the year in order to allow time to prepare the land before planting. The second 400-acre increment would be needed early in 2000, although if other fields are quick-cycled, then the need for this second increment could be postponed to the year 2001.

IMPACT IF REPLACEMENT LANDS AND WATER ARE AVAILABLE

If about 800 acres of good-quality lands are made available to Del Monte in 1999 and 2000, or earlier, along with water to irrigate the replacement lands, then the impact of the Project on Del Monte would be small, with no loss in production, revenues or employment. The major change would be that Del Monte eventually would farm different lands.

This assumes, however, that the current leases will be renewed at comparable rents (or at rents that would allow profitable operations), including the leases for the remaining acreage of Galbraith Trust, Campbell Estate, and the State of Hawaii. As mentioned above, the current leases expire at the end of 1994. Of significance, Dole has expressed an interest in farming the remaining Galbraith acreage, although Galbraith has indicated its willingness to continue leasing its remaining land to Del Monte. Also, OSCo could farm a portion of the State and Campbell Estate lands that are now leased to Del Monte.

The required 800 acres could come from pineapple lands near Poamoho that are owned and farmed by Dole. However, it is highly unlikely that Dole will lease land to Del Monte since the two companies are strong competitors, and Dole has indicated that it needs these lands for its own operations. Dole's position could change, however, if due to low sugar prices Waialua Sugar Co., Inc. (WSCo) were to close, thereby freeing land which could then be farmed by Dole.

The only other replacement lands are some fields which are now leased to OSCo. Sugarcane lands that are suitable for pineapple production are located in upper Kunia—above and slightly below the high-voltage power lines that cross Central Oahu. The upper Kunia lands to the west of Kunia Road are owned by Campbell Estate, while the lands to the east of Kunia Road are owned by Robinson Estate. The Campbell Estate lease to OSCo expires in mid-1995, and the Robinson Estate lease to OSCo expires at the end of 1996.[4]

Del Monte may have difficulty obtaining a lease for land that is now leased to OSCo because OSCo is short of land and most major landowners and the State have expressed a strong desire to have OSCo remain in operation. Also, if alternate land is not available to Del Monte, it may have the effect of forcing pineapple operations to remain on Galbraith Trust lands, thereby eliminating competition from a new housing project. As of December 1992, new leases to allow OSCo to continue operations were being negotiated.

Nevertheless, if Del Monte is able to secure about 800 acres of land in upper Kunia, the plantation would also need over 1 mgd of water to irrigate the new fields. This would require a groundwater allocation from the State Water Commission, or water from Waiahole Ditch which is owned by OSCo. Of significance, the State plans to claim 6 mgd from Waiahole Ditch based on its ownership of one of the Windward Oahu watersheds which supplies water to the Ditch.[5] All of the 6 mgd is slated for use in Kunia so that the underlying aquifer can continue to be recharged. The State has plans for about 3 mgd; plans for the remaining 3 mgd have not been developed.

Del Monte would have to expend about $700,000 to convert the Kunia lands from sugarcane to pineapple.[6] Fields would have to be laid out with proper spacing for Del Monte's harvesting equipment, and the existing drip irrigation system would have to be modified. In addition, the planting schedule of fields throughout the Del Monte plantation would have to be modified since Poamoho fields produce summer fruit, while Kunia lands produce winter fruit.

If replacement lands in Kunia are in fact made available to Del Monte, and if OSCo survives beyond the year 2000, then the major agricultural impact of the Project would fall on OSCo rather than on Del Monte because OSCo would be losing acreage to Del Monte. This impact is discussed in the section on OSCo.

IMPACT IF REPLACEMENT LANDS AND WATER ARE NOT AVAILABLE

Impact on Del Monte

If sufficient replacements lands, along with water to irrigate the new lands, are *not* made available to Del Monte to replace the fields lost to the Project, then the probability is high that Del Monte will close its Hawaii plantation, and replace it with a larger pineapple plantation in Mexico or Guatemala. Del Monte would be forced to take this action in order to maintain production and deliveries of fresh pineapple, and to retain its existing market. As discussed previously under "Need for Replacement Lands" (pages 18-19), the loss of two large fields would be very disruptive to Del Monte's operations. The phase-down of Hawaii operations would likely occur over a single crop cycle starting around the year 2000.

The advantages to Del Monte of relocating the plantation to Mexico or Guatemala include sufficient acreage to fill customer orders, wage rates and production costs that are lower than in Hawaii, and the potential for inexpensive and frequent delivery of fresh pineapple to the West Coast on ships which now deliver bananas. Also, a larger plantation combined with a processing plant on the mainland would allow Del Monte to carry through with its plans to develop the fresh-chilled market.

Impact on Other Oahu Plantations

If Del Monte were to close, then other Oahu plantations would benefit because land would be released for their use. Depending on the availability of water and pumping costs, OSCo could expand its acreage into upper Kunia by an estimated 2,000 acres—assuming that OSCo survives beyond the year 2000.[7] Such an expansion could compensate for the loss of OSCo acreage to housing projects in Ewa and Central Oahu.

Also, Dole has already expressed an interest in leasing the remaining 1,200 acres of Galbraith Trust lands that are now leased to Del Monte—lands which are a short trucking distance to Dole's packing plant. However, an expansion of Dole's market is not expected since Del Monte would attempt to maintain its existing market share using a new plantation in Mexico or Guatemala. Rather, Dole may release some of its pineapple acreage to allow WSCo to expand its plantation—assuming that WSCo survives beyond the year 2000.

Loss in Employment

If Del Monte closes, about 1,500 direct and indirect jobs supported by the plantation would be lost. Because of their poor language skills, some Del Monte workers are likely to experience difficulty in finding new jobs. Increases in employment at other plantations are expected to be small because net acreage gains would be relatively small, especially for Dole and OSCo, and employment per acre is low for sugar plantations. Mitigation measures for the loss in employment would include language and job training, and job-placement assistance.

Fallowed Acreage

If Del Monte closes, the net effect would be that an additional 1,700 acres would be fallowed. This is based on about 5,700 acres currently being farmed by Del Monte, less about 800 acres to the Project, 1,200 acres to Dole, and 2,000 acres to OSCo—assuming that OSCo survives beyond the year 2000. The fallowed Del Monte fields would be in an area of considerable rainfall so that the area would remain green through the winter months but possibly not during the summer months.

Comparative Benefits of Del Monte and OSCo

The Project may force the landowners in upper Kunia to choose between leasing their land to Del Monte or to OSCo—particularly since land leases to OSCo are scheduled to end in 1995 and 1996. The State is involved in the choice also because it, too, leases land to Del Monte and OSCo. Consequently, a comparison of the two plantations is relevant.

OSCo is the larger plantation of the two, farming about 10,800 acres versus Del Monte's 5,700 acres. Thus OSCo provides more greenery than Del Monte. If the latter closes and OSCo survives, then the resulting increase in fallowed acreage and

loss of greenery would amount to about 1,700 acres.[1] Fallowed fields would be in an area of considerable rainfall so that the lands would remain green through the winter but possibly not during the summer months. On the other hand, if OSCo closes and Del Monte continues, then the increase in fallowed acreage and the loss of greenery would amount to about 6,300 acres.[2] This could cause a major loss in greenery because Ewa and lower Kunia receive little rainfall and fallowed fields would therefore not remain green. It is also possible that Del Monte could close (due to a lack of replacement lands), followed by OSCo or WSCo, or both (due to problems in the sugar industry). In this case, fallowed acreage on Oahu could rise by about 25,000 acres.[3]

OSCo also uses far more water; it averages about 88 mgd while Del Monte averages less than 1 mgd. About 27 mgd used by OSCo comes from the windward side of the island via Waiahole Ditch, and some of this water seeps down to recharge the groundwater supply beneath Kunia.

Even though OSCo uses more land and water, Del Monte generates more revenues: about $62 million per year versus about $25 million for OSCo.

Del Monte also provides more employment: an average of about 710 jobs at Del Monte versus about 350 jobs at OSCo. Also, direct plus indirect employment supported by Del Monte is higher than that for OSCo: about 1,500 jobs for Del Monte versus about 750 jobs for OSCo. If Del Monte were to close, followed by OSCo or WSCo, or both, then the total loss in employment loss rise to 3,200 jobs.[4]

1. About 5,700 acres farmed by Del Monte, less about 800 acres for the proposed Project, 1,200 acres to Dole, and 2,000 acres to OSCo.
2. About 10,800 acres farmed by OSCo, less 2,000 acres to Del Monte (thereby freeing land for the proposed Project and for Dole) and, over the next 10 years, about 1,500 acres to other projects and about 1,000 acres to diversified agriculture.
3. About 5,700 farmed by Del Monte, 10,800 acres farmed by OSCo, plus 12,000 acres farmed by WSCo, less 800 acres for the proposed Project and, over the next 10 years, about 1,500 acres to other projects and about 1,000 acres to diversified agriculture.
4. Including direct and indirect employment, 1,500 jobs for Del Monte, 750 jobs for OSCo, and 950 jobs for WSCo.

If sufficient lands are available, Del Monte is the healthier of the two plantations, while the outlook for OSCo (and WSCo) is uncertain due to low sugar prices. However, the nature of a fresh pineapple operation make Del Monte more vulnerable to a loss in acreage than OSCo. As discussed above, when a pineapple plantation that sells to the fresh market loses significant acreage, it causes missed plantings, missed production, missed deliveries of fresh fruit, and lost customers which would continue even after production is restored. Thus a significant loss of acreage would cause Del Monte to relocate the plantation to Mexico or Guatemala so that consistent fresh-fruit deliveries could be assured.

For OSCo, a loss of significant acreage would reduce economies of scale and undermine their profitability. To compensate for these losses, the major landowners would have to make greater concessions to OSCo when renegotiating the leases to make it attractive to OSCo to continue operations.

References

[1] Unless otherwise noted, the material in this section was obtained from Del Monte Fresh Produce (Hawaii), Inc.
[2] Kehlor, Robert R. *The History of Del Monte Pineapple in Hawaii.* Kunia, Hawaii. 1992.
[3] Based on employment multipliers from the State Department of Business, Economic Development & Tourism.
[4] Decision Analysts Hawaii, Inc. *Hawaii's Sugar Industry and Sugarcane Lands: Outlook, Issues and Options.* Honolulu, Hawaii. April 1989.
[5] Department of Agriculture.
[6] Del Monte Fresh Produce (Hawaii), Inc.
[7] Oahu Sugar Co., Ltd.

DOLE FOOD COMPANY, INC.

Background Information[1]

HISTORY[2]

Dole Food Company, Inc. (Dole) began its pineapple operations at the turn of the century when James Dole planted pineapple on a portion of 61 acres of Wahiawa homestead land which he purchased in 1900. The original company was organized the following year as the Hawaiian Pineapple Co., Ltd. (Hapco). This company grew rapidly, soon becoming the largest pineapple producer in the world, which it remains to this day.

Hapco built a cannery in Wahiawa in 1903, which was replaced in 1907 by a larger one at Iwilei. To add to its Oahu plantation, Hapco purchased nearly all of the island of Lanai in 1922 and developed a 20,000-acre plantation there.

Castle & Cooke, Inc. (C&C) took control of Hapco in 1932 after the company encountered financial difficulties due to poor sales during the Depression and high debt following development of the Lanai plantation.

In 1961, Hapco was merged into C&C and renamed Dole Pineapple Co.; later it was later renamed Dole Foods Co.

In the early 1980s, C&C itself encountered financial difficulties, and was merged with Flexi-Van in 1985. Within a few years, Flexi-Van assets were sold and the remaining interest were divested via a rights offering. In 1991, C&C was renamed Dole Food Co., Inc. However, C&C survives as the development company owned by Dole; this company was formally named Oceanic Properties, Inc.

The only remaining Dole plantation is located on Oahu and produces fresh pineapple for the mainland market in competition with Del Monte. Dole had a plantation on Molokai which it closed in the 1970s; recently, it closed its Lanai plantation and its Oahu cannery.

Overseas pineapple operations include plantations in Honduras, the Dominican Republic, the Philippines, and Thailand.

LAND AREA AND OWNERSHIP

The net planted area (i.e., the planted and fallow fields, but not the roads) of Dole's Oahu plantation in Wahiawa amounts to approximately 7,000 acres. The gross area, all of which is owned by Dole, exceeds 8,000 acres.

In the 1950s before it contracted its cannery operations, Dole's Oahu plantation was much larger. Most of the former pineapple land was used or is slated for urban development (Mililani and Mililani Mauka), or was replanted in sugarcane by Dole's sister company, Waialua Sugar Co., Inc. (WSCo).

Although Dole is fallowing about 300 acres of its land south of Mililani due to access problems through Mililani, it would like to lease 1,200+ acres of Galbraith Trust land now leased to Del Monte. This would consolidate Dole operations closer to its packing plant, allow it to fallow its lower quality fields, and free some acreage for use by WSCo.

EMPLOYMENT

Dole employs about 500 people: 320 in the fields, 150 at the packing plant, and 30 in the fresh-chilled pineapple operation at Iwilei.

ECONOMIC HEALTH

Without the Lanai plantation and the Oahu cannery, Dole anticipates profitable operations from selling fresh pineapple on the mainland. In addition, Dole is also developing a fresh-chilled market.

Impact of the Project on Dole

Since it would not be practical to farm pineapple fields once homes abut them and are downwind of them, the Project will probably result in Dole's fallowing its pineapple lands that will be sandwiched between the Project and Whitmore Village. This will result in approximately 60 acres of land being released for a possible C&C housing development. This is likely to occur around the year 2000 or even later.

Since the Whitmore Village baseyard will also be near homes in the Project, Dole may choose to take advantage of market opportunities and relocate its base-

yard to the Dole packing plant area on Kamehameha Highway, thereby freeing the existing baseyard site for a housing development or a neighborhood shopping center. The baseyard contains about 30,000 square feet of office space and a shop, and covers approximately 60 acres of land. Even though such a move would cost a few million dollars, the parent company would profit from developing the site. As before, this is likely to occur around the year 2000 or even later.

The Dole pineapple acreage which will be affected by the Project is sufficiently small that replacement lands could be found from Dole's existing inventory. Consequently, although Dole's pineapple production and employment would not be affected by the Project, the parent company would eventually profit by developing about 120 acres of Dole land.

If the Project causes the demise of Del Monte's Oahu plantation, Dole would benefit in two ways. First, it could lease about 1,200+ acres from the Galbraith Trust which are now being leased to Del Monte, thereby consolidating Dole's pineapple operations and adding good-quality fields near its packing plant. In turn, Dole could free land which could be farmed by WSCo—assuming WSCo survives beyond the year 2000.

Second, Dole would gain a marketing advantage if Del Monte were to close its Hawaii operations, since it could advertise itself as the only major supplier of premium fresh pineapple from Hawaii, while Del Monte's identification with Hawaii would be lost. It is not anticipated, however, that Dole would be able to make significant inroads into Del Monte's market, since Del Monte is likely to counter by underselling Dole with pineapple from Mexico or Guatemala. This pineapple would be of the same type and quality as that grown in Hawaii.

References

[1] Unless otherwise noted, the material in this section was obtained from Dole Food Company, Inc.
[2] Dole, Richard and Elizabeth Dole Porteus, *The Story of James Dole*, 1990.

THE SUGAR INDUSTRY

History of Sugar in Hawaii

The growing of sugarcane in Hawaii has a long and prominent history.[1] Following unsuccessful earlier attempts, the sugar industry took hold in 1833 on Kauai, and expanded in subsequent years to include all the major islands of the Kingdom of Hawaii. Rapid growth occurred during the California gold rush and the Civil War in the United States, then again following the negotiation of the Reciprocity Treaty between Hawaii and the United States in 1876, and then again after Hawaii became a U.S. Territory. Sugar was Hawaii's economic mainstay from the 1860s until World War II.

From 1930 to 1987, approximately 1 million tons of raw sugar were produced annually in Hawaii.[2] By 1991, production had fallen to 724,100 tons, a decline of 27%. As recently as 1968, 242,476 acres were cultivated in sugarcane. But by 1991, the sugar companies farmed 155,609 acres—a decrease of 86,867 acres, or 36%. Between 1960 and 1990, employment in the industry fell 62%, from 14,700 jobs to 5,600 jobs.[3,4]

Hawaii's Current Sugar Industry

Even though Hawaii's sugar industry has been declining since the late 1960s, it is still Hawaii's largest agricultural industry, and the State's dominate user of land and water. Sugarcane is still a major crop on Kauai, Oahu, Maui, and the Big Island, with about a dozen plantations growing the crop.

However, few plantations are profitable. Most barely cover operating costs or are losing money, including the two sugar plantations on Oahu. Furthermore, two plantations on the Big Island are closing: Hamakua Sugar Co., Inc. and C. Brewer's Mauna Kea Agribusiness Co., Inc. These closings will reduce sugarcane acreage by an additional 43,507 acres.

Outlook for Sugar Prices

The principal problem of Hawaii's sugar industry is that the price of sugar is too low to allow profitable operations for most plantations. But on the mainland,

many sugarbeet and sugarcane producers are profitable and, as a group, have been expanding production in recent years.[5] Profitability is possible because of improvements in yield and overall efficiencies, and lower shipping cost to major markets.

WORLD SUGAR MARKET

In the world market, the average price of sugar is expected to remain well below the production costs for all countries because most sugar is traded in controlled and/or subsidized markets, while surplus sugar is "dumped" onto the world market for sale at a loss. Dramatic price increases have followed a 6- to 9-year cycle, with prices increasing when world production falls short of consumption. However, a number of fundamental developments have taken place in sugar and in related industries in the past two decades which appear to have altered the pattern of sugar prices, thereby reducing peak prices and extending the periods of low prices. These changes include: the decline or stagnation of sugar consumption in some developed countries; market inroads made by the liquid sweetener high-fructose corn syrup (HFCS); the availability of substantial sugar reserves in the form of sugarcane now devoted to ethanol production; major gains in sugarbeet production in several European countries which were traditionally cane sugar importers; the appearance of the European Economic Community (EEC) as a major exporter of refined sugar; and, in the world market, major importers have shifted from being develop*ed* countries to being develop*ing* countries which have far less purchasing power and less ability to drive sugar prices to high levels during shortfalls.[6-9]

U.S. SUGAR LEGISLATION

In the United States, Federal legislation protects sugar from the low world prices by imposing import quotas, tariffs, and import fees. However, U.S. sugar prices are managed so that they remain fairly low in order to prevent an acceleration in the growth of competing sweeteners, and to maintain public support for the program. Under the U.S. Food Security Act, the target farm price for sugar is 18 cents per pound, with no adjustments for inflation.[6,8]

The competing sweetener of major concern has been HFCS. It is as sweet, or sweeter, than regular sugar, costs less to produce, sells for less, is more profitable, is very similar to liquid sugar, can be substituted readily in many applications, and is easier and cheaper to handle. It has experienced a rapid growth in sales at the expense of regular sugar sales. However, HFCS has captured nearly all of the liquid-sweetener market so that its continued growth will depend on the market acceptance of Crystar, the crystalline version of HFCS. In addition, the new low-calorie sweetener aspartame, sold under the brand name "Equal," is capturing market share and putting additional downward pressure on U.S. sugar prices.

Regarding the outlook for sugar legislation, it should be noted that, because of the advent of HFCS, many corn states (HFCS is produced from corn) joined the sugar and sweetener coalition, making this coalition larger and stronger than in the past.

TRADE AGREEMENTS

Negotiations are in progress on two international trade agreements which, if successful, threaten the U.S. sugar industry. These agreements include the General Agreement on Tariffs and Trade (GATT) and the North American Free Trade Agreement (NAFTA).

The long-term objective of these trade agreements, which have been supported by past administrations, is to expand trade and economic development by greatly reducing or eliminating trade barriers and export subsidies. These agreements may result in lower U.S. sugar prices by allowing increased imports of low-cost sugar. Also, they would be subject to an accept-or-reject decision by the U.S. Senate without opportunity for modification, and they would supersede U.S. sugar legislation.

NEW SWEETENERS

Regarding the longer-term outlook for sugar prices, the major concern is that a number of new sweeteners are being introduced for which the target market is that portion of the sweetener market still being held by cane and beet sugar. New sweet-

eners include Crystar (crystalline HFCS), high-temperature aspartame, super aspartame, sunette, sucralose, alitame, talin, and stevioside.[6,8] Some of the sweeteners have recently won approval for human consumption in the United States, and others are in the process of obtaining approvals. If at least one of these new sweeteners achieves significant market success, then the downward pressure on sugar prices will increase.

References

[1] Plasch, Bruce S., *Hawaii's Sugar Industry: Problems, Outlook and Urban Growth Issues,"* Department of Planning and Economic Development, April 1981.

[2] Hawaiian Sugar Planters' Association. Hawaiian Sugar Manual 1991. Honolulu, Hawaii. 1991.

[3] Department of Labor and Industrial Relations. Employment Records.

[4] Department of Business, Economic Development & Tourism. *The State of Hawaii Data Book: 1991.* Honolulu, Hawaii. November 1991.

[5] United States Department of Agriculture. *Agriculture Outlook '92: New Opportunities for Agriculture.* Washington, D.C. December 3-5, 1991

[6] Decision Analysts Hawaii, Inc. *Hawaii's Sugar Industry and Sugarcane Lands: Outlook Issues, and Options.* Honolulu, Hawaii. April 1989.

[7] James G. Brown. *The International Sugar Industry, Developments and Prospects.* World Bank Staff Commodity Working Papers, Number 18. The World Bank, Washington, D.C. March 1987.

[8] U.S. Department of Agriculture, Economic Research Service. *Sugar and Sweetener, Situation and Outlook.* Washington, D.C. Semi-annual.

[9] U.S. Department of Agriculture, Economic Research Service. *World Sugar Situation and Outlook.* Washington, D.C. Semi-annual.

OAHU SUGAR COMPANY, LTD.

Background Information[1]

HISTORY

OSCo, a subsidiary of Amfac/JMB Hawaii (Amfac), first milled sugar in 1899.[2] In 1970, the plantation took over the lands of Ewa Plantation to compensate for acreage lost above Pearl Harbor.

PRODUCTION AND REVENUES

OSCo is now the third largest sugar producer in the State. In 1991, it produced 68,265 tons of raw sugar (about 8% of the State's total 1991 sugar production) and 22,207 tons of molasses. In addition, it produced 70.7 million kWh of electrical energy, and sold 27.4 million kWh to Hawaiian Electric Co., Inc. Revenues exceeded $20 million.

LAND AREA

In 1991 and 1992, OSCo cultivated about 10,800 acres of sugarcane lands which covered portions of Central Oahu on each side of Kunia Road above Pearl Harbor, lands on Waipio Peninsula, and portions of the Ewa Plain to the west of Pearl Harbor.

In the early 1980s, about 7,500 additional acres were in production. Most of these lands—about 4,200 acres—were fallowed voluntarily because they are (1) mauka lands which incurred high pumping costs; or (2) lands close to the ocean where soils tend to be inferior, yields low, and hauling costs high due to their distance from the mill. A few hundred acres close to the ocean have since been urbanized. In addition to OSCo's voluntary fallowing of land, about 3,300 acres of its sugarcane lands have been withdrawn by landowners and developers for homes and other urban uses.

LAND OWNERSHIP

OSCo leases all of the land it cultivates. Until recently, the principal landowners were Campbell Estate whose lease to OSCo expires in mid-1995, Robinson Estate

whose lease to OSCo expires at the end of 1996, and the U.S. Navy whose lease to OSCo expires in mid-1995. The Campbell Estate lands included most of the Ewa Plain and Central Oahu lands above the H-1 Freeway and west of Kunia Road. The Robinson Estate lands are in Central Oahu above the H-1 Freeway and between Kunia Road and Waikele Stream. Navy lands include Waipio Peninsula and most of the eastern portion of the Ewa Plain.

To a major extent, the control of OSCo lands recently has passed—or is in the process of being passed—from the two major estates to developers, including about 3,300 acres of Campbell Estate land and over 1,500 acres of Robinson Estate land. The new landowners include about a half-dozen private companies, plus the State of Hawaii and the City & County of Honolulu. In addition, the State of Hawaii recently acquired from Campbell Estate an additional 1,100 acres in the central portion of the Ewa Plain, with the intention of "banking" the land for eventual housing developments. Because of this purchase, the State will also play a role in determining the future of OSCo.

WATER USAGE

OSCo's 1992 groundwater allocation from the State allows it to pump about 61 million gallons per day (mgd) of potable and brackish water from the basal lens, although actual usage has been somewhat lower than the amount allocated. In addition, OSCo diverts surface water from the Windward side via Waiahole Ditch; the 1991 diversion averaged 27 mgd. Average per-acre usage by OSCo exceeds 8,000 gallons per day (gpd). In comparison, domestic water provided by the Honolulu Board of Water Supply for Oahu averaged 155.8 mgd in 1991,[3] and per-acre usage for single-family homes (at 7 units per acre) averages about 3,500 gallons per day.

EMPLOYMENT

In 1992, about 350 people worked at OSCo including field, mill, and management employees. This level of employment reflects a significant and continuing decline in OSCo's labor force: there were 804 employees in early 1981, about 600 in early 1986, and 427 in early 1990. The reduction in employment has been accomplished by attrition—that is, employees who retire or leave their jobs voluntarily are generally not replaced.

The indirect employment dependent upon OSCo is estimated at an additional 400 jobs, based on a multiplier of 1.13 indirect jobs for each direct job.[4]

YIELDS

Because of favorable growing conditions, good farming practices, and drip irrigation, sugar yields at OSCo are comparatively high: 13.53 tons per acre in 1991, versus a Statewide average of 10.69 tons per acre in 1991.[5] In fact, OSCo holds the world-record sugar yield at 21.63 tons per acre set in April 1985.[6] The 1990 average yield for OSCo was about 20% higher than the 1979 yield of 11.3 tons per acre.

PROFITABILITY

Even though OSCo enjoys good agronomic conditions over most of the plantation, relatively high yields, and increasingly efficient operations, the plantation only manages to be marginally profitable in good years. This measure of profitability does not take into account new capital investment that may be required to replace equipment.

CAPITAL IMPROVEMENTS

Because of the uncertainty regarding the future of OSCo (see below), investment in capital improvements is at a low level.

Factors Affecting the Future of OSCo

The future of OSCo is uncertain. Its survival will depend upon Federal price supports for sugar that are sufficiently high to justify continued operations, and on OSCo's success in negotiating favorable lease terms for the major leases discussed above. Also of significance is the loss of sugarcane land to urbanization and OSCo's success in downsizing the plantation to accommodate this loss.

OUTLOOK FOR SUGAR PRICES

The survival of OSCo will depend greatly on the price of sugar in the United States—a price which is currently too low to allow profitable operations for most sugar plantations in Hawaii. The target farm price for sugar under the U.S. Food Security Act is 18 cents per pound, with no adjustments for inflation. Therefore, in order to survive, OSCo must continually increase yields and reduce production costs—a task which is made increasingly difficult with a shrinking plantation and a loss of economies of scale.

Over the long-term, there is a serious risk that prices will decline because newly negotiated international trade agreements may allow low-cost sugar to enter the U.S. market, and/or because there may be new competition from new sweeteners (see pages 32-33). Even a small decrease in U.S. sugar prices would probably cause OSCo to close, along with other sugar plantations in Hawaii.

RENEGOTIATION OF LAND LEASES

As indicated above, the continued survival of OSCo will also depend upon the renegotiation of its land leases with Campbell Estate, Robinson Estate, the State of Hawaii, and the U.S. Navy—all of these leases are scheduled to expire in 1995 or 1996.

It is not certain that all of the major leases will be renegotiated. From the perspective of OSCo's parent company, it must be convinced that remaining in sugar will be profitable, although profits can be structured so as to derive from participation in non-sugar-related activities such as land development.

The major landowners plan to keep most of their lands in agriculture, largely because the supply of land is so large and alternatives are lacking. The benefits of agriculture include greenery, care and management of the land, maintenance of water systems, avoidance of property taxes, etc. Sugarcane is generally regarded as the only realistic crop for such a large expanse of land, at least for the short term.

It is not clear, however, whether *all* landowners plan to commit their lands to sugarcane, and whether new leases will include *all* existing sugarcane land. Also uncertainty exists regarding lease rents, the duration of any new leases, withdrawal rights, lease termination clauses, and other lease terms and conditions. Another agricultural company or developer could outbid OSCo for a major portion of the lands now farmed by OSCo. Also, major landowners may be unwilling to commit their lands to continued sugar operations over an extended period if this commitment poses a threat to their plans, or limits their flexibility to take advantage of new and more profitable opportunities.

The uncertainty regarding renegotiation of its leases has affected OSCo's long-term investment in the plantation.

URBANIZATION PRESSURES ON OSCO

OSCo's success in downsizing the plantation to accommodate the loss of lands to urbanization will be important. The agricultural quality of the lands which remain, and the form of the plantation will also play a significant part in OSCo's survival. The preferred contraction of the plantation is from the periphery inward because this would result in a compact plantation and would retain high-quality lands: a more compact plantation reduces trucking and other costs, while higher-quality lands contribute to higher yields.

The gradual growth westward of urban Honolulu has consumed a large amount of former sugarcane land, as evidenced by the fact that the eastern boundary of OSCo lands has been moved westward by 9 miles from Moanalua Valley to the area beyond Waikele Stream. Since the 1960s, four ridges west of Halawa have been urbanized. Even with this level of urbanization, sufficient acreage was cultivated by OSCo to maintain economies of scale because of increasing yields and new plantings in the foothills of the Waianae mountains on former pasture lands. The westward expansion of Honolulu continues to put pressure on OSCo lands; however, it is no longer feasible to plant new lands to compensate for lost fields, while replanting fallow fields in the foothills of the Waianae mountains is limited by high pumping costs.

The economic forces which create urbanization pressures on OSCo are very strong:

—Financial returns from urban land far exceed those from agriculture.
— OSCo fields are near the new or growing employment centers of Ko Olina Resort, Barbers Point Harbor, Campbell Industrial Park, the City of Kapolei, and downtown Honolulu.
—Because of OSCo's proximity to the H-1 Freeway, its lands are within reasonable travel distance of these new and growing employment centers.
—Water supplies would become available for other uses if it were freed from sugar production.
—OSCo lands are near the Honouliuli waste-treatment facility.
—Construction costs are low on former sugarcane lands in comparison to areas that require extensive grading or removal of existing structures.

In contrast, the redevelopment of downtown Honolulu suffers from the high expense and displacement problems required to remove existing structures, the cost and inconvenience of redeveloping inadequate infrastructure, less desirable high-rise housing compared to single-family homes, and occasional strong community opposition. Further development of Hawaii Kai and Windward Oahu suffers from: a lack of major employment growth centers, the relatively small amount of land available for additional single-family housing, commuter traffic problems, and community opposition to more development.

In view of these factors, the City & County of Honolulu has designated the Ewa area as a "Secondary Urban Center" which will be developed to accommodate a major portion of Honolulu's future growth. This policy carries with it the implication that sugarcane lands in the Ewa area will be urbanized.

Developments approved and proposed for the Ewa/Central-Oahu area which would affect OSCo acreage are shown in Table 2. When the 800 acres of replacement lands for Del Monte are added to this list, and the fallowed acreage in the foothills are added to the OSCo acreage, the size of the plantation could be reduced by over 3,600 acres. In this listing of major developments, it should be noted that some projects lack development approvals. Also, lands for some projects are to be withdrawn gradually from sugar production as they are needed for development, while

Table 2. PLANNED AND PROPOSED DEVELOPMENTS AFFECTING OSCO ACREAGE: 1992

Project	Sugarcane Acreage
Replacement Lands for Del Monte	800
City of Kapolei, Campbell Estate (partially approved)	416
Ewa Gentry (partially approved)	250
Ewa Marina, Phase I (partially approved)	410
Ewa Marina, Phase II (partially approved)	389
Ewa Villages	320
Kapolei Business-Industrial Park	145
Ko Olina Resort (approved)	281
Kunia Golf Course	190
Laulani/Fairways	301
Royal Kunia, Phase II	640
Eventual Remnant Property	94
Subtotal	4,236
Less Replanting of Fallow Fields	-586
Total	3,650

Source: Land use applications and discussions with Oahu Sugar Co., Ltd.

lands for other projects may be withdrawn during a single harvesting cycle. On the other hand, the listing is probably incomplete; other projects will surely be proposed.

Assuming that all of the projects listed in Table 2 are developed, and about 800 acres are made available to Del Monte, then the land area available to OSCo would eventually be reduced to about 7,150 acres (10,800 - 3,650). If OSCo survives over the next 20 or so years, then it will be one of the smallest plantations in Hawaii.

Recent OSCo Plans

As recently as early 1992, OSCo had planned—in response to its loss of acreage to urbanization—to reduce processing capacity by operating a single mill rather than the current two mills in parallel. It was determined that approximately 8,200 acres would remain after land was removed for urbanization, and that a single mill would be sufficient to process a projected 48,000 to 50,000 tons of raw sugar per year, compared to OSCo's historic level of 90,000 to 95,000 tons per year.

At its reduced size, the core of the plantation was to include:

—the central portion of the Ewa Plain (including land which the State has acquired from Campbell Estate as a "land bank" for future housing);

—Navy lands on the Ewa Plain which are within the blast zone for West Loch;

—Navy lands on the Waipio Peninsula which are within the blast zone for West Loch;

—Kunia lands owned by Robinson Estate which are to the east of Kunia Road and north of the high-voltage transmission lines in the area; and

—Kunia lands owned by Campbell Estate which lie to the west of Kunia Road.

In addition, OSCo had planned to replant 586 acres which it had fallowed in the early 1980s; this Kunia land is owned by Campbell Estate and located in the Waianae foothills. Also, OSCo had planned to continue farming other sugarcane lands scheduled for development until such time as they were withdrawn for development, or until the affected fields became uneconomical to farm because of their small size, isolation, or close proximity to homes.

The conversion from the existing two-mill operation to a single mill would have required new investment in the plantation but, given the lower production levels resulting from decreased acreage, the average cost per ton of sugar was expected to be lower with one mill running at full capacity than would be the case with two mills running below capacity. The single mill, however, was expected to result in a marginally higher cost of production when compared to the average cost per ton under the two-mill operation running at full capacity.

The planned single-mill, 8,200-acre plantation is no longer regarded as economically feasible. Nor does OSCo have a long-term plan for the plantation. The problem is the uncertainty over what will be required to achieve profitability in view of low U.S. sugar prices, uncertainty over future sugar prices, how much land will be made available to OSCo, which lands will be made available, lease rents, the duration of the leases, withdrawal rights, termination clauses, etc. Also, tests with a single mill have revealed that a two-mill operation with a short grinding season is more economical than a single-mill operation. With the single mill, insufficient bagasse was produced to fuel the boiler, thus requiring that OSCo purchase expensive oil to supplement the bagasse.

Outlook for OSCo

It is the considered opinion that most (but possibly not all) major landowners will discount rents and provide other concessions to entice OSCo to stay in operation over an initial short-term period lasting at least to the late 1990s. As indicated above, growing sugarcane on such a large amount of land is generally perceived as providing greater benefits than other land-use alternatives.

However, the greater OSCo's anticipated difficulties, the greater the concessions will have to be to entice OSCo to renew its leases and remain in operation.

Over the longer term, the survival of OSCo becomes increasingly uncertain, largely because sugar prices may be too low to allow profitable operations in Hawaii. Furthermore, OSCo will suffer a loss of economies of scale because it will be losing land to urbanization.

Impact of the Project on OSCo

Assuming that OSCo survives beyond the year 2000, then the impact of the Project on OSCo will depend on whether or not sugarcane lands are made available to Del Monte to replace acreage lost to the Project, and whether or not Del Monte is forced to close its Oahu plantation.

IMPACT IF OSCO LOSES LANDS TO DEL MONTE

Direct Impacts

If about 800 acres of land now farmed by OSCo are leased instead to Del Monte to replace the pineapple lands lost to the Project, then the impact of the Project will fall on OSCo rather than on Del Monte—assuming that OSCo survives beyond the year 2000. Under these assumptions, the impact on OSCo would be a loss in production of about 6,800 tons of raw sugar per year, or about 10% of the 1991 production of 68,265 tons. This is based on a yield of 17 tons per acre and a 2-year crop. The associated loss in molasses output would be 2,240 tons, based on a molasses yield equal to 33% of the sugar yield. Based on the 1991 ratio of energy generation to sugar, the loss in energy production would be 7 million kWh of electricity.

The loss in gross export revenues (but not profits) would be about $2.6 million per year, based on a combined sugar/molasses return of $380 per ton of sugar. The impacts on profits would be much less than the loss in export revenues since the cost of farming the land and processing the cane would be eliminated.

Water requirements for sugar would decline by about 6.4 mgd, based on a requirement of 8,000 gallons per day (gpd) per acre of sugar. However, this savings would be partially offset by the water required for growing pineapple in Kunia and by the Project.

Approximately 14 field jobs and 12 factory jobs are associated with 800 acres of cane land, assuming the 1992 ratio of labor to land. However, in practice, the number of jobs lost will be lower since specialized mill and field employees must be retained. Also, any reduction in employment is likely to occur through attrition.

With regard to how the form of the plantation will be affected, the loss of upper Kunia lands would *not* conform to OSCo's preferred sequence for contracting the plantation, which is from the periphery of the plantation inward. Lands in upper Kunia are a short trucking distance from the mill, soils are superior to those of most other fields, and yields are higher than average.

Cumulative Impact

If the price of sugar remains sufficiently high to justify continued sugar operations in Hawaii, and if major leases are renegotiated, then the gradual and cumulative loss of sugarcane acreage to urbanization, and the corresponding loss of OSCo's economies of scale, becomes a issue affecting the long-term survival of OSCo.

Assuming, as discussed above, that most or all planned and proposed projects are approved and fully developed within 20 years, and OSCo is able to survive for this long, then the amount of land under cultivation by OSCo would decline from 10,800 acres in 1992 to about 7,150 acres, more or less, in 2010.

At this reduced size, the survival of OSCo is uncertain since profitability will depend heavily upon the price of sugar, lease rents, and future improvements in yields and operating efficiencies. However, if it loses 800 acres to Del Monte this would contribute to OSCo's difficulties.

The impact of the loss of 800 acres of sugarcane land may fall more heavily on the major landowners than on OSCo. As discussed above, the more difficulties OSCo anticipates, the more concessions OSCo will have to receive in order to be to enticed to renegotiate its leases and remain in operation.

If OSCo were to close, then the loss of direct and indirect employment supported by the plantation would be about 750 jobs. However, this figure will decline over time as the plantation becomes smaller. There would also be a significant loss of greenery in Ewa and Central Oahu.

IMPACT IF DEL MONTE CLOSES

If Del Monte is forced to close because it is unable to secure land to replace land lost to the proposed Project, then OSCo would probably benefit—provided that OSCo survives beyond the year 2000. Depending on water availability and pumping costs, OSCo would be able to cultivate sugarcane on upper Kunia lands now farmed by Del Monte. Although water from Waiahole Ditch could be used to irrigate these fields, water from this source is already being used on high-elevation OSCo land. It is estimated that pumping costs would limit a pineapple-to-sugarcane land-use shift to about 2,000 acres.[7]

Additional upper Kunia sugarcane lands would partially compensate for the loss of acreage to housing projects.

References

[1] Unless otherwise noted, the material in this section was obtained from Oahu Sugar Co., Ltd.

[2] Plasch, Bruce S. *Hawaii's Sugar Industry: Problems, Outlook and Urban Growth Issues.* Department of Planning and Economic Development. Honolulu, Hawaii. April 1981.

[3] Honolulu Board of Water Supply.

[4] Decision Analysts Hawaii, Inc. *Hawaii's Sugar Industry and Sugarcane Lands: Outlook Issues, and Options.* Honolulu, Hawaii. April 1989.

[5] Hawaiian Sugar Planters' Association. *Hawaiian Sugar Manual, 1992.* Honolulu, Hawaii.

[6] Hawaiian Sugar Planters' Association. "Hawaii Sugar News." June 26, 1985.

[7] Oahu Sugar Co., Inc.

WAIALUA SUGAR CO., INC.

Background Information[1]

HISTORY

Waialua Sugar Co., Inc. (WSCo), a subsidiary of Dole Food Co., Inc. (Dole) first milled sugar in 1883; the current "new" mill has been in operation since 1896.[2]

PRODUCTION, YIELD AND REVENUES

In 1991, WSCo produced about 57,505 tons of raw sugar which, along with molasses and other sales, generated about $24 million in revenues. The average yield from the plantation was 10.6 tons per acre, which was slightly lower than the Statewide average of 10.69 tons in 1991.[3]

LAND AREA AND OWNERSHIP

WSCo cultivated 12,054 acres of sugarcane land in 1991.[3] The fields are located on the north shore of Oahu between Waimea Bay and Dillingham Air Force Base, and extend inland into the northern part of Central Oahu.

The majority of the lands farmed by WSCo is owned by its parent company Dole. However, about 5,600 acres are leased from Bishop Estate with an expiration date of December 31, 2000.

WATER

WSCo, one of the major water users on Oahu, diverts in normal-rainfall years about 40 million gallons per day (mgd) from mountain systems, and pumps about 40 mgd. However, both surface and groundwater requirements vary greatly over time, depending on changing climatic conditions.

EMPLOYMENT

Field, mill, and management employment at WSCo is approximately 440 jobs. Indirect employment dependent upon WSCo is estimated to be 500 jobs.[4]

ECONOMIC HEALTH

Even with efficient operations, WSCo is only marginally profitable in good years—the principal problem being low sugar prices.

Impact of the Project on WSCo

If WSCo survives beyond the year 2000, and if the Project causes Del Monte to close its Oahu plantation because of an inability to secure replacement lands, then the Project could benefit WSCo indirectly. The closure of Del Monte would free about 1,200 acres of Galbraith Trust lands for possible use by Dole. In turn, Dole could free some of its pineapple land for use by WSCo. More acreage would allow WSCo to benefit through greater economies of scale.

A similar result could occur if OSCo were to close, either because of low sugar prices and/or a loss of land to other uses, possibly including a loss of land to Del Monte. The closure of OSCo would free up land in upper Kunia, which could allow Del Monte to move off the Galbraith Trust lands and farm more land in Kunia. In turn, Dole could farm the Galbraith Trust lands, and free land for use by WSCo. Without OSCo, WSCo would have to absorb the full cost of the sugar terminal at Honolulu Harbor. However, labor savings would be possible by shifting workers between the harbor and the Aiea refinery, depending on deliveries from WSCo. Overall, WSCo would gain because it would have more acreage.

If WSCo were to close because of financial problems, then Del Monte could benefit. In this case, needed replacement lands could be made available to Del Monte from Dole's land inventory, which includes both pineapple and sugarcane lands. However, in order for this to be of help to Del Monte, the lands would have to be available by 1999 (see page 20). Also, Dole would have to be willing to provide land to a its main competitor.

References

[1] Unless otherwise noted, the material in this section is from Waialua Sugar Co., Inc.

[2] Decision Analysts Hawaii, Inc. *Hawaii's Sugar Industry and Sugarcane Lands: Outlook, Issues and Options. Honolulu, Hawaii.* April 1989.

[3] Hawaiian Sugar Planters' Association. *Hawaiian Sugar Manual 1992.*

[4] Based on employment multipliers from the State Department of Business, Economic Development & Tourism.

DIVERSIFIED AGRICULTURE

The development of the Project will constitute a commitment to a non-agricultural use of over 800 acres of agricultural land that is suitable for growing a limited number of crops. This commitment of agricultural land raises the question of whether the Project will affect adversely the growth of diversified agriculture—either immediately or over the long term. To address this issue, the impact on existing diversified-agriculture activities, the availability of land for diversified agriculture, potential diversified-agriculture crops, the land requirements for diversified agriculture, and the supply of land for diversified agriculture are discussed below.

Impact on Existing Diversified-Agriculture Activities and the Availability of Land for Diversified Agriculture

Since all of the Project area is planted in pineapple, the proposed development will not directly affect any existing diversified-agriculture activity, nor will it affect the amount of land available for diversified agriculture

Potential Diversified-Agriculture Crops

Given the climatic conditions, the soil types, and other agronomical conditions of Poamoho, *crops suited for the area* include: avocados, Chinese bananas, snap beans, bittermelon, sweet corn, cucumbers, daikon, long eggplant, round eggplant, semi-head lettuce, limes, mustard cabbage, dry onions, green onions, Chinese peas, sweet peppers, potatoes, sweet potatoes, pumpkins, radishes, Italian squash, oriental squash, tomatoes, watermelon, seed crops, forage crops, flowers, and potted foliage.

However, most of the crops which are agronomically suited for the site would be unprofitable given the high cost of water prevailing in the area, and low winter yields due to cloudy conditions and low temperatures. These problems are reflected in a low "c" rating by the LSB (see page 4). Also, most of the demand for these crops is already supplied by growers elsewhere in the State. And for many of these crops, production is declining on Oahu, often as a result of a shift to the Neighbor Islands where land and labor is generally less expensive.[1]

Land Requirements for Diversified Agriculture

Based on projections made by the State Department of Agriculture (DOA) in 1991, additional land requirements to accommodate the growth of diversified agriculture to the year 2010 will amount to approximately 42,000 acres.[2] Over 80% of this new acreage will be required for macadamia nut and coffee orchards, with about 7,000 acres required to accommodate the growth of the other diversified-agriculture crops.

Supply of Prime Agricultural Land

With regard to the supply of land in the State as a whole, an enormous and growing supply of prime agricultural land is available for alternative uses. Since 1968, about 120,000 acres of Hawaii's prime agricultural land have been freed from sugar and pineapple production: nearly 90,000 acres have been freed from sugar production and over 35,000 acres from pineapple production.[1,3,4] In addition, two sugar plantations on the Big Island are closing. By 1996, the total release of land from plantation agriculture will be about 170,000 acres. For comparison, the two sugar plus the two pineapple plantations on Oahu farmed about 35,000 acres in 1992.[5]

Some of the land which has been freed from sugar and pineapple production has been or is scheduled to be converted to urban, diversified-agriculture, and other uses. After making allowances for these conversions, uncommitted acreage which remains available to diversified agriculture amounts to about 130,000 acres.[6] Much of this land is or will soon be fallow, in pasture, or in some other low-value land-holding operation.

The Statewide supply of prime agricultural land that is fallow may increase given the real possibility of future sugar plantation closings. Some of Hawaii's sugar plantations are unprofitable but remain in operation today only because they are committed to lease and/or energy contracts which make closing prohibitively expensive. However, these contracts will eventually come to an end.

Furthermore, a portion of the sugarcane land is in holding awaiting the discovery of profitable replacement activities. This land forms part of the supply of

prime agricultural land available to profitable diversified-agriculture crops. Moreover, the greater the success of large-scale diversified agriculture, the greater the amount of land which will be released for diversified agriculture. Recent examples of sugarcane land being released for other crops include: macadamia nut orchards on land released from Mauna Kea Agribusiness Co., Inc.; macadamia nut and citrus orchards on land released from Ka'u Agribusiness Co., Inc.; macadamia nut orchards and pineapple operations on land released from Wailuku Agribusiness Co., Inc.; coffee orchards on land released by McBryde; seed corn and nursery operations on land released from HC&S; and seed corn operations on land released from Kekaha Sugar Co., Ltd.

Many of the lands freed, to be freed, or which can be freed from sugar and pineapple production have excellent agricultural qualities and climatic conditions, and are well-suited for a variety of crops. Also, water is available for most of these lands, particularly those lands which have been freed from sugar production.

Additional lands which have been made available for diversified agriculture are in government-sponsored agricultural parks throughout the State. Lands for agricultural activities which do not require prime agricultural land include pasture land, land for livestock operations, and "unique" lands as classified by ALISH (see page 4). Unique lands are not prime agricultural lands, but are important lands for certain crops, the principal examples are the coffee lands in Kona, and certain lava lands in Puna which are particularly well-suited for growing papaya. The supply of unique lands is quite large and is distinct from the supply of prime agricultural lands.

Outlook for Diversified Agriculture

Based on the above assessment, ample prime agricultural land will be available to easily accommodate the Statewide requirements of diversified agriculture. This conclusion derives from the following: (1) a vast amount of prime agricultural land and water is available Statewide, having been freed from sugar and pineapple production in recent years; (2) it is very possible that additional sugarcane acreage and water will be freed, given the existence of unprofitable sugar operations; (3) some, if not most, of the sugar operations would make their lands available for profitable replacement crops to the extent that such crops exist; and, in contrast, (4) land requirements for diversified agriculture are surprisingly modest. In other words, the *limiting factor is not the land supply, but rather the market demand for those crops that can be grown profitably in Hawaii.*

The proposed Galbraith Estate project involves far too little land to affect this conclusion, and will therefore not affect adversely the Statewide growth of diversified agriculture.

References

[1] Hawaii Agricultural Statistics Service. *Statistics of Hawaiian Agriculture 1990*. Honolulu, Hawaii. October 1991.

[2] State Department of Agriculture, unpublished projections, February 28, 1991.

[3] Hawaiian Sugar Planters' Association. *Hawaiian Sugar Manual, 1990*. Honolulu, Hawaii. 1991.

[4] Robert C. Schmitt. *Historical Statistics of Hawaii*. The University Press of Hawaii, Honolulu, Hawaii. 1977.

[5] Hawaii Agricultural Statistics Service. *Statistics of Hawaiian Agriculture 1990*. Honolulu, Hawaii. October 1991.

[6] Estimated by Decision Analysts Hawaii, Inc.

ORGANIZATIONS CONTACTED

Amfac/JMB Hawaii
Del Monte Fresh Produce (Hawaii), Inc.
Department of Agriculture, State of Hawaii
Dole Food Co., Inc.
George Galbraith Trust
Hawaiian Trust Co., Ltd.
Helber, Hastert & Fee Planners
JLP Robinson Limited Partnership, Mark A. Robinson Trusts
Maui Land & Pineapple Co.
Oahu Sugar Co., Ltd.
Office of State Planning, State of Hawaii
The Estate of James Campbell
Waialua Sugar Co., Inc.
Wailuku Agribusiness Co., Inc.
Water Commission, State of Hawaii

Del Monte Fresh Produce (Hawaii) Inc.

Daniel R. Wilson
Vice President
General Manager

April 6, 1993

Mr. Robin Foster
Chief of Planning
Planning Department
City and County of Honolulu
650 S. King Street
Honolulu, Hawaii 96813

Dear Mr. Foster:

Local newspaper accounts of the proposed development of Galbraith Estate lands by Hawaiian Trust have indicated severe impacts on the Del Monte pineapple operation. I am writing this letter to be certain that your department clearly understands that these accounts have significantly overstated probable impacts. Del Monte believes that the commitments and agreements we have made with Hawaiian Trust relating to the Galbraith lands Master Plan will allow us to remain a major force in the Hawaii pineapple industry. The proposed development will remove approximately 900 acres of land from agriculture , currently used for the cultivation of pineapple, and convert it to predominately affordable housing. However, positive steps are being taken by Hawaiian Trust and Del Monte to mitigate any impact.

From the initiation of the development proposal, Del Monte's position has been very clear. The land is owned by the Galbraith Trust, not by Del Monte and, therefore, Del Monte is not in a position and would not take a position of dictating to the land owner what should occur with the land. Our lease with the Galbraith Estate expires at the end of 1994. We fully intend to renew the lease on the balance of the land not under development and, therefore, would not want to oppose the development of the land. That issue clearly is between Hawaiian Trust, the Galbraith heirs and the City and County of Honolulu.

The Hawaiian Trust group handling the development, led by Mike Angotti, has been very helpful in assisting Del Monte to find replacement land, and in working with Del Monte for a smooth and orderly transition from the development lands. Because of Hawaiian

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Trust's close coordination with Del Monte, we have been able to adjust our planting schedules and are not required to have replacement lands until 1999. As discussed in the EIS Report, we will require 400 acres of replacement land in 1999, and in 2001, 400 additional acres. It is necessary for us to obtain replacement land, but not necessarily in the short term. We have discussed additional land with two land owners, Robinson Trust and Campbell Estate, to identify potential replacement lands and both are interested in working with us.

To date, we have identified 400 acres of replacement land currently not in cultivation that could be used to replace the 1999 land requirement. Additional replacement land has been identified and may be available sooner, depending upon the continuation of Oahu Sugar at its current land use level.

We feel that with proper and close communication, agriculture and development can co-exist. Del Monte believes it has a solid future in pineapple from Hawaii as a supplier of premium, fresh pineapple to mainland markets. We are currently negotiating renewals of our leases with all land owners that will extend our leases through the expiration of the various Trusts, about 2007. I hope that this letter clarifies Del Monte's position regarding the impact of the development of the Galbraith lands.

Sincerely,

Daniel R. Wilson
Vice President & General Manager

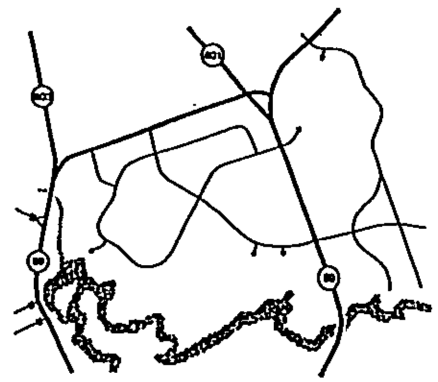
DRW:djn

C&C/HawnTrust

APPENDIX K

Traffic Study
Wilbur Smith Associates

WAHIAWA
GALBRAITH TRUST LANDS
TRAFFIC STUDY



Prepared for

HELBERT, HASTERT & FEE

Prepared by

Wilbur Smith Associates

December 22, 1992

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1. INTRODUCTION

The Galbraith Trust Lands are located on Kamehameha Highway just north of Wahiawa town. The site, shown in Figure 1, consists of about 890 acres. The land is controlled by the Hawaiian Trust Company, which has a fiduciary responsibility to the beneficiaries to pursue the highest and best use of the land. An advisory committee, the Wahiawa Lands Community Advisory Committee, has been established to aid in the development of a land use concept for the land. Several alternative development concepts have been explored for the land including a Military Family Housing Concept, Sports Center Concept, University Concept, and Affordable Housing Concept. Each concept includes an open space preserve, continued agricultural use, and a town center/civic center.

The development concept as analyzed in this analysis, would consist of about 3,100 dwelling units -- 1,500 single-family and 1,600 multi-family and medium density units, a 38 acre business center, 33 acres of commercial/industrial uses, an 18-hole golf course, and a variety of other uses including two elementary schools, about 100 acres of parks, neighborhood commercial facilities, and a park-and-ride lot. Full development of the Project area could occur by the year 2010.

The majority of the Project area is currently leased by Del Monte for pineapple production with portions of the Wahiawa Reservoir leased to the Waialua Sugar Company for irrigation purposes. Those leases will expire in 1994 and 1992 respectively.

This traffic report has been prepared by Wilbur Smith Associates (WSA), in coordination with Helbert Hastert & Fee. The report documents the traffic impacts associated with the proposed development of the Project lands. Transportation has been identified as a critical issue concerning the development potential of the Project lands.

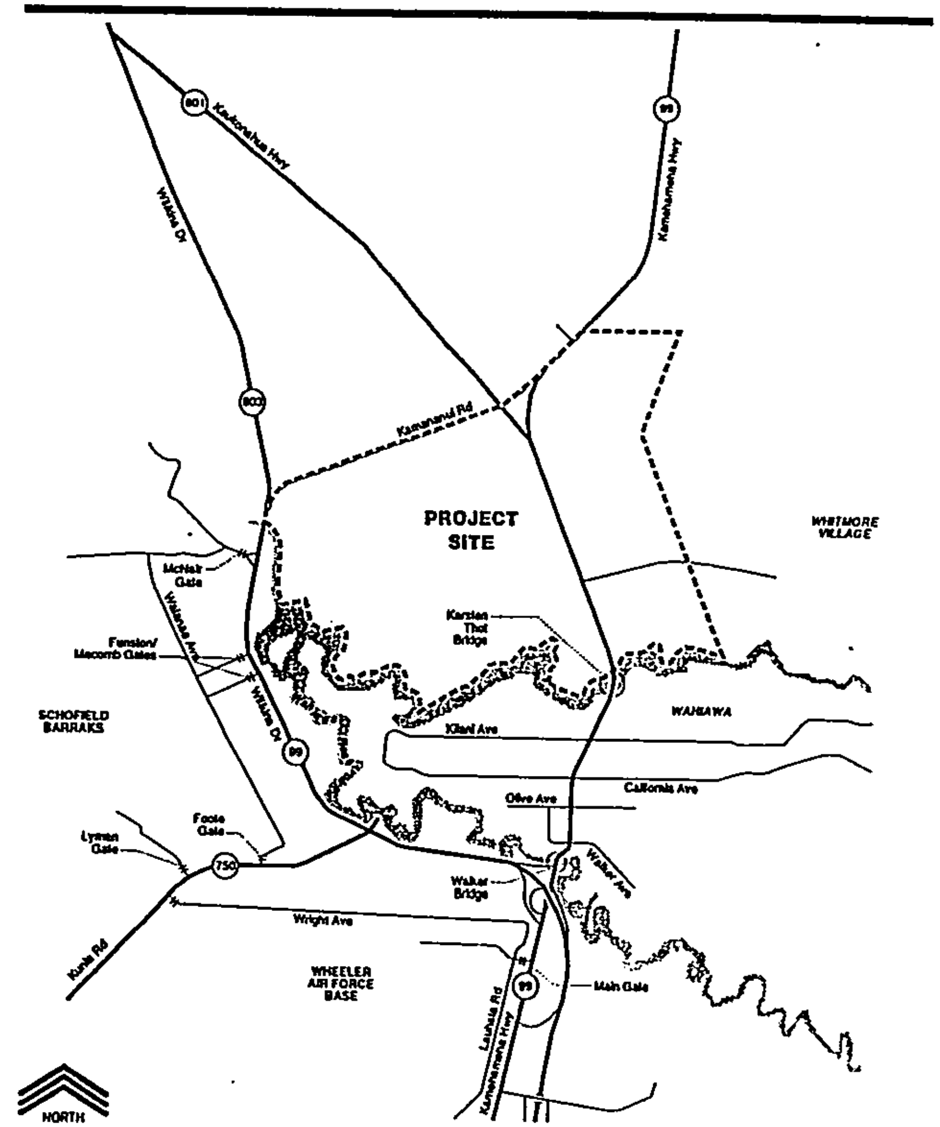

Figure 1
PROJECT SITE

WAHIAWA - GALBRAITH TRUST LANDS TRAFFIC STUDY

2. EXISTING CONDITIONS

The proposed development of the Galbraith Trust lands could potentially affect a number of transportation facilities including Kamehameha and Kaukonahua Highways, the H-2 Freeway, Wilikina Drive, Kunia and Kamananui Roads, and Whitmore Avenue. Each of these facilities is studied in this report.

Roadway System

The Galbraith Trust Lands are located just north of the town of Wahlawa. The major roadways that provide access to the lands include Kamehameha Highway, which crosses the lands; Kaukonahua Highway, which connects with Wilikina Drive and Kamehameha Highway; the H-2 Freeway, in combination with Kamehameha Highway or Wilikina Drive; and Kunia Road, which links with Wilikina Drive. In addition to these facilities, Kamananui Road and Whitmore Avenue also provide circulation within the area. Each of these roads is discussed below:

Kamehameha Highway - Kamehameha Highway provides a link between Oahu's North Shore and South Shore through Central Oahu. Currently Kamehameha Highway provides between two- and six-lanes of travel:

- between Mililani and Wahiawa it provides four-lanes;
- through Wahiawa it provides six-lanes in the peak periods but not all of the lanes are striped for use by through vehicles; and
- north of Kilani Avenue, in Wahiawa, it provides two-lanes.

The speed limit on Kamehameha Highway is 25 miles per hour (MPH) through Wahiawa and 45 MPH north of Whitmore Avenue.

Based on recent State counts, Kamehameha Highway carries an average daily traffic volume (ADT) of about 40,000 vehicles through Wahiawa and 13,200 north of Kamananui Road. In the area of the Project, Kamehameha Highway experiences relatively uncongested travel. Through Wahiawa, delays to vehicles can sometimes be lengthy, but this is primarily a result inefficient use of traffic lanes and lack of signal coordination.

Kaukonahua Highway - Kaukonahua Highway is two-lane rural highway travelling between Wahiawa and the North Shore. Based in recent State counts, it carries an ADT of about 1,500 between Kamananui Road and Wilikina Drive and 9,400 vehicles north of Wilikina Drive. Due to these low daily traffic volumes, the Highway experiences no congestion. The posted speed on the Kaukonahua Highway is 45 MPH in the area of the Project.

The H-2 Freeway - The H-2 Freeway provides a link between the South Shore, where it junctions with the H-1 Freeway, and Wahiawa. The H-2 Freeway terminates at Wahiawa with traffic continuing up Wilikina Drive to Kaukonahua Highway or travelling through Wahiawa on Kamehameha Highway. The freeway provides two travel lanes in each direction north of Meheula Parkway in Mililani, and three lanes in each direction south of Mililani. Based on recent State counts the H-2 Freeway carries an ADT of about 44,300 vehicles. The H-2 Freeway operates with little congestion in the area of the Project.

Wilikina Drive - Wilikina Drive originates at the junction of Kamehameha Highway and the H-2 Freeway, extends northeast to terminate at Kaukonahua Highway. Wilikina Drive provides access to Schofield Barracks and also provides an outlet for traffic using Kunia Road as an alternative to the H-2 Freeway. Between the H-2 Freeway and Macomb Gate to Schofield, Wilikina provides four-lanes of travel. North of the Macomb Gate, Wilikina provides two-lanes.

Wilikina Drive carries daily traffic of about 41,600 vehicles between the H-2 Freeway and Kunia Road, 26,600 between Kunia Road and the Macomb/Funston Gates to Schofield Barracks, 15,100 between the Macomb/Funston Gates and Kamananui Road, and 7,900 vehicles between Kamananui Road and Kaukonahua Highway.

Wilikina Drive has posted speed limits of 25 - 35 MPH and experiences relatively uncongested operations. Peaking characteristics on Wilikina Drive are affected by Schofield Barracks and Wheeler Air Force Base (AFB). During shift changes, traffic on Wilikina Drive can be slightly more congested.

Kunia Road - Kunia Road is a two-lane highway travelling between the Ewa/Waipahu area and Wahiawa. Between the Wright Avenue Gate to Wheeler AFB and Wilikina Drive, Kunia Road provides four-lanes of travel. It accommodates about 21,500 vehicles per day between the Foote Gate to Schofield and Wilikina Drive. As with Wilikina Drive, peaking characteristics on Kunia Road are affected by Schofield Barracks and Wheeler Air Force Base.

Kamananui Road - Kamananui Road is a two-lane rural highway with a posted speed limit of 45 MPH. It carries an estimated ADT of 7,500 vehicles. Kamananui Road operates at free flow speeds experiencing no congestion. Near Wilikina Drive a turn in the roadway, in combination with a change in elevation, result in reduced sight distances. This reduced sight distance could pose a safety concern at this location as traffic volumes along this segment increase.

Whitmore Avenue - Whitmore Avenue is a two-lane roadway which provides access from Kamehameha Highway to Whitmore Village and the Wahiawa Naval Radio Receiving Station. Whitmore Avenue does not provide through access to any other roads. The posted speed limit on Whitmore Avenue is 35 MPH and it carries an ADT of about 11,300 vehicles. No congestion was observed on Whitmore Avenue.

Methodologies Used for Traffic Operations Analysis

Before proceeding with the analysis of traffic operations, it is important to outline the methodology used in analyzing these operations. The Transportation Research Board (TRB), a division of the National Science Foundation, has developed standardized methods for use in evaluating the effectiveness and quality of service for roadways and streets. Different methodologies are available for analyzing freeways, highways, rural highways, unsignalized intersections, traffic signal controlled intersections, and freeway ramps.

The TRB evaluation methods use a concept known as level-of-service (LOS) to describe facility operations on a letter basis from A to F, which signify excellent to unacceptable conditions respectively. The methods generally compare travel demand (traffic volume) on a facility to the facility's theoretical capacity. Capacity is based on a facility's physical characteristics (e.g. number of lanes), traffic conditions (e.g. types of vehicles), and type of traffic controls. The comparison of travel demand to capacity is referred to as a volume-to-capacity (V/C) ratio.

Each of the methodologies discussed below is described in the *Highway Capacity Manual*[1].

Freeways and Multi-Lane Highways - The level-of-service criteria characteristics for freeway and multi-lane highways used in this analysis are shown in Table 1.

Table 1

LEVEL-OF-SERVICE CRITERIA FOR FREEWAYS AND MULTI-LANE HIGHWAYS
Wahlawa – Galbraith Lands Traffic Study

Level of Service	FREE-FLOW SPEED: 60 MPH – Average Speed (MPH)	60 MPH – Maximum V/C Ratio	60 MPH – Maximum Service Flow Rate (pchpl)	45 MPH – Average Speed (MPH)	45 MPH – Maximum V/C Ratio	45 MPH – Maximum Service Flow Rate (pchpl)
A	60	0.33	720	50	0.28	540
B	60	0.55	1,200	50	0.47	900
C	59	0.75	1,650	50	0.66	1,260
D	57	0.89	1,940	49	0.79	1,500
E	55	1.00	2,200	47	1.00	1,900

NOTES: Los F is characterized by highly unstable and variable traffic flow.
pcphpl = passenger cars per hour per lane.

Source: "Highway Capacity Manual", Revised Chapter 7, Page 7–8; and Wilbur Smith Associates, October, 1992.

HIGHWAY.MDR

[1] Transportation Research Board, *Highway Capacity Manual: Special Report 209* (with Revised Chapter 7 - May, 1992), 1985.

A freeway is defined as a divided highway facility with four or more lanes and full control of access and egress. A multi-lane highway is defined as four or more lane highway facility, usually divided, with traffic control spaced a minimum of 2.0 miles or more apart. Although freeways and multi-lane highways are two distinct categories of roadways, recent developments in the research of multi-lane highways has indicated that previous estimates of capacity on these facilities were low and a revised Chapter 7 of the *Highway Capacity Manual* has been published to replace the previous chapter. The significance of this to freeway analysis is that the revised capacity estimate for multi-lane highways (2,200 passenger cars per hour per lane (pcphpl)) is higher than the capacity estimate for freeway (2,000 pcphpl). TRB has recommended the use of the multi-lane highway capacity estimates for freeways until a more comprehensive analysis of freeway capacity can be conducted.

Two-Lane Rural Highways - On a two-lane roadway having one lane in each direction, passing of slower vehicles requires the use of the opposing lane where sight distance and gaps in opposing traffic permit. The level-of-service criteria for two-lane rural highways, in sections without interruption due to traffic controls, are defined primarily in terms of percent time delay behind slower vehicles, with speed and capacity utilization as secondary measures.

Table 2 presents the level-of-service criteria for two-lane rural highways.

Table 2

LEVEL-OF-SERVICE CRITERIA FOR TWO-LANE RURAL HIGHWAYS
Wahlawa – Galbraith Lands Traffic Study

level of Service	Percent of Time Delay	Maximum V/C Ratio	Maximum Service Flow Rate (pch)	Description
A	30%	0.15	420	Free flow.
B	45%	0.27	750	Platoons begin to form.
C	60%	0.43	1,200	Traffic flow stable, but long platoons begin to form.
D	75%	0.64	1,800	Traffic flow stable, but long platoons begin to combine into longer chains of vehicles and control speeds.
E	More Than 75%	1.00	2,800	Platooning intense and speeds become significatly slower.
F	--	--	--	Heavily congested with volumes exceeding capacity.

NOTES: Assumes level terrain and zero percent no passing zones.
Maximum service flow rate represents two-way traffic volumes.

Source: "Highway Capacity Manual", Chapter 8, Page 8–5; and Wilbur Smith Associates, October, 1992.

HIGHWAY.MDR

Signalized Intersections - The operations approach was used in analyzing signalized intersections in this analysis. As with analysis of other types of traffic facilities, signalized intersection analysis also calculates the volume-to-capacity (V/C) ratio. Modern signals allocate time in a variety of ways, from the most simple two-phased pretimed signal, to the most complex multi-phase actuated signal. Signal phasing and timing control the various traffic streams which meet at an intersection. As such, they are key in the evaluation of intersection level-of-service. While capacity is evaluated in terms of the V/C ratio, with the operations approach, level of service is based on average delay (seconds/vehicle) rather than V/C ratio.

The level-of-service criteria for signalized intersections is defined in Table 3.

Table 3

LEVEL-OF-SERVICE CRITERIA FOR SIGNALIZED INTERSECTIONS
Wahiawa – Galbraith Lands Traffic Study

Level-of-Service	Stopped Delay Per Vehicle (seconds)
A	5.0 or less
B	5.1 – 15.0
C	15.1 – 25.0
D	25.1 – 40.0
E	40.1 – 60.0
F	Over 60.0

Source: "Highway Capacity Manual", Chapter 9, Page 9–4.; and Wilbur Smith Associates, October, 1992.

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Unsignalized Intersections - In T-intersection and four-leg-two-way STOP unsignalized intersection analysis, a standard procedure provides a comparative measure of delay at STOP and YIELD controlled intersections for those movements which must yield to conflicting movements at the intersection. The movements which must yield include:

- Left-turn out of the side street;
- Right-turn out of the side street; and
- Left-turn into the side street.

Through vehicles on the major street are not required to yield to other movements at T- and two-way controlled intersections. The general indicator of intersection delay is determined by calculating the one-hour capacity for each key movement, based on conflicting traffic volumes, and then comparing the number of vehicles making that maneuver to the calculated capacity. The unused or "reserve" capacity for that movement is then used to identify a level of service for than movement. Unlike signalized analysis, an overall intersection level of service is not calculated but rather, a level-of-service is calculated for each lane group.

The level-of-service criteria for unsignalized intersections is defined in Table 4.

Table 4

LEVEL OF SERVICE CRITERIA FOR UNSIGNALIZED INTERSECTIONS
Wahiawa – Galbraith Lands Traffic Study

Level-of-Service	Reserve Capacity (pcph)	Expected Delay
A	400 or more	Little or no delays
B	300 – 399	Short traffic delays
C	200 – 299	Average traffic delays
D	100 – 199	Long traffic delays
E	0 – 99	Very long traffic delays
F	Negative Value	Exceeds capacity with extreme traffic delays

Source: "Highway Capacity Manual", Chapter 10, Page 10–9; and Wilbur Smith Associates, October, 1992.

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Freeway Ramps - The freeway ramps analysis contained in the *Highway Capacity Manual* focusses on the impact of ramps on the freeway. The analysis of the subject ramp in this analysis, the southbound H-2 Freeway ramp from Kamehameha Highway, is concerned more with the capacity and operation of the ramp rather than its impact on the freeway. Since there is no methodology for analyzing this aspect of a ramp, a common sense approach was taken.

The primary concern about the subject ramp is that the radii of the on-ramp causes reduced speeds and therefore reduced carrying capacity. The methodology applied for analyzing the ramp is based on an assumed safe speed and safe following distance. As a worst case, the assumed safe speed for the ramp was estimated at 20 MPH. At 20 MPH, the safe following distance is 50 feet and the total distance per vehicle is 75 feet from front bumper to rear bumper (this assumes a 25 foot car length). The capacity of the ramp, therefore, can be estimated by calculating the number of vehicles per hour that can use the ramp at 20 MPH with 75 feet distances between each car. This is solved as follows:

20 MPH * 5,280 feet (the number of feet in a mile) / 75 feet/vehicle = 1,408 vehicles/hour

In determining the operating characteristics of this ramp, actual and projected travel demands are compared to this capacity to get a V/C ratio. Since level-of-service is a perceived measure and no analysis of driver perceptions has been performed, it is not appropriate to categorize V/C ratios into levels-of-service so the discussion of this ramp will focus solely on the demand versus capacity (V/C ratio).

Traffic Operations

Existing weekday peak period traffic counts were conducted in October of 1992. Intersections studied were:

- Kamehameha Highway/Olive Avenue;
- Kamehameha Highway/California Avenue;
- Kamehameha Highway/Kilani Avenue;
- Kamehameha Highway/Whitmore Avenue;
- Kamehameha Highway/Kaukonahua Highway;
- Kamehameha Highway/Kamananui Road;
- Wilikina Drive/Kunia Road;
- Wilikina Drive/Kamananui Road; and
- Kaukonahua Highway/Kamananui Road.

In addition to these intersections, several critical roadway segments were also analyzed. These include:

- Kamehameha Highway south of the Wheeler AFB Main Gate;
- Wilikina Drive between the H-2 Freeway and Kunia Road;
- Wilikina Drive between Kunia Road and the Macomb/Funston Gates;
- Wilikina Drive between the Macomb/Funston Gates and Kamananui Road;
- the H-2 Freeway south of Wilikina Drive; and
- the southbound on-ramp to the H-2 Freeway from Kamehameha Highway.

Figure 2 shows existing AM and PM peak hour weekday traffic volumes at each of these locations. Tables 5 and 6 show the results of existing conditions analysis at each of the locations.

Table 5 shows existing intersection operations. At those locations with traffic signal controls existing operations are in the LOS C range indicating that little congestion occurs.

Two of the unsignalized intersections in the area are experiencing long delays at the minor street approaches. The westbound Kamananui Road left-turn to Wilikina Drive experiences long delays. This movement operates at LOS F during both the AM and PM peak hours. This indicates that vehicles experience extremely long delays at these movements. Also, the eastbound shared right/left-turn movement from Kamananui Road to Kamehameha Highway operates at LOS D during the AM peak hour and LOS E during the PM peak hour. This indicates that vehicles attempting to execute these movements are delayed by through traffic on Kamehameha Highway.

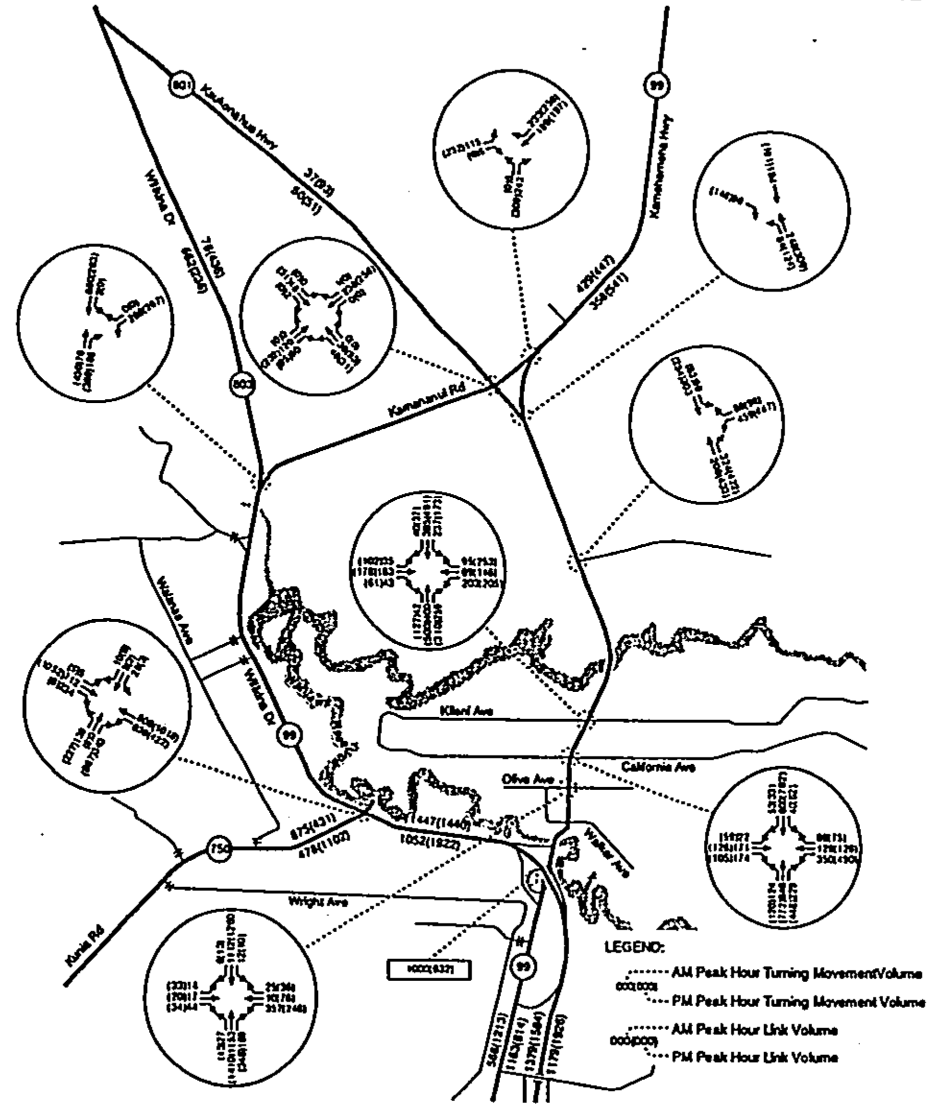

Figure 2

EXISTING AM AND PM PEAK HOUR TRAFFIC VOLUMES

WAHIAWA - GALBRAITH TRUST LANDS TRAFFIC STUDY

Table 5

EXISTING INTERSECTION OPERATIONS
Wahiawa – Galbraith Lands Traffic Study

SIGNALIZED INTERSECTIONS	AM Peak Hour V/C Ratio	AM Peak Hour Delay (sec./veh.)	AM Peak Hour LOS	PM Peak Hour V/C Ratio	PM Peak Hour Delay (sec./veh.)	PM Peak Hour LOS
Kamehameha Highway/Olive Avenue	0.71	18.0	C	0.86	23.5	C
Kamehameha Highway/California Avenue	0.65	18.3	C	0.86	24.3	C
Kamehameha Highway/Kilani Avenue	0.66	15.2	C	0.83	20.6	C
Kamehameha Highway/ Whitmore Avenue	0.44	16.4	C	0.56	15.3	C
Wilikina Drive/Kunia Road	0.32	19.0	C	0.45	22.4	C

UNSIGNALIZED INTERSECTIONS	AM Reserve Capacity	AM LOS	PM Reserve Capacity	PM LOS
Kamehameha Highway/Kamananui Road				
Kamananui EB right/left	119	D	31	E
Kamehameha NB left	563	A	681	A
Kaukonahua Highway/Kamananui Road				
Kaukonalua NB right/thru/left	317	B	209	C
Kaukonalua SB right/thru/left	411	A	289	C
Kamananui EB left	865	A	840	A
Kamananui WB left	945	A	768	A
Wilikina Drive/Kamananui Road				
Kamananui WB left	–7	F	–39	F
Kamananui WB right	945	A	535	A
Wilikina SB left	955	A	490	A

EXNTAOA

Source: Wilbur Smith Associates, October, 1992.

Table 6

EXISTING FREEWAY, HIGHWAY, AND ON–RAMP OPERATIONS
Wahiawa – Galbraith Lands Traffic Study

	Estimated Capacity	AM Peak Hour Volume	AM Peak Hour V/C Ratio	AM Peak Hour LOS	PM Peak Hour Volume	PM Peak Hour V/C Ratio	PM Peak Hour LOS
Kamehameha Highway S of Wheeler AFB							
Northbound	3,800	1,163	0.31	B	814	0.21	A
Southbound	3,800	566	0.15	A	1,213	0.32	B
Wilikina btwn the H–2 Freeway and Kunia							
Northbound	3,800	1,447	0.38	B	1,440	0.38	B
Southbound	3,800	1,052	0.28	A	1,922	0.51	C
H–2 Freeway S of Wilikina							
Northbound	4,400	1,779	0.40	B	1,926	0.44	B
Southbound	4,400	1,379	0.31	A	1,584	0.36	B
SB On–Ramp to H–2 Freeway	1,408	1,000	0.71	N/A	632	0.45	N/A

EXSEOAOA

Source: Wilbur Smith Associates, October, 1992.

Table 6 shows existing freeway, highway, and on-ramp operations. All of the critical roadway segments in the area of the Project are currently operating at LOS C or better. The southbound on-ramp from Kamehameha Highway to the H-2 Freeway operates at a V/C ratio of 0.71 (71 percent of capacity) during the AM peak hour and a V/C ratio of 0.45 (45 percent of capacity) during the PM peak hour.

3. TRAFFIC GROWTH AND IMPACTS WITHOUT THE PROJECT

The proposed development of the Galbraith Trust Lands could be accomplished by the year 2010. This section presents the approach by which future traffic without the Project was estimated and provides an analysis of traffic operations with those projections. The analysis of traffic operations reflects those planned regional roadway improvements. Some additional mitigation measures would be necessary. This section identifies impacts. Mitigation measures are discussed in section 5.

Roadway Improvements

The Oahu Regional Transportation Plan (RTP) lists one major roadway improvement in the study area by the 2005 horizon year of the Plan[2]. Kamehameha Highway is planned to provide four-lanes with left-turn pockets at intersections for the two-lane section between Wahiawa and Haleiwa.

In addition to this improvement, a few other planned improvements are noteworthy even though they do not directly affect traffic operations in the area of the Project. These include:

> The widening of Kunia Road - In the area of the Project, Kunia Road is already a four-lane arterial. The State plans to widen Kunia to four-lanes along its entire length. While this does not affect the capacity of Kunia Road at its intersection with Wilikina Drive, it will increase the carrying capacity of Kunia which could result in a shift of some traffic from Kamehameha Highway and H-2 to Kunia Road.
>
> The construction of a Haleiwa Bypass - This will not impact the analysis performed in this report but is noteworthy because the bypass will alleviate any potential congestion and safety problems in Haleiwa which would result from increased traffic on Kamehameha Highway north of the study area.
>
> Adding an additional lane to the H-2 Freeway between Mililani and the H-1 Freeway - Although the additional lane being added to the H-2 Freeway would not extend north to the Project area, the additional lane will increase the carrying capacity of the H-2 Freeway lessening the impacts of future traffic and Project-generated traffic.

While no other roadway improvements were assumed in the area, it was assumed that signal timings would be adjusted to reflect changing demand. No changes were made to signal phasing or cycle lengths assumptions, but signal timings were adjusted where warranted.

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[2] Oahu Metropolitan Planning Organization, *The Oahu Regional Transportation Plan*, June, 1991.

Traffic Increases

In calculating future background traffic volumes, two different increases were assumed.

North of Wahiawa, existing traffic volumes on Kamehameha and Kaukonahua Highways were adjusted upward by 48.6 percent to reflect traffic growth through the year 2010. This growth factor was based on the Oahu RTP forecasts for the Helemano analysis screenline through the year 2005.

An increase of 0.9 percent annually was assumed on cross streets through Wahiawa and on Whitmore. This is the annual growth rate calculated from previous State DOT traffic counts on these cross streets in Wahiawa[3]. This increase was applied to the year 2005 (14 years) with the total increase amounting to 12.8 percent. No additional increase was assumed between the year 2005 and 2010 because a 12.8 percent increase in traffic in an area which is already largely built out seemed a conservative estimate.

Traffic increases in Wahiawa and south of Wahiawa were estimated by continuing south the whole number increase determined by applying the above described increases. Approximations of the resulting percentage traffic increases on various routes are listed below.

- Kamehameha Highway through Wahiawa — 32 percent increase
- Kamehameha Highway south of Wilikina — 13 percent increase
- Wilikina Drive between Kunia and H-2 — 14 percent increase
- H-2 Freeway south of Wilikina — 24 percent increase

Figure 3 shows projected future traffic volumes in the area without the Project.

Traffic Operations

Tables 7 and 8 present future traffic service levels in the year 2010 without the Project. Table 7, which shows projected intersection operations, shows operational deficiencies at four of the eight study intersections during one or both of the peak hours. These are discussed below:

<u>Kamehameha Highway/Olive Avenue</u> - This intersection is significantly impacted by future traffic growth as it is estimated to operate at LOS F (V/C = 1.03) during the PM peak hour. The combination of heavy westbound and northbound traffic at this location cannot be adequately served with the existing signal and lane configurations. The average delays for vehicles using this intersection would be 64 seconds.

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[3] State DOT counts station numbers 20-B and 20-C (California Avenue and Kilani Avenue at Kamehameha Highway).

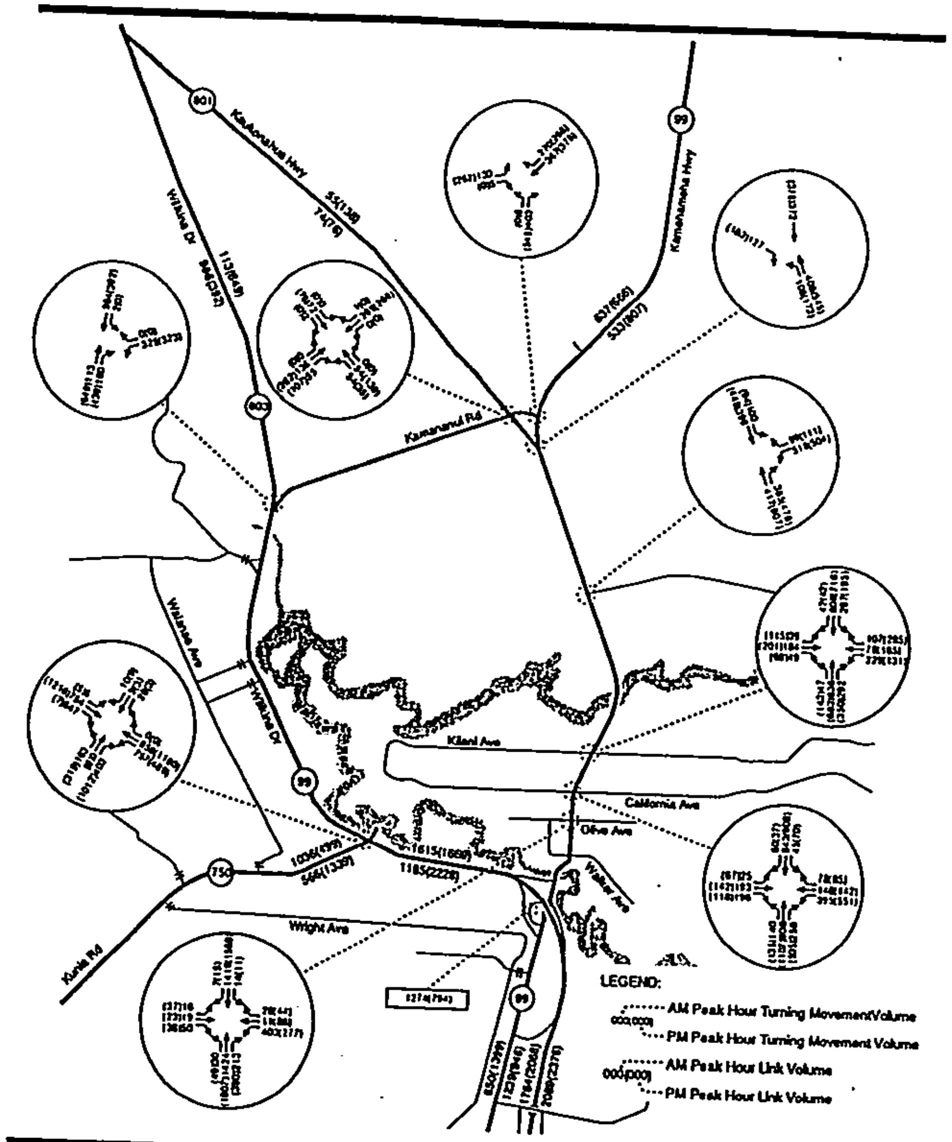

Figure 3
FUTURE AM AND PM PEAK HOUR TRAFFIC VOLUMES WITHOUT PROJECT
WAHIAWA - GALBRAITH TRUST LANDS TRAFFIC STUDY

Table 7

INTERSECTION CONDITIONS FOR THE YEAR 2010 WITHOUT THE PROJECT
Wahiawa – Galbraith Lands Traffic Study

SIGNALIZED INTERSECTIONS	AM Peak Hour V/C Ratio	AM Peak Hour Delay (sec./veh.)	AM Peak Hour LOS	PM Peak Hour V/C Ratio	PM Peak Hour Delay (sec./veh.)	PM Peak Hour LOS
Kamehameha Highway/Olive Avenue	0.90	30.3	D	1.03	64.0	F
Kamehameha Highway/California Avenue	0.92	30.0	D	1.22	-- (1)	F
Kamehameha Highway/Kilani Avenue	0.80	20.5	C	0.78	16.1	C
Kamehameha Highway/ Whitmore Avenue	0.61	14.9	B	0.69	19.2	C
Wilikina Drive/Kunia Road	0.35	24.0	C	0.55	29.9	D

UNSIGNALIZED INTERSECTIONS	AM Peak Hour Reserve Capacity	AM Peak Hour LOS	PM Peak Hour Reserve Capacity	PM Peak Hour LOS
Kamehameha Highway/Kamananui Road				
Kamananui EB right/left	1	E	-186	F
Kamehameha NB left	460	A	450	A
Kaukonahua Highway/Kamananui Road				
Kaukonalua NB right/thru/left	244	C	104	D
Kaukonalua SB right/thru/left	348	B	219	C
Kamananui EB left	840	A	815	A
Kamananui WB left	918	A	745	A
Wilikina Drive/Kamananui Road				
Kamananui WB left	-180	F	-198	F
Kamananui WB right	890	A	400	A
Wilikina SB left	885	A	360	B

(1) Delay and level-of-service are meaningless when any V/C ratio exceeds 1.2.

FUNTAICR

Source: Wilbur Smith Associates, October, 1992.

Table 8

FREEWAY, HIGHWAY, AND ON-RAMP CONDITIONS FOR THE YEAR 2010 WITHOUT THE PROJECT
Wahiawa – Galbraith Lands Traffic Study

	Estimated Capacity	AM Peak Hour Volume	AM Peak Hour V/C Ratio	AM Peak Hour LOS	PM Peak Hour Volume	PM Peak Hour V/C Ratio	PM Peak Hour LOS
Kamehameha Highway S of Wheeler AFB							
Northbound	3,800	1,239	0.33	B	946	0.25	A
Southbound	3,800	650	0.17	A	1,399	0.37	B
Wilikina btwn the H-2 Freeway and Kunia							
Northbound	3,800	1,615	0.43	B	1,669	0.44	B
Southbound	3,800	1,185	0.31	B	2,228	0.59	C
H-2 Freeway S of Wilikina							
Northbound	4,400	2,089	0.47	B	2,376	0.54	B
Southbound	4,400	1,764	0.40	B	2,068	0.47	B
SB On-Ramp to H-2 Freeway	1,408	1,274	0.90	N/A	794	0.56	N/A

FUNTAICR

Source: Wilbur Smith Associates, October, 1992.

Kamehameha Highway/California Avenue - As with the previous intersection, the combination of heavy northbound and westbound PM peak hour traffic at this location significantly impact the intersection's operations. The intersection operates at LOS F (V/C = 1.22). No average delay value can be predicted for an intersection with any V/C ratio over 1.2.

Kamehameha Highway/Kamananui Road - The eastbound shared left/right-turn movement of this intersection would operate at LOS E during the AM peak hour and LOS F during the PM peak hour. As such, it would be significantly impacted by future traffic growth.

Wilikina Drive/Kamananui Road - The westbound left-turn movement at this location would operate at LOS F during both peak hours as this intersection would be significantly impacted by future growth.

Table 8 shows the future service levels without the Project for several of the roadway segments and the on-ramp to H-2. All of the roadway segments would operate at LOS C or better. The southbound on-ramp to H-2 from Kamehameha Highway, however, would experience some operational difficulties during the AM peak hour. This ramp would operate at 90 percent of capacity during the AM peak hour. While traffic would continue to move at normal speeds, congestion on the ramp would be noticeable.

4. FUTURE TRAFFIC CONDITIONS WITH THE PROJECT

This section presents traffic projections and analysis for the year 2010 with the addition of Project traffic. Mitigation measures for the anticipated impacts are discussed in section 5.

Roadway Improvements

No additional roadway improvements beyond those discussed in the previous section are assumed in this analysis except at the Project's access points. The proposed Project access points and internal circulation scheme are shown in Figure 4.

Several modifications were assumed at the intersection of Kamehameha Highway/Whitmore Avenue including the following:

- the eastbound approach was assumed to provide three approach lanes - a right-turn lane, a through lane, and a left-turn lane;
- an additional left-turn lane was assumed at the westbound approach to the intersection; and
- a new signal was assumed which operates with four phases providing protected left-turn phases.

No modifications were assumed on Kamehameha Highway except for the improvement discussed in the previous section - the addition of two through lanes - which would occur with or without the Project.

At the access points other than Kamehameha Highway/Whitmore Avenue, it was assumed that left-turn pockets would be provided on Kamehameha Highway and Kamananui Road. In addition, right-turn lanes were assumed on Kamananui Road at the two access points. At the new access point on Whitmore Avenue east of Kamehameha Highway left-turn lanes would not be necessary on Whitmore Avenue but may be desirable in order to allow for shorter delays for through traffic. Two-lane approaches were assumed at the new intersection approaches created by the Project.

Trip Generation

The Project includes a variety of land uses including single-family, multi-family, and medium density residential land uses, a commercial/industrial, two business center areas, several neighborhood commercial facilities, some office and retail space, two elementary schools, an 18-hole golf course, several parks, and some civic areas.

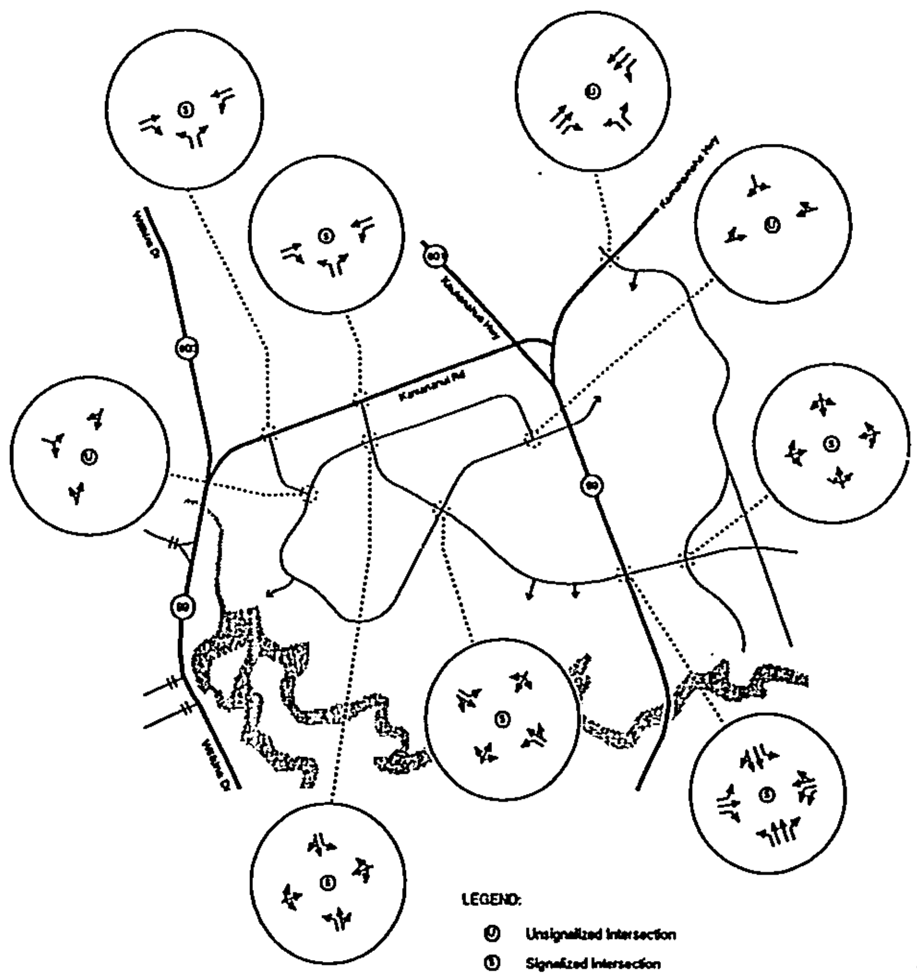

Figure 4
INTERNAL CIRCULATION AND ACCESS POINT GEOMETRIES
WAHIAWA - GALBRAITH TRUST LANDS TRAFFIC STUDY

The Project's vehicle trip generation was calculated using standard Institute of Transportation Engineer (ITE) trip factors[4]. In a few cases, San Diego Association of Government (SANDAG) trips rates were used because ITE did not provide the necessary rates per acre[5]. The list of trip generation rates used in this analysis is contained in Table 9.

Table 10 shows the quantity of various land uses, and the total daily and peak hour generations for each of the land uses. The Project as a whole would generate an estimated 40,680 vehicle trips daily. During the AM peak hour, it would generate about 3,800 trips (1,820 inbound and 1,980 outbound). During the PM peak hour, it would generate about 4,410 vehicle trips (2,300 inbound and 2,110 outbound).

Because of the various land uses within the Project, many trips were assumed to be internal to the Project. In calculating the percentage of internal trips, the inbound/outbound relationships from various land uses were compared and some professional judgement applied to yield the following percentages of internal trips:

Land Use	Percent Internal Trips
• Residential	25 percent
• Employee-Based/Golf Course (Commercial/Industrial, Business Center, Office, and Golf Course)	15 percent
• Neighborhood Commercial	50 percent
• Other (Schools, Parks, and Civic Uses)	90 percent

Internal trips were distributed within the Project but were not assumed to leave the Project area. For analysis purposes, the Project area was subdivided into 18 zones, as shown in Figure 5. The Project's vehicle trip generation, by zone, is listed in Table 11.

Distribution

Project external trips were distributed to other areas of Oahu based on the *Hali 2005 Travel Study Forecast*. Trip distribution to/from nearby Whitmore Village, Wahiawa, Schofield Barracks, and Wheeler AFB were estimated using population and employment data for these areas. The distribution of external trips is as follows:

- North via Kaukonahua Highway — 3.0 percent

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[4] Institute of Transportation Engineers, *Trip Generation Fifth Edition*, January, 1991.

[5] San Diego Association of Governments, *Traffic Generators*, January, 1990.

Table 9
Trip Generation Rates
Wahiawa Lands Traffic Study

RATES

Land Use (ITE Code)	Units of Measure	Daily Rates	AM Peak Rates	AM Peak In	AM Peak Out	PM Peak Rates	PM Peak In	PM Peak Out
Residential								
Single-Family (210)	units	9.55	0.74	26%	74%	1.01	65%	35%
Medium Density (221)	units	6.59	0.47	20%	80%	0.58	66%	34%
Multi-Family (220)	units	6.47	0.51	17%	83%	0.63	68%	32%
Commercial								
Commercial/Industrial (130)	KSF [1]	6.97	0.88	82%	18%	0.91	21%	79%
Business Center (770)	KSF	14.37	1.62	85%	15%	1.48	22%	78%
Neighborhood Commercial (81	KSF	40.67	4.93	57%	43%	6.41	48%	52%
Office (710)	KSF	23.35	3.04	89%	11%	3.22	17%	83%
Retail (814)	KSF	40.67	4.93	57%	43%	6.41	48%	52%
Other								
Elementary School [2]	acres	60.00	15.60	60%	40%	3.00	30%	70%
Civic (Church) [2]	acres	40.00	1.60	80%	20%	3.20	50%	50%
Golf Course (430)	holes	37.59	3.22	83%	17%	3.36	52%	48%
Parks (411) [3]	acres	2.23	0.09	50%	50%	0.18	50%	50%

NOTES:
[1] KSF = thousand square feet
[2] San Diego Association of Government rates were used for these land uses because they provide trip generation estimates on an acre basis.
[3] The ITE City Park rate was used in generating daily trips but no AM and PM data was provided by ITE so AM and PM peak hour percentages were taken from the San Diego Association of Government rates.

TRIPGENMOR

Source: Wilbur Smith Associates, October, 1992.

Table 10
Project Trip Generation
Wahiawa Lands Traffic Study

TRIP GENERATION

Land Use	Quantity	Daily Trips	AM Peak Trips	AM Peak In	AM Peak Out	PM Peak Trips	PM Peak In	PM Peak Out
Residential								
Single-Family	1,482 units	14,153	1,097	285	812	1,497	973	524
Medium Density	660 units	4,349	310	62	248	383	253	130
Multi-Family	810 units	5,241	413	70	343	510	347	163
Commercial								
Commercial/Industrial	359.37 KSF [1]	2,505	316	259	57	327	69	258
Business Center	413.82 KSF	5,947	670	570	101	612	135	478
Neighborhood Commercial	108.90 KSF	4,429	537	306	231	698	335	363
Mixed Use								
Multi-Family Res	148 units	958	75	13	63	93	63	30
Office	12.40 KSF	290	38	34	4	40	7	33
Retail	12.40 KSF	504	61	35	26	79	38	41
Other								
Elementary School	12 acres	720	187	112	75	36	11	25
Civic	17 acres	680	27	22	5	54	27	27
Golf Course	18 holes	677	58	48	10	60	31	29
Parks	101 acres	225	9	5	5	18	9	9
		40,677	3,799	1,821	1,979	4,409	2,298	2,111

NOTE:
[1] KSF = thousand square feet.

TRIPGENMOR

Source: Wilbur Smith Associates, October, 1992.

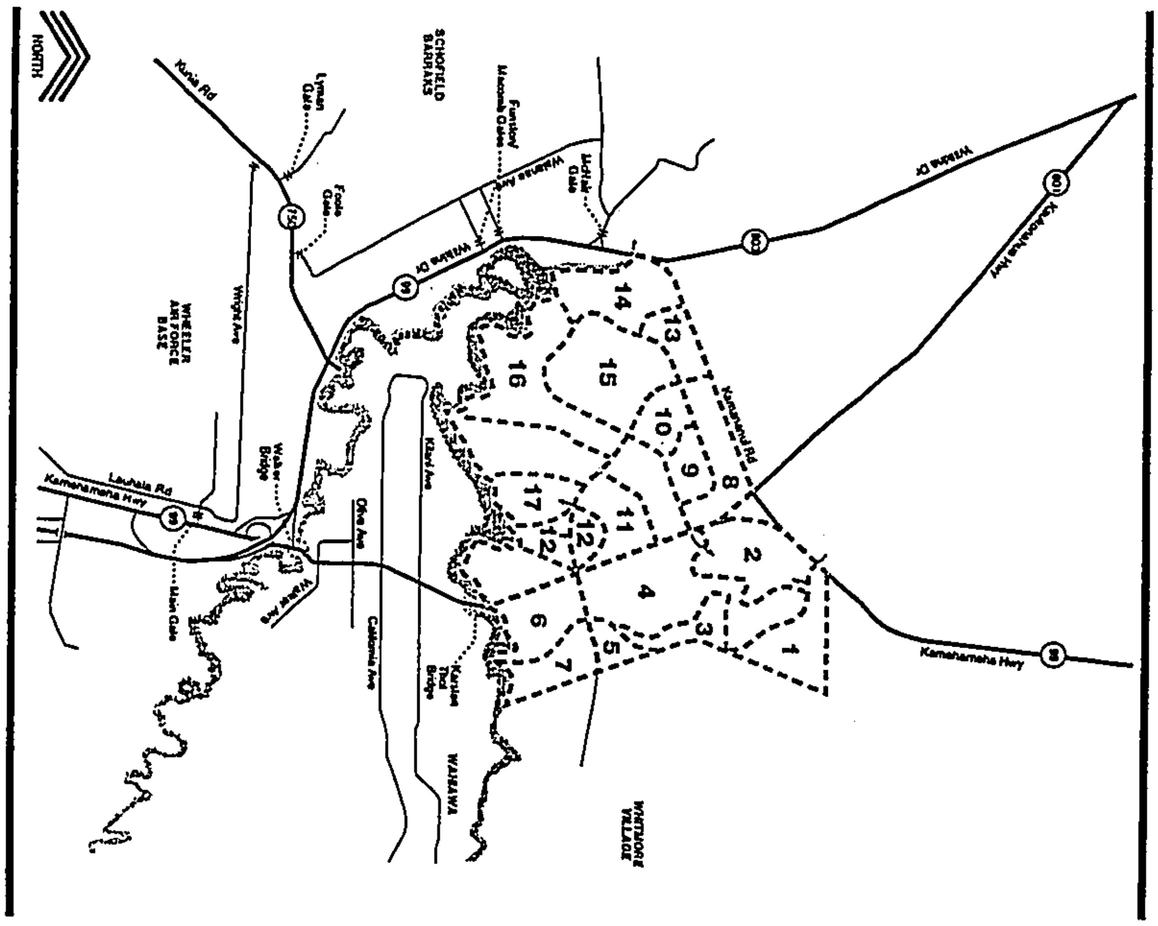


Figure 5
TRIP GENERATION ZONES
WAHIAWA - GALBRAITH TRUST LANDS TRAFFIC STUDY

Table 11
Project Trip Generation By Internal Zone
Wahiawa Lands Traffic Study

TRIP GENERATION

			Daily	AM Peak			PM Peak		
Land Use		Quantity	Trips	Trips	In	Out	Trips	In	Out
Zone 1	Park	14 acres	31	1	1	1	2	1	1
Zone 2	Single-Family Res	216 units	2,063	160	42	118	218	142	76
Zone 3	Single-Family Res	156 units	1,490	115	30	85	158	102	55
Zone 4	Golf Course	18 holes	677	58	48	10	60	31	29
Zone 5	Elementary School	6 acres	360	94	56	37	18	5	13
	Neighborhood Commercial	32.67 KSF	1,329	161	92	69	209	101	109
	Park	4 acres	9	0	0	0	1	0	0
			1,698	255	148	107	228	106	122
Zone 6	Commercial/Industrial	359.37 KSF	2,505	316	259	57	327	69	258
Zone 7	Medium Density Res	250 units	1,648	118	24	94	145	96	49
Zone 8	Business Center	337.59 KSF	4,851	547	465	82	500	110	390
	Civic	2 acres	80	3	3	1	6	3	3
			4,931	550	467	83	506	113	393
Zone 9	Multi-Family Res	180 units	1,165	92	16	76	113	77	36
	Business Center	76.23 KSF	1,095	123	105	19	113	25	88
			2,260	215	121	95	226	102	124
Zone 10	Multi-Family Res	165 units	1,068	84	14	70	104	71	33
	Neighborhood Commercial	16.34 KSF	664	81	46	35	105	50	54
	Mixed Use								
	Multi-Family Res	148 units	958	75	13	63	93	63	30
	Office	12.40 KSF	290	38	34	4	40	7	33
	Retail	12.40 KSF	504	61	35	26	79	38	41
			3,483	339	141	198	421	229	192

- North via Kamehameha Highway — 4.5 percent
- South to Pearl City and Honolulu via H-2 — 27.5 percent
- South to Mililani via Kamehameha Highway — 22.5 percent
- South to Ewa via Kunia Road — 10.0 percent
- Wahiawa/Schofield/Wheeler/Whitmore — 32.5 percent
  - Wahiawa west of Kamehameha Highway — 3.2 percent
  - Wahiawa east of Kamehameha Highway — 9.4 percent
  - Schofield Barracks — 16.4 percent
  - Wheeler AFB — 2.0 percent
  - Whitmore Village — 1.5 percent

In the assignment of trips to the area roadway system, it was assumed that most vehicles travelling to/from south of Wahiawa would use Wilikina Drive rather than Kamehameha Highway to reach the H-2 Freeway and Kamehameha Highway south of Wahiawa. The assumption was made because the number of traffic signals, and projected operations of these signalized intersections, on Kamehameha Highway in Wahiawa, would make it possible for trips around Wahiawa on Wilikina Drive to be accomplished in less time than the shorter distance trip on Kamehameha Highway through Wahiawa.

Traffic Operations

Figure 6 shows the projected traffic volumes for the year 2010 with the Project. Tables 12 and 13 indicate traffic service levels with the Project. As Table 12 shows, four of the five signalized intersections would function at LOS F during one or both of the peak hours. In addition, all three of the unsignalized intersections would have failing movements. All of the roadway segments would continue to operate within acceptable parameters, although the southbound on-ramp to H-2 from Kamehameha Highway would operate at 96 percent of capacity during the AM peak hour. Each location is discussed below.

Kamehameha Highway/Olive Avenue - This intersection would function at LOS F during both peak hours with the Project. During the AM peak hour, the V/C ratio would deteriorate from 0.90 to 0.98. During the PM peak hour, it would deteriorate from 1.03 to 1.14.

Kamehameha Highway/California Avenue - This intersection, which also would function at LOS F during the PM peak hour without the Project is also expected to experience deterioration in traffic conditions as a result of the Project. The Project is forecast to increase the V/C ratio to 1.2 from 0.92 without the Project in the AM peak hour and to

Table 11
Project Trip Generation By Internal Zone
Wahiawa Lands Traffic Study

TRIP GENERATION

Land Use		Quantity	Daily Trips	AM Peak Trips	AM Peak In	AM Peak Out	PM Peak Trips	PM Peak In	PM Peak Out
Zone 11	Multi-Family Res	465 units	3,009	237	40	197	293	199	94
	Park	4 acres	8	0	0	0	1	0	0
			3,017	238	40	197	294	200	94
Zone 12	Park	48 acres	106	4	2	2	8	4	4
Zone 13	Single-Family res	126 units	1,203	93	24	69	127	83	45
	Civic	3 acres	120	5	4	1	10	5	5
			1,323	98	28	70	137	88	49
Zone 14	Single-Family Res	204 units	1,948	151	39	112	206	134	72
Zone 15	Single-Family Res	318 units	3,037	235	61	174	321	209	112
	Medium Density Res	80 units	527	38	8	30	46	31	16
	Elementary School	6 acres	360	94	56	37	18	5	13
	Civic	12 acres	480	19	15	4	38	19	19
	Park	9 acres	20	1	0	0	2	1	1
			4,424	387	141	246	426	265	161
Zone 16	Single-Family Res	282 units	2,693	209	54	154	285	185	100
	Medium Density Res	70 units	461	33	7	26	41	27	14
	Neighborhood Commercial	59.90 KSF	2,436	295	168	127	384	184	200
	Park	23 acres	50	2	1	1	4	2	2
			5,641	539	230	309	713	398	315
Zone 17	Single-Family Res	180 units	1,719	133	35	99	182	118	64
Zone 18	Medium Density Res	260 units	1,713	122	24	98	151	100	51

TRIPGENMOR

Source: Wilbur Smith Associates, October, 1992.

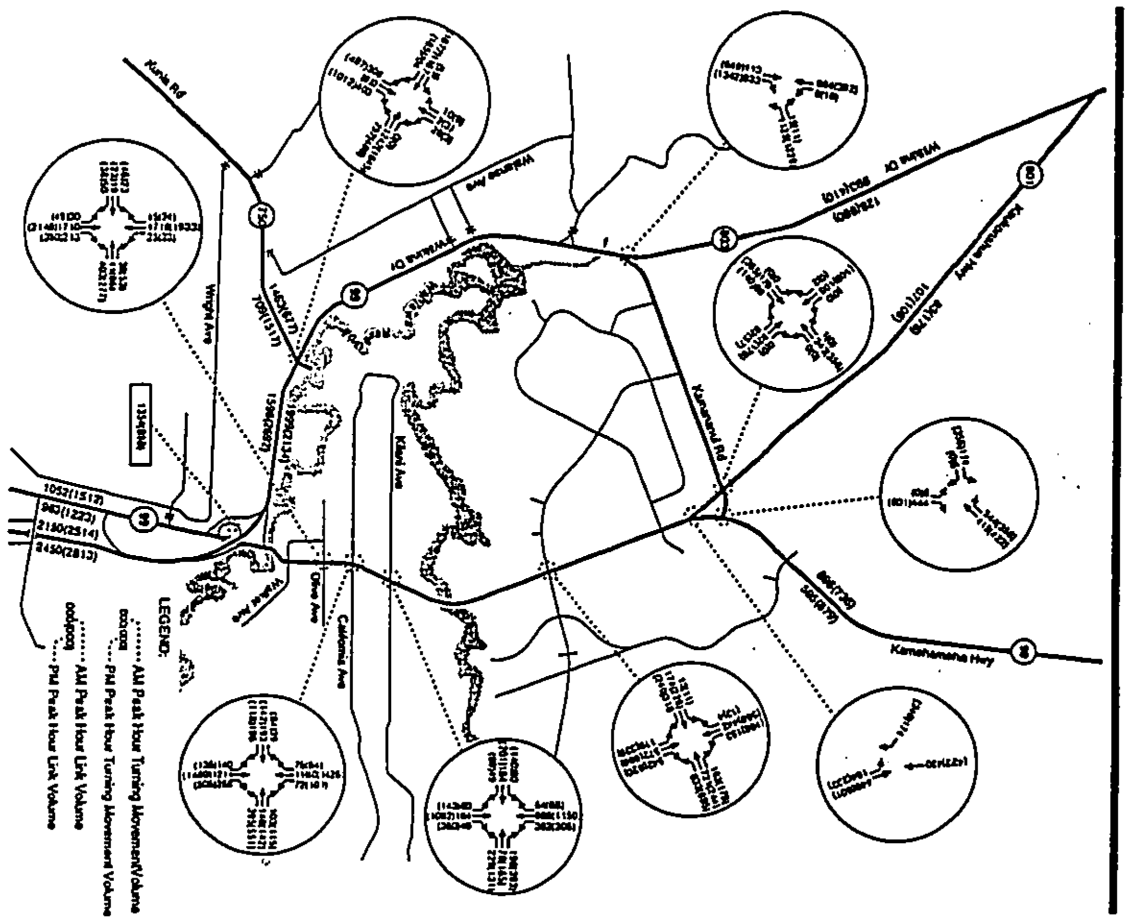


Figure 6
FUTURE AM AND PM PEAK HOUR TRAFFIC VOLUMES WITH PROJECT
WAHIAWA - GALBRAITH TRUST LANDS TRAFFIC STUDY

Table 12

INTERSECTION CONDITIONS FOR YEAR 2010 WITH THE PROJECT
Wahiawa – Galbraith Lands Traffic Study

	AM Peak Hour			PM Peak Hour		
SIGNALIZED INTERSECTIONS	V/C Ratio	Delay (sec./veh.)	LOS	V/C Ratio	Delay (sec./veh.)	LOS
Kamehameha Highway/Olive Avenue	0.98	74.3	F	1.14	-- (1)	F
Kamehameha Highway/California Avenue	1.20	-- (1)	F	1.44	-- (1)	F
Kamehameha Highway/Kilani Avenue	1.97	-- (1)	F	2.87	-- (1)	F
Kamehameha Highway/ Whitmore Avenue	0.87	21.8	C	0.94	33.5	D
Wilikina Drive/Kunia Road	0.55	51.0	E	0.81	-- (1)	F
UNSIGNALIZED INTERSECTIONS	Reserve Capacity		LOS	Reserve Capacity		LOS
Kamehameha Highway/Kamananui Road						
Kamananui EB right/left	-86		F	-321		F
Kamehameha NB left	387		B	379		B
Kaukonahua Highway/Kamananui Road						
Kaukonalua NB right/thru/left	78		E	-75		F
Kaukonalua SB right/thru/left	230		C	103		D
Kamananui EB left	768		A	745		A
Kamananui WB left	865		A	644		A
Wilikina Drive/Kamananui Road						
Kamananui WB left	-1135		F	-1266		F
Kamananui WB right	563		A	208		C
Wilikina SB left	378		B	160		D

(1) Delay and level-of-service are meaningless when any V/C ratio exceeds 1.2.

Source: Wilbur Smith Associates, October, 1992.

1.44 from 1.22 without the Project in the PM peak hour. These conditions reflect operations with a continuation of the present lane striping and signal phases.

Kamehameha Highway/Kilani Avenue - Projected future traffic volumes are expected to exceed the capacity of this intersection either with or without the Project. The addition of the Project would substantially worsen the AM and PM peak hour levels of service resulting in a deterioration of both peak hour operations from LOS C to LOS F.

Wilikina Drive/Kunia Road - This intersection would deteriorate from LOS C to LOS E during the AM peak hour and from LOS D to LOS F during the PM peak hour as a result of traffic added by the Project.

Kamehameha Highway/Kamananui Road - This unsignalized intersection is expected to experience operational problems at the eastbound shared right/left-turn movement with or without the Project. The addition of Project trips would cause this movement to further deteriorate.

Kaukonahua Highway/Kamananui Road - The shared right/through/left-turn movement from northbound Kaukonahua Highway would deteriorate from LOS C to LOS E during the AM peak hour and from LOS D to LOS F during the PM peak hour with the addition of Project traffic.

Wilikina Drive/Kamananui Road - The westbound left-turn movement at this intersection, which was forecast to operate at LOS F conditions during the AM and PM peak hours without the Project, would further deteriorate as a result of Project-generated traffic.

Southbound On-Ramp to the H-2 Freeway - This ramp would operate at 90 percent of capacity without the Project and noticeable congestion would occur. The addition of the Project would result in operation at 96 percent of capacity. It is likely that some of the southbound traffic seeking to enter the H-2 Freeway may continue south on Kamehameha Highway and use the on-ramp to the southbound H-2 Freeway at Kehalu Avenue. Kamehameha Highway and the on-ramp at Kehalu Avenue could accommodate the additional traffic.

Internal Circulation

This section is divided into two subsections: access evaluation and internal operations. The first discusses the intersections which would intersect with existing roadways and the control-type and physical configurations which would be needed at those locations. The second discusses traffic conditions within the Project and makes recommendations regarding the configurations of roadways and intersections within the Project. Figure 7 shows traffic volumes internal to the Project and at access points.

Table 13

FREEWAY, HIGHWAY, AND ON-RAMP CONDITIONS FOR THE YEAR 2010 WITH THE PROJECT
Wahiawa – Galbraith Lands Traffic Study

		Estimated Capacity	AM Peak Hour Volume	AM Peak Hour V/C Ratio	AM Peak Hour LOS	PM Peak Hour Volume	PM Peak Hour V/C Ratio	PM Peak Hour LOS
Kamehameha Highway S of Wheeler AFB								
	Northbound	3,800	1,534	0.40	B	1,302	0.34	B
	Southbound	3,800	965	0.25	A	1,763	0.46	B
Wilikina btwn the H-2 Freeway and Kunia								
	Northbound	3,800	1,999	0.53	C	2,134	0.56	C
	Southbound	3,800	1,598	0.42	B	2,692	0.71	D
H-2 Freeway S of Wilikina								
	Northbound	4,400	2,450	0.56	C	2,813	0.64	C
	Southbound	4,400	2,150	0.49	B	2,514	0.57	C
SB On-Ramp to H-2 Freeway		1,408	1,354	0.96	N/A	898	0.64	N/A

Source: Wilbur Smith Associates, October, 1992.

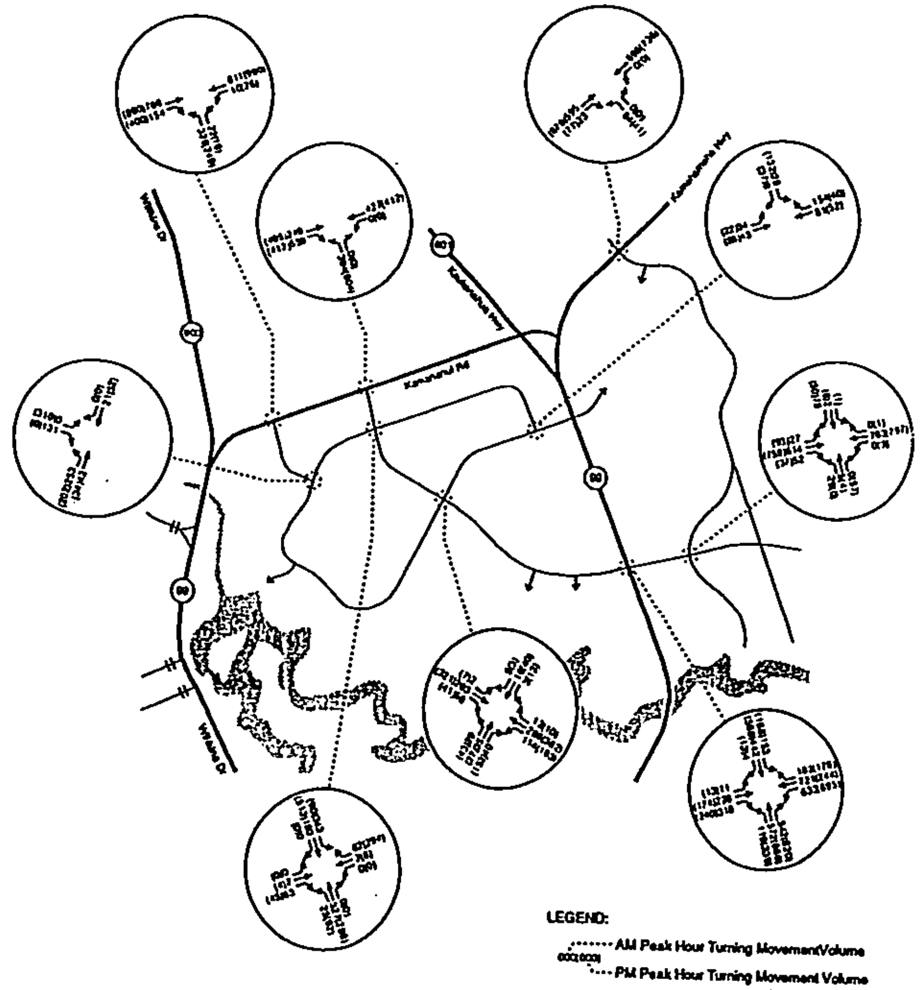


Figure 7
INTERNAL CIRCULATION AND ACCESS POINT VOLUMES

WAHIAWA - GALBRAITH TRUST LANDS TRAFFIC STUDY

Access Evaluation - All new access points, with one exception, would require signalization. The access point on Kamehameha Highway north of Kamananui Road could function as an unsignalized intersection although this would result in LOS E operations on the minor street (access road) approach.

All access point intersections are expected to operate at LOS C or better, with most operating at LOS A and B, except the intersection of Kamehameha Highway/Whitmore Avenue which would operate at LOS D during the PM peak hour. The addition of signals in the area of the Project would result in longer delays for through traffic on Kamehameha Highway and Kamananui Road.

Internal Operations - The traffic volume forecast for roadways internal to the Project are consistent with the capacity of two-lane roadways. Signalized intersections would be desirable at the two new intersections on Whitmore Avenue between Kamananui Road and Kamehameha Highway. All other intersections could function as STOP controlled intersections.

5. MITIGATION

This section presents mitigation measures for impacts identified in the proceeding chapters. Mitigation measures are presented separately for future conditions without the Project and future conditions with the Project. Figure 8 depicts the proposed number of lanes at key intersection and roadway sections with the mitigation measures described in the following sections. Figure 9 shows a schematic drawing of Kamehameha Highway through Wahiawa Town with the year 2010 conditions with Project mitigation.

Overview of Mitigation Measures

The following paragraphs provide an overview of the major mitigation necessary with and without the Project.

Future Without the Project - Under future conditions without the Project, Kamehameha Highway would experience operational problems through Wahiawa during the PM peak hour. In addition, the unsignalized intersections of Kamehameha Highway/Kamananui Road and Wilikina Drive/Kamananui Road would experience significant congestion. Mitigation for these conditions are listed below:

Location	Improvement(s)
Kamehameha Highway/Olive Avenue	- Add a westbound left-turn lane on Olive Avenue within the existing roadway width - Restrict on-street parking to accommodate the left turn lane
Kamehameha Highway/California Avenue	- Restripe Kamehameha Highway lanes - Restripe the westbound California Avenue approach - Restrict on-street parking
Kamehameha Highway/Kamananui Road	- Install a northbound acceleration lane
Wilikina Drive/Kamananui Road	- Install traffic signal

Future Conditions With the Project - Operational problems on Kamehameha Highway would be exacerbated by the addition of Project-generated traffic. In addition, operations on Wilikina Drive would be worsened significantly by the Project. Increased traffic in the area of the Project would

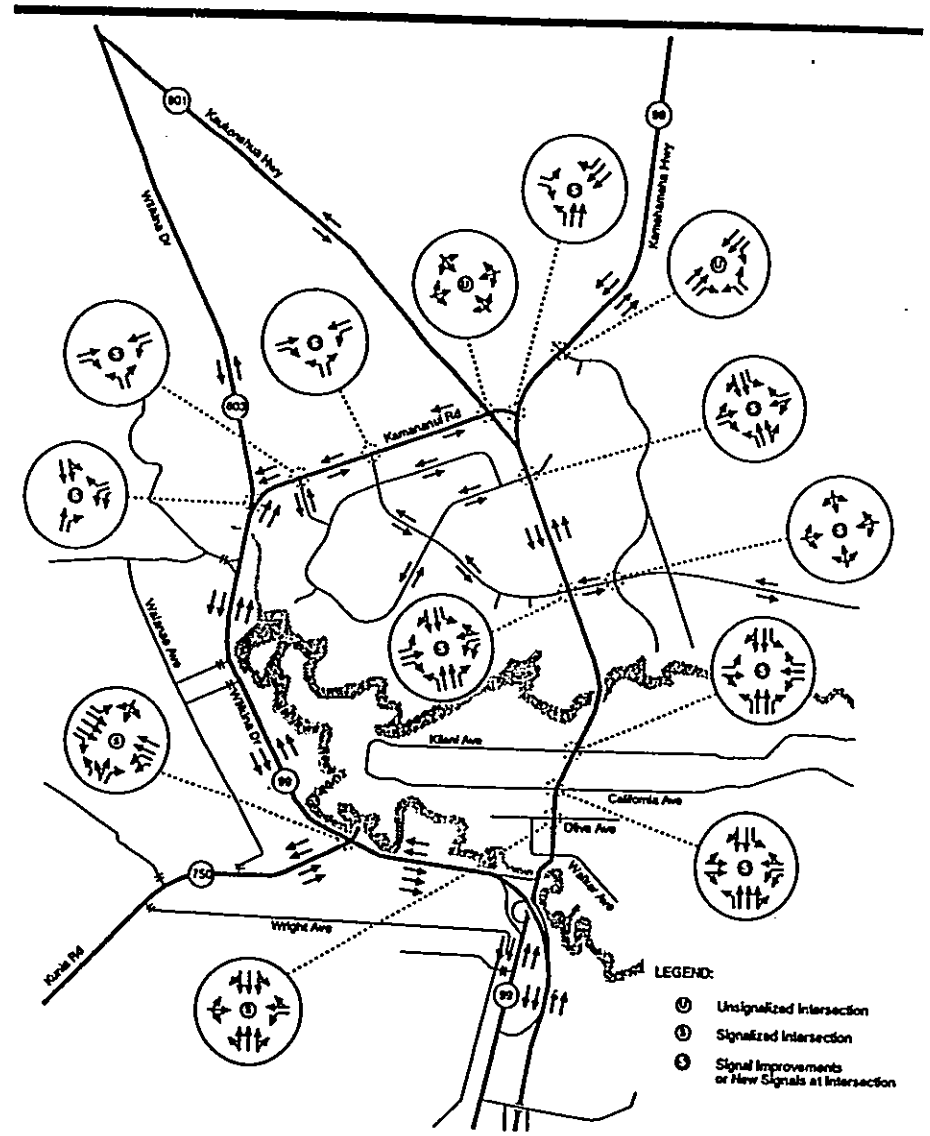


Figure 8
PROPOSED ROADWAY LANES WITH PROJECT

WAHIAWA - GALBRAITH TRUST LANDS TRAFFIC STUDY

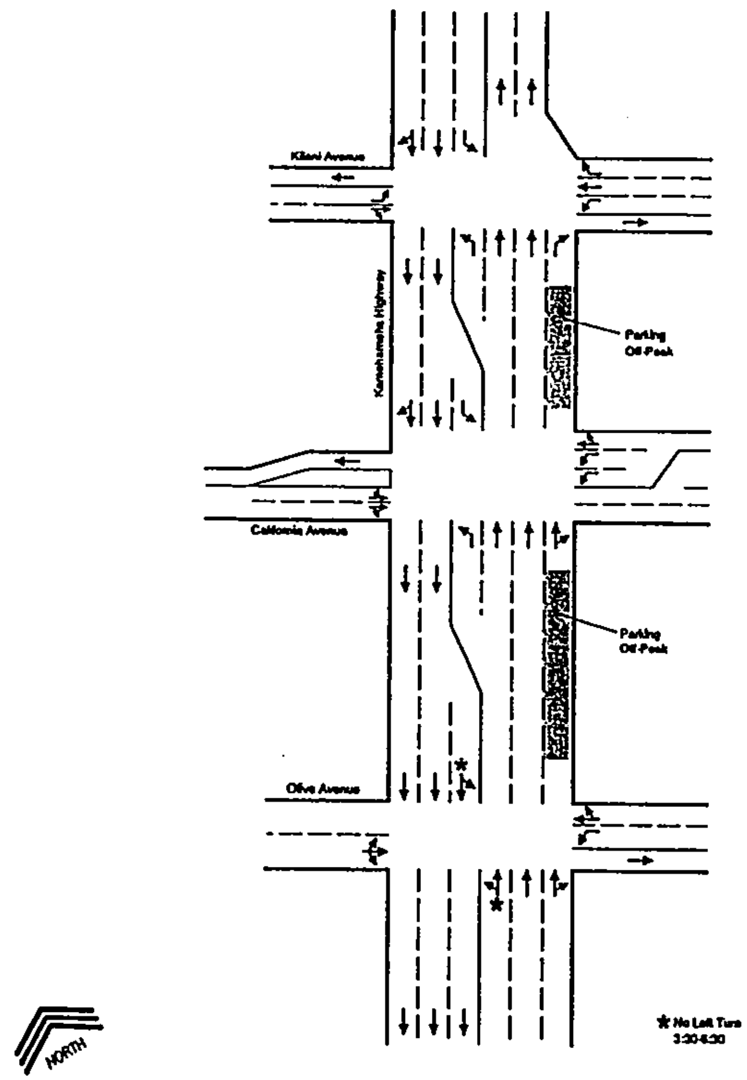


Figure 9

YEAR 2010 WITH PROJECT MITIGATION ON KAMEHAMEHA HIGHWAY THROUGH WAHIAWA TOWN

WAHIAWA - GALBRAITH TRUST LANDS TRAFFIC STUDY

substantially increase traffic delays at all of the unsignalized intersections. Additional mitigation measures, beyond those described for future conditions without the Project are listed below:

Location	Improvement(s)
Kamehameha Highway/Olive Avenue	- Restrict northbound and southbound left-turn movements during the PM peak period (3:30 to 6:30 PM)
Kamehameha Highway/California Avenue	- Modify signal phasing
Kamehameha Highway/Kilani Avenue	- Add a westbound right-turn lane - Restrict on-street parking - Modify signal phasing
Kamehameha Highway/Kamananui Road	- Install traffic signal
Wilikina Drive/Kunia Road	- Add a second northbound left-turn lane - Add a third southbound through lane
Wilikina Drive/Kamananui Road	- Add a second westbound left-turn lane - Add a second southbound through lane
Kaukonahua Highway/Kamananui Road	- Add an eastbound acceleration lane
Wilikina Drive	- Widen the segment between Kunia Road and H-2 to five lanes (three southbound and two northbound) - Widen the segment from the McNair Gate to Kamananui Road to four lanes
Kamananui Road	- Widen the segment between Wilikina Drive and the Project's western-most access point to four lanes

Assessment of Individual Mitigation Measures

Individual impacts and mitigation are presented below. Table 14 presents traffic operations with implementation of mitigation measures for year 2010 conditions with the Project.

Table 14

MITIGATED INTERSECTION CONDITIONS FOR YEAR 2010 WITH THE PROJECT
Wahiawa – Gabraith Lands Traffic Study

	AM Peak Hour			PM Peak Hour		
SIGNALIZED INTERSECTIONS	V/C Ratio	Delay (sec./veh.)	LOS	V/C Ratio	Delay (sec./veh.)	LOS
Kamehameha Highway/Olive Avenue	0.86	23.3	C	0.78	11.7	B
Kamehameha Highway/California Avenue	0.75	19.9	C	0.81	22.1	C
Kamehameha Highway/Kilani Avenue	0.75	32.9	D	0.89	32.2	D
Kamehameha Highway/Whitmore Avenue	0.87	21.8	C	0.94	33.5	D
Wilikina Drive/Kunia Road	0.58	21.7	C	0.82	28.7	D
Kamehameha Highway/Kamananui Road	0.40	5.2	B	0.63	8.3	B
Wilikina Drive/Kamananui Road	0.77	21.6	C	0.89	24.2	C

UNSIGNALIZED INTERSECTIONS	AM Reserve Capacity	AM LOS	PM Reserve Capacity	PM LOS
Kaukonahua Highway/Kamananui Road				
Kaukonahua NB right/thru/left	318	B	126	D
Kaukonahua SB right/thru/left	230	C	103	D
Kamananui EB left	768	A	745	A
Kamananui WB left	865	A	644	A

Key: | 0.77 | 21.6 | C | — shading indicates conditions after mitigation.

Source: Wilbur Smith Associates, October, 1992.

MITZMOR

Kamehameha Highway/Olive Avenue

Without the Project - This intersection is impacted during the PM peak hour during which time it operates at LOS F.

Mitigation - The addition of a westbound left-turn lane would improve the operation of the intersection to LOS D conditions.

With the Project - This intersection functions at LOS F during both peak hours under future with Project conditions.

Mitigation - The westbound left-turn lane which mitigated future conditions without the Project, in combination with a PM peak period (3:30 - 6:30 PM) restriction of northbound and southbound left-turns, would mitigate Project conditions. This improvement would improve operations to LOS C during the AM peak hour and LOS B during the PM peak hour.

Kamehameha Highway/California Avenue

Without the Project - This intersection would operate at LOS F conditions during the PM peak hour.

Mitigation - The mitigation at this location would involve restriping Kamehameha Highway to provide three northbound through lanes and a northbound left-turn lane and two southbound through lanes and a left-turn lane. This restriping could be done within the existing roadway width. In addition to this restriping, the westbound California Avenue approach would be restriped to provide a shared right/through lane and two left-turn lanes. With this mitigation the intersection would operate at LOS C during the PM peak hour.

With the Project - This intersection would operate at LOS F during both peak hours under future conditions with the Project.

Mitigation - The same mitigation which was used under future conditions without the Project plus modifying the signal phasing would mitigate this intersection to LOS C conditions during the AM and PM peak hours. The signal should be modified to operate as a four-phased signal with protected left-turn phases on both streets.

Kamehameha Highway/Kilani Avenue

Without the Project - No mitigation.

With the Project - This intersection would function at LOS F during both peak hours under future conditions with the Project.

<u>Mitigation</u> - The addition of a westbound right-turn lane and improvements to the signal would improve the operations of this intersection to LOS D conditions during both peak hours. The addition of the westbound right-turn lane would necessitate the removal of on-street parking on the north side of Kilani Avenue near the intersection. The traffic signal should be modified to provide a four-phased signal with protected left-turn phases.

<u>Wilikina Drive/Kunia Road</u>

Without the Project - No mitigation.

With the Project - This intersection would function at LOS E during the AM peak hour and LOS F during the PM peak hour under future conditions with the Project.

<u>Mitigation</u> - Mitigation at this location would involve the addition of a northbound left-turn lane on Wilikina Drive, and the addition of a third southbound through lane on Wilikina Drive. The third southbound through lane would continue to the junction with H-2. This mitigation would improve operations to LOS C during the AM peak hour and LOS D during the PM peak hour.

<u>Kamehameha Highway/Kamananui Road</u>

Without the Project - The shared eastbound right/through movement on Kamananui Road at this intersection would operate at LOS E during the AM peak hour and LOS F during the PM peak hour.

<u>Mitigation</u> - The addition of a northbound acceleration lane on Kamehameha Highway for eastbound left-turn traffic from Kamananui Road would improve this intersection's eastbound shared movement to LOS D in the AM peak hour and LOS E during the PM peak hour. Although the PM peak hour LOS E would not be desirable, the intersection would not warrant signalization.

With the Project - The shared eastbound right/through movement would operate at LOS F conditions during both peak hours under future conditions with the Project.

<u>Mitigation</u> - Based on an assessment of peak hour volumes, this intersection would meet signal warrants as a result of traffic added by the Project. When signalized, it would operate at LOS B during both peak hours.

<u>Kaukonahua Highway/Kamananui Road</u>

Without the Project - No mitigation.

With the Project - The northbound shared left/through/right-turn movement at this intersection would operate at LOS E conditions during the AM peak hour and LOS F conditions during the PM peak hour.

<u>Mitigation</u> - The construction of a westbound acceleration lane within the median on Kamananui Road would facilitate easier northbound left-turn movements. This mitigation would improve the northbound shared movement to LOS B during the AM peak hour and LOS D during the PM peak hour.

<u>Wilikina Drive/Kamananui Road</u>

Without the Project - The westbound Kamananui Road left-turn movement would function at LOS F conditions during the AM and PM peak hour conditions.

<u>Mitigation</u> - Based on peak hour volumes, this intersection would meet signal warrants and signalization is the recommended mitigation. When signalized, the intersection would operate at LOS B conditions during both the AM and PM peak hours.

With the Project - The westbound left-turn movement would continue to function at LOS F under Project conditions.

<u>Mitigation</u> - The mitigation described for future conditions without the Project plus the addition of a second westbound left-turn lane and a second southbound through lane would improve the intersection to LOS B conditions during the AM peak hour and LOS C conditions during the PM peak hour. The two southbound through lanes would continue through to the Funston/Macomb Gate where Wilikina already provides two southbound through lanes. In addition to this, two northbound through lanes should also be provided between the Funston/Macomb Gate and Kamananui Road.

6. INTERIM YEAR ANALYSIS

This section presents an interim year analysis in order to asses what mitigation would be necessary by completion of Phase I of the Project. Phase I of the Project would be expected to be occupied by the year 1998. Phase I of the Project would consist of the construction of 500 multi-family housing units, 100 single-family housing units, a 10 acre business center, one acre of neighborhood commercial, and a variety of other uses including an elementary school, parks, civic uses, and a park-and-ride lot. The area of the site to be developed would be internal zones 9 and 10 and portions of zones 11, 13, and 15 (see Figure 5).

Roadway Assumptions

The only planned roadway improvement in the immediate area of the Project is the widening of Kamehameha Highway to four-lanes from Wahiawa north. It is not anticipated that this improvement will be implemented by the year 1998, so analysis in this section does not include this improvement project.

In terms of internal roadways, Phase I of the Project would be served by a single access point which would be the intersection of the western end of Whitmore Avenue extension with Kamananui Road. The western end of Whitmore Avenue would not be extended through the Project to connect to the existing eastern segment of Whitmore Avenue at Kamehameha Highway for Phase I of the Project.

Non-Project Traffic Increases

The annual growth rates identified in Section 3 were used to calculate traffic without the Project for the year 1998. A 16.2 percent increase was estimated for traffic north of Wahiawa on Kamehameha and Kaukonahua Highways. The whole number increase resulting from this factor was then carried south. A 4.3 percent increase was estimated for the cross streets in Wahiawa.

Trip Generation

The trip generation rates employed in the analysis of Project Buildout were also used to analyze Phase I of the Project. Those rates are shown in Table 9. Table 15 shows the estimated trips generation characteristics for Phase I of the Project. The Project would generate an estimated 5,493 daily vehicle trips during Phase I with 541 AM peak hour trips (206 inbound and 335 outbound) and 531 PM peak hour trips (316 inbound and 216 outbound). When compared to the generation of the Project at buildout, Phase I represents about 14 percent of the total Project.

Table 15
Project Phase I Trip Generation
Wahiawa -- Galbraith Lands Traffic Study

TRIP GENERATION

Land Use	Quantity	Daily Trips	AM Peak Trips	AM Peak In	AM Peak Out	PM Peak Trips	PM Peak In	PM Peak Out
Residential								
Single-Family	100 units	955	74	19	55	101	66	35
Multi-Family	500 units	3,235	255	43	212	315	214	101
Commercial								
Business Center	39.60 KSF	569	64	55	10	59	13	46
Neighborhood Commercial	3.96 KSF	161	20	11	8	25	12	13
Other								
Elementary School	8 acres	480	125	75	50	24	7	17
Civic	2 acres	80	3	3	1	6	3	3
Parks	6 acres	13	1	0	0	1	1	1
		5,493	541	206	335	531	316	216

NOTE:
[1] KSF = thousand square feet.

Source: Wilbur Smith Associates, October, 1992.

TRIPGEN/MDR

Distribution

As with previous analysis, a portion of the total trips were assumed to be internal trips. Internal trip percentages are listed below for each land use.

Land Use	Percent Internal Trips
• Residential	16 percent
• Employee-Based (Business Center)	15 percent
• Neighborhood Commercial	50 percent
• Other (School, Parks, and Civic Uses)	90 percent

The same external distribution assumptions as were assumed for Project buildout conditions were assumed for Phase I of the Project.

Because Whitmore Avenue would not provide through access to Kamehameha Highway, trips between the Project and the South Shore are assigned primarily to Wilikina Drive instead of Kamehameha Highway.

Traffic Operations

Figure 10 depicts the projected traffic volumes for the year 1998 with Phase I of the Project. With the much smaller traffic increases anticipated for 1998, the number of locations analyzed during this interim year analysis was limited to four intersections and two roadway segments. The other intersections and roadway segments should not be significantly affected with Phase I of the Project conditions. The study locations are:

- Wilikina Drive/Kamananui Road;
- Wilikina Drive/Kunia Road;
- Kamehameha Highway/Kilani Avenue;
- Kamehameha Highway/California Avenue;
- the southbound ramp to the H-2 Highway from Kamehameha Highway; and
- the segment of Wilikina Drive south of Kamananui Road.

The segment of Wilikina Drive south of Kamananui Road had not been analyzed in great depth in analysis of year 2010 conditions with buildout of the Project because it was assumed that the conditions at the intersection of Wilikina Drive/Kamananui Road would determine the number of lanes necessary for this segment. Under year 2010 conditions with the Project, it was recommended that this section be widened to four-lanes.

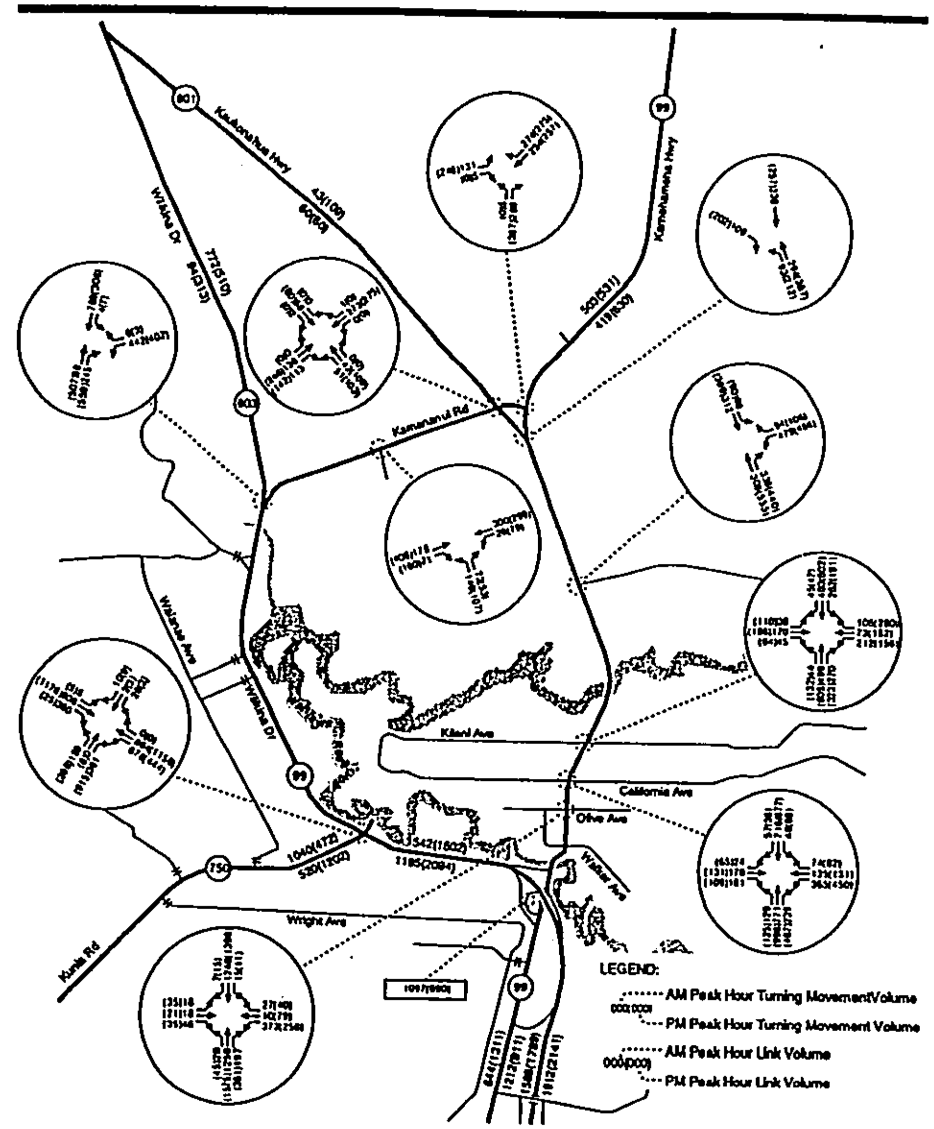


Figure 10
INTERIM YEAR AM AND PM PEAK HOUR TRAFFIC VOLUMES WITH PHASE I OF PROJECT
WAHIAWA - GALBRAITH TRUST LANDS TRAFFIC STUDY

Table 16 summarizes the projected conditions at these intersection under year 1998 conditions with Phase I of the Project. As the table shows, two of the study intersections would be impacted with cumulative growth through the year 1998 and Phase I of the Project: the intersection of Kamehameha Highway/California Avenue would operate at LOS E during the PM peak hour; and the westbound left-turn movement of the unsignalized intersection of Wilikina Drive/Kamananui Road would operate at LOS F during both peak hours.

At the southbound on-ramp, traffic volumes would be 1,097 vehicles during the AM peak hour and 690 vehicles during the PM peak hour. This represents 78 percent and 49 percent of capacity during the AM and PM peak hours respectively. The on-ramp would be expected to operate with little congestion.

The segment of Wilikina Drive south of Kamananui Road has projected traffic volumes of 1,543 vehicles during the AM peak hour and 1,774 vehicles during the PM peak hour. For purposes of analysis, this segment was defined as a two-lane highway and has an estimated carrying capacity of 1,800 vehicles at LOS D and 2,600 vehicles at LOS E (see Table 2). As a two-lane roadway, this section of Wilikina Drive would function at LOS D during both peak hours.

Access Evaluation

With Phase I of the Project, only one access would be provided to the Project. This access would be on Kamananui Road at the location of the proposed connection of Whitmore Avenue/Kamananui Road.

Because prevailing speeds on Kamananui Road are high, it was assumed that the Project would provide a westbound left-turn bay and an eastbound deceleration lane for right-turning vehicles. These lanes would remove slower turning traffic from through lanes on Kamananui Road. In addition, it was assumed that the Project access would provide two approach lanes - a left-turn lane and a right-turn lane.

An analysis of the operations of this intersection with these assumptions resulted in the following levels of service:

	AM Peak Hour Reserve Capacity	AM Peak Hour Level-of-Service	PM Peak Hour Reserve Capacity	PM Peak Hour Level-of-Service
Northbound Access left-turn	138	D	30	E
Northbound Access right-turn	641	A	449	A
Westbound Kamananui left-turn	749	A	428	A

Table 16

INTERSECTION CONDITIONS FOR YEAR 1998 WITH PHASE I OF PROJECT
Wahiawa – Galbraith Lands Traffic Study

SIGNALIZED INTERSECTIONS	AM Peak Hour V/C Ratio	AM Peak Hour Delay (sec./veh.)	AM Peak Hour LOS	PM Peak Hour V/C Ratio	PM Peak Hour Delay (sec./veh.)	PM Peak Hour LOS
Kamehameha Highway/California Avenue	0.75	20.3	C	1.05	56.0	E
Mitigated (1)	0.57	17.1	C	0.86	22.0	C
Kamehameha Highway/Kilani Avenue	0.76	14.1	B	0.90	20.7	C
Wilikina Drive/Kunia Road	0.35	22.0	C	0.52	20.5	C

UNSIGNALIZED INTERSECTIONS	AM Reserve Capacity		AM LOS	PM Reserve Capacity		PM LOS
Wilikina Drive/Kamananui Road						
Kamananui WB left	-247		F	-237		F
Kamananui WB right	883		A	438		A
Wilikina SB left	860		A	362		B
Mitigated (2)	0.73	12.3	B	0.63	7.2	B

NOTES:
(1) Mitigation at this location includes restriping the westbound approach to provide a signal shared right/through lane and two left-turn lanes.
(2) Mitigation at this location is the signalization of the intersection. No additional improvements would be necessary beyond signalization.

Source: Wilbur Smith Associates, October, 1992.

trwt.wk

During the PM peak hour the operation of the northbound left-turn movement would be LOS E, indicating that vehicles attempting to execute this movement would experience very long delays.

Mitigation

For year 1998 conditions with Phase I of the Project, three mitigation measures would be necessary.

1. Restripe the westbound approach to the intersection of Kamehameha Highway/California Avenue to provide a single right/through lane and two left-turn lanes. No additional roadway width would be necessary for this mitigation. With this modification, the intersection would function at LOS C during both peak hours. See Table 16 for V/C ratio and delay values.

2. The intersection of Wilikina Drive/Kamananui Road would require signalization. No additional mitigation would be necessary beyond signalization and the intersection would function at LOS B during both peak hours when signalized.

3. A westbound left-turn bay and an eastbound deceleration lane for right-turning vehicles should be provided at the Project's access road intersection with Kamananui Road. Even with these lanes, the left-turn movement from the Project's access road would experience LOS E conditions during the PM peak hour. Peak hour volumes suggest that the intersection might meet signal warrants by the year 1998 with Phase I of the Project. Traffic volumes at this intersection should be monitored to determine if the intersection would satisfy traffic volume warrants. The intersection should be signalized when it has met warrants.

Of the above listed mitigation, mitigation numbers 2 and 3 would be expected to mitigate impacts created by the Project. However, the restriping of the westbound approach to the intersection of Kamehameha Highway/California Avenue (Mitigation number 1) would be necessary either with or without the Project in the year 1998.

Table A

LEVEL-OF-SERVICE CRITERIA FOR FREEWAYS
Wahiawa – Galbraith Lands Traffic Study – Response to Comments

Level of Service	FREE-FLOW SPEED 60 MPH		
	Average Speed (MPH)	Maximum V/C Ratio	Maximum Service Flow Rate (pchpl)
A	60	0.33	720
B	60	0.55	1,200
C	59	0.75	1,650
D	57	0.89	1,940
E	55	1.00	2,200

NOTES:

Los F is characterized by highly unstable and variable traffic flow.
pcphpl = passenger cars per hour per lane.

Source: "Highway Capacity Manual", Revised Chapter 7, Page 7–8; and Wilbur Smith Associates, October, 1992.

RCT1/MDR

Table B

YEAR 2010 PEAK HOUR FREEWAY VOLUMES AND OPERATIONS
Wahiawa – Galbraith Lands Traffic Study – Response to Comments

AM PEAK HOUR	ESTIMATED CAPACITIES		YR 2010 WITHOUT THE PROJECT						YR 2010 WITH THE PROJECT					
			NB/WB			SB/EB			NB/WB			SB/EB		
Freeway Segment	NB/WB	SB/EB	Volume	V/C	LOS	Volume	V/C	LOS	Volume	V/C	LOS	Volume	V/C	LOS
H–2 Freeway														
Between Wahiawa and Mililani	8,800	8,800	5,058	0.57	C	5,271	0.60	C	5,419	0.62	C	5,657	0.64	C
Between Mililani and Waipio	8,800	8,800	5,525	0.63	C	5,915	0.67	C	5,886	0.67	C	6,301	0.72	C
Between Waipio and Waiawa	8,800	8,800	7,895	0.90	E	10,137	1.15	F	8,256	0.94	E	10,523	1.20	F

PM PEAK HOUR	ESTIMATED CAPACITIES		YR 2010 WITHOUT THE PROJECT						YR 2010 WITH THE PROJECT					
			NB/WB			SB/EB			NB/WB			SB/EB		
Freeway Segment	NB/WB	SB/EB	Volume	V/C	LOS	Volume	V/C	LOS	Volume	V/C	LOS	Volume	V/C	LOS
H–2 Freeway														
Between Wahiawa and Mililani	8,800	8,800	6,422	0.73	C	5,376	0.61	C	6,859	0.78	D	5,822	0.66	C
Between Mililani and Waipio	8,800	8,800	7,312	0.83	D	6,057	0.69	C	7,749	0.88	D	6,503	0.74	C
Between Waipio and Waiawa	8,800	8,800	10,455	1.19	F	10,031	1.14	F	10,892	1.24	F	10,477	1.19	F

Source: Wilbur Smith Associates, April 1993.

RCT2/MDR

Table C

CONDITIONS WITH KAMEHAMEHA HIGHWAY AS A TWO–LANE FACILITY NORTH OF KILANI AVENUE

Wahiawa – Galbraith Lands Traffic Study – Response to Comments

	Cumulative Without the Project						Cumulative With the Project					
Kamehameha Highway	Northbound			Southbound			Northbound			Southbound		
	Volume	V/C	LOS	Volume	V/C	LOS	Volume	V/C	LOS	Volume	V/C	LOS
Btwn Kilani and Whitmore Avenues (1)												
AM Peak Hour	802	0.49	A	917	0.56	A	1233	0.75	C	1392	0.84	D
PM Peak Hour	1083	0.66	B	953	0.58	A	1625	0.98	E	1523	0.92	E
Btwn Whitmore Ave and Kamananui Rd (1)												
AM Peak Hour	516	0.31	A	499	0.30	A	613	0.37	A	599	0.36	A
PM Peak Hour	718	0.44	A	543	0.33	A	834	0.51	A	789	0.48	A

	Cumulative Without the Project					Cumulative With the Project				
	NB	SB	Total	V/C	LOS	NB	SB	Total	V/C	LOS
North of Kamananui Road (2)										
AM Peak Hour	533	637	1,170	0.42	C	595	696	1,291	0.46	D
PM Peak Hour	807	666	1,473	0.53	D	879	736	1,615	0.58	D

Notes:

(1) Analysis based on signalized intersection V/C ratio relationships with a capacity of 1,650 vehicles per hour.

(2) Analysis based on two–lane rural highway analysis with a two–directional capacity of 2,800 vehicles per hour.

Source: Wilbur Smith Associates, April, 1993.

RCT3/MDR

Table D

INTERSECTION CONDITIONS WITH KAMEHAMEHA HIGHWAY AS A TWO-LANE FACILITY NORTH OF KILANI AVENUE
Wahiawa – Galbraith Lands Traffic Study – Response to Comments

Signalized Intersections	Cumulative Without the Project V/C	Delay	LOS	Cumulative With the Project V/C	Delay	LOS
Kamehameha Highway at Whitmore Avenue						
AM Peak Hour	0.71	14.9	B	0.982	38.6	D
PM Peak Hour	0.79	19.2	C	1.21	**(1)	F
Kamehameha Highway at Kamananui Road (1)						
AM Peak Hour	0.42	9.0	B	0.54	10.4	B
PM Peak Hour	0.57	10.5	B	0.72	12.2	B

Notes:
(1) Delay values cannot be predicted when a volume–to–capacity ratio exceeds 1.20.
(2) This analysis assumes the elimination of the leg of Kaukonahua Highway between Kamehameha Highway and Kamananui Road.

Source: Wilbur Smith Associates, April, 1993.

RCT4/MDR

APPENDIX L

Infrastructure Report
Sam O. Hirota, Inc.

WAHIAWA LANDS INFRASTRUCTURE REPORT
DRAFT CONCEPT DEVELOPMENT PLAN
Galbraith Trust Estate
Hawaiian Trust Company, Ltd., Trustee
Tax Map Key 1-7-01

Prepared By

SAM O. HIROTA, INC.
Engineers and Surveyors
864 South Beretania Street
Honolulu, Hawaii 96813

December 22, 1992

TABLE OF CONTENTS

I. INTRODUCTION

This report explores the existing on-site conditions and potential requirements for grading, drainage, road construction and required utilities to support a concept development plan for the 2,000-acre Galbraith Trust Estate land on Oahu.

The George Galbraith Trust Estate owns approximately 2,000 acres of land just north of Wahiawa, Oahu, Tax Key No. 1-7-01 (see Figures 1, 2 and 3). This land is currently leased to Del Monte Fresh Produce (Hawaii), Inc., and is actively used for the cultivation of pineapple. The lease will expire on December 31, 1994. The Hawaiian Trust Company Ltd., as trustee for the estate, is exploring other alternative uses for the land. Accordingly, the Hawaiian Trust Company has engaged the firm of Helber, Hastert & Fee Planners (HH&F) to prepare a master plan for the best use of the area.

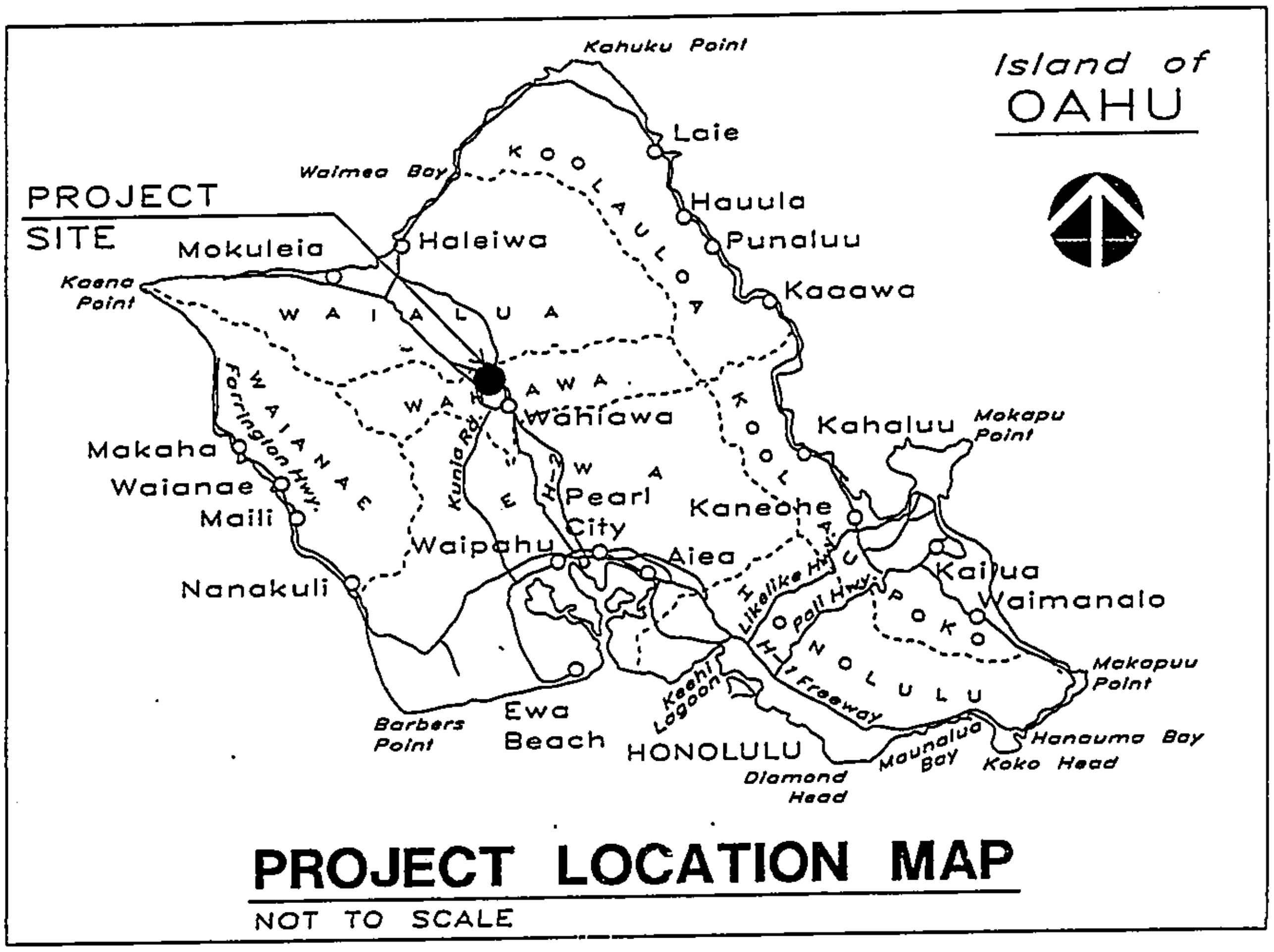
The Draft Concept Development Plan conceived by Helber, Hastert & Fee, Planners (HH&F) provides for a combination of single and multi family housing, a commercial complex, a school, a pineapple museum, civic center site, park areas and an 18-hole golf course (see Figure 4 and Table 1). The planned development will occupy 892 acres while the remaining land would be reserved for continued farming. The implementation of the master plan will require rezoning for the proposed uses since most of the project site is now zoned for agriculture use. The exception is the small portion of the site along Wahiawa Reservoir which is zoned for forest preservation.

Land Use And Zoning

The project site is primarily zoned as an agriculture area, Zone AG-1, with a small portion of forest preservation along Wahiawa Reservoir. The present use of the land is primarily as a pineapple plantation, operated and managed by Del Monte Fresh Produce, Hawaii. The land may be identified on the tax maps as TMK: 1-7-01 (see Figure 2).

Topography

The site has a gentle two percent slope upward from an elevation of around 880 feet around Wahiawa Reservoir northeast to an elevation of about 985 feet and then downwards towards Poamoho Stream. Grading within the project area should not present any great difficulty. However, the recommendations of a geotechnical engineer should be obtained to establish the cut and fill slopes and pavement structure design. A grading permit would have to be obtained from the City and the work would have to comply with the Department of Health Administrative Rules (Reference 4) and City ordinances (Reference 15) with respect to dust and erosion control. The maximum size of a single parcel of land that can be opened for grading or grubbing is 15 acres. The county also requires the preparation of a grading and erosion control plan and a determination of degree of the erosion and sedimentation hazard.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Hauula
Punaluu
Haleiwa
Mokuleia
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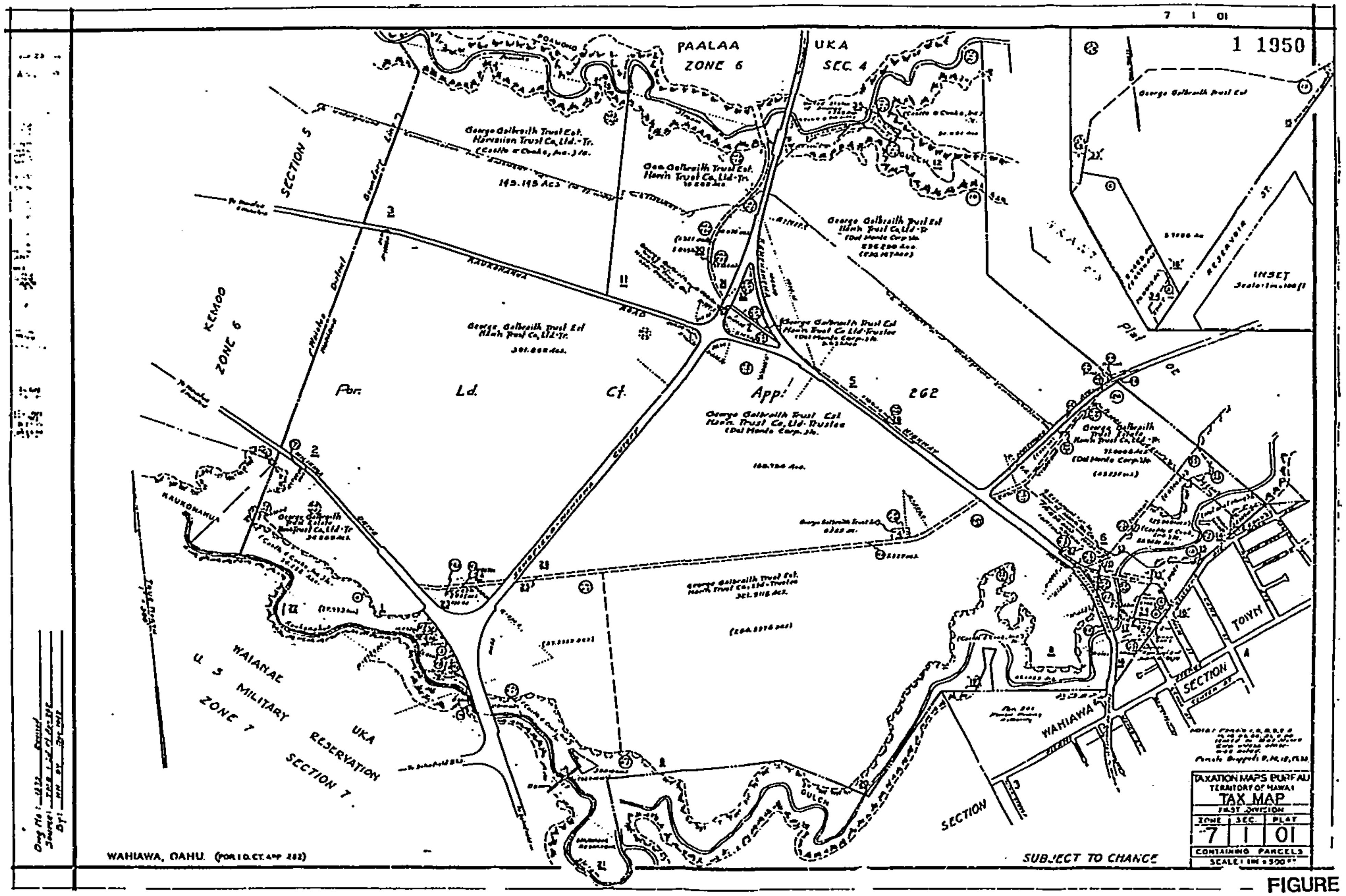
WAIALUA
KOOLAULOA
WAHIAWA
Wahiawa
Kahaluu
Mokapu Point
Makaha
Waianae
Maili
Nanakuli
WAIANAE
Farrington Hwy.
Kunia Rd.
H-2
EWA
Pearl
City
Kaneohe
KOOLAUPOKO
Waipahu
Aiea
Kailua
Waimanalo
Likelike Hwy.
Pali Hwy.
H-1 Freeway
HONOLULU
Keehi Lagoon
Makapuu Point
Barbers Point
Ewa
Beach
HONOLULU
Diamond Head
Maunalua Bay
Hanauma Bay
Koko Head
PROJECT LOCATION MAP
NOT TO SCALE

FIGURE 1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CONTAINING PARCELS

FIGURE 2

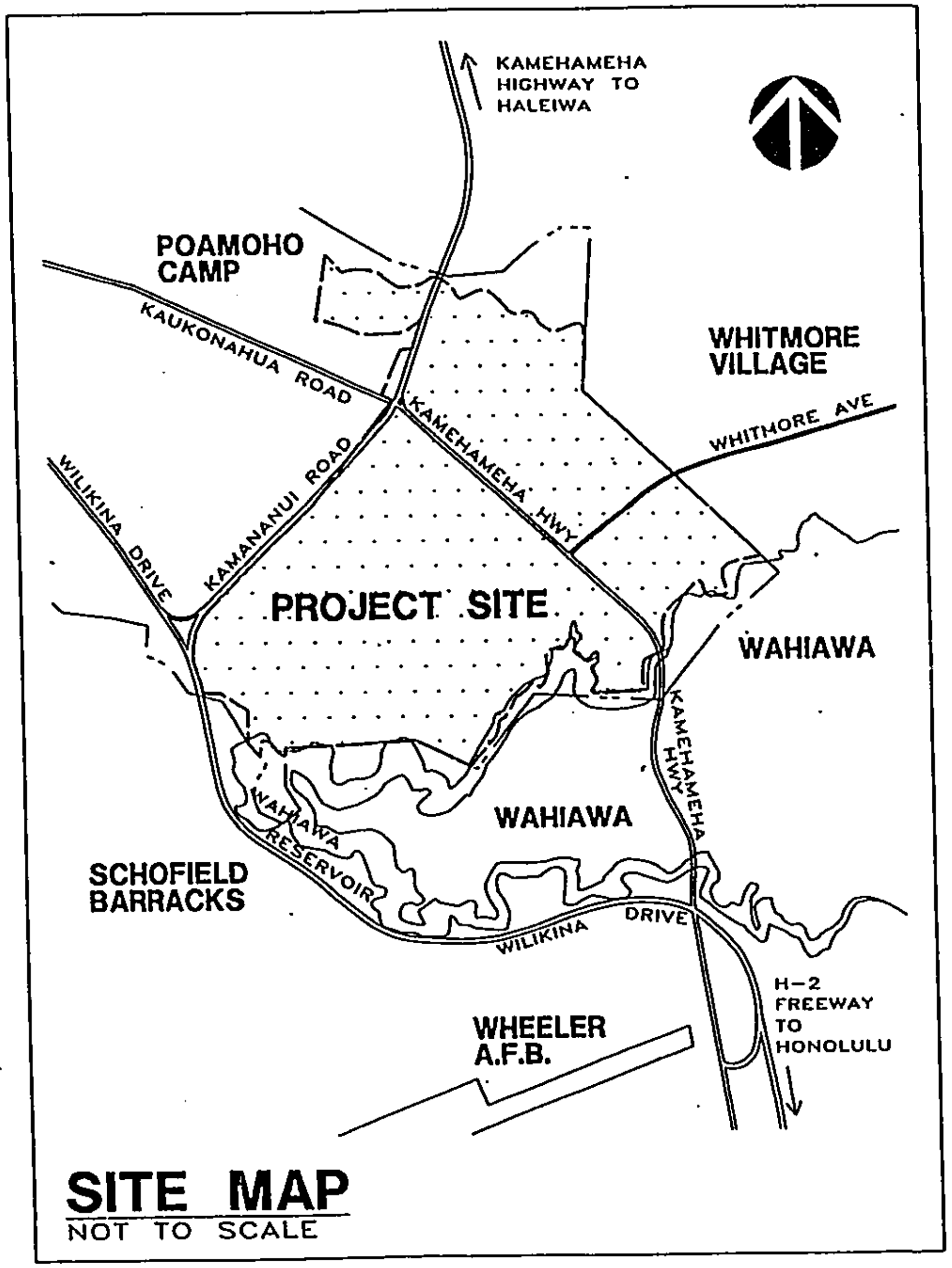


FIGURE 3

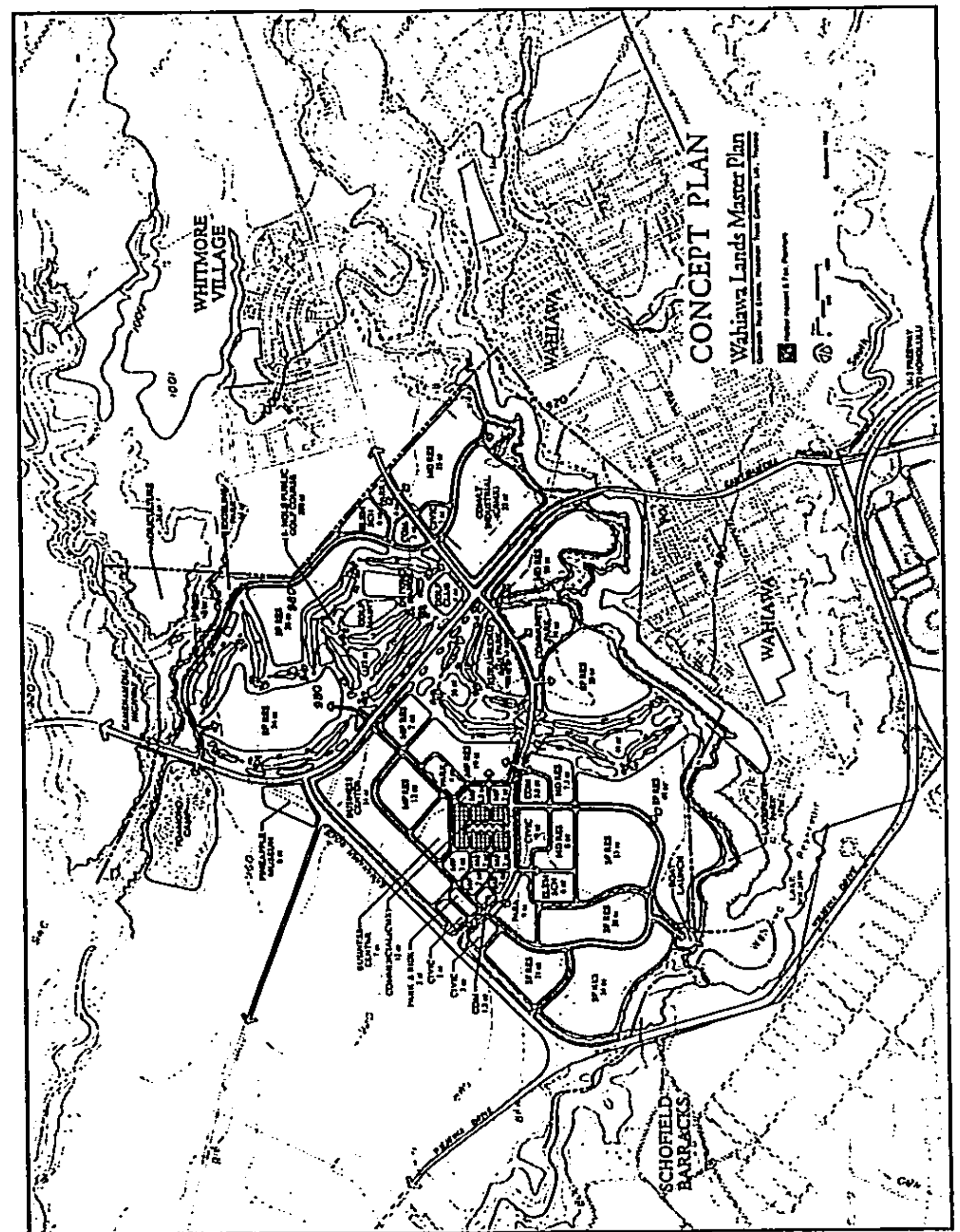


FIGURE 4

DEVELOPMENT CONCEPT PLAN

TABLE 1

LAND USE		AREA (ACRES)	DENSITY (Du/Ac)	DWELLING UNITS
Residential				
Single Family (S.F.)		247.0	6.0	1,482
Medium Density (M.D.)		66.0	10.0	660
Multi-Family (M.F.)		54.0	15.0	810
	Sub-total	367.0	10.3 (Ave.)	2,952
Commercial				
Convenience		10.0		
Mixed Use (Comm/Res)		12.0	15.0	148
Commercial/Industrial Mixed Use (C/IMX)		33.0		
Business Center (CMS)		38.0		
	Sub-total	93.0		148
Other				
Elementary Schools (2)		12.0		
Civic		17.0		
Park and Ride		2.0		
18-Hole Public Golf Course		200.0		
Golf Clubhouse		4.0		
Parks		31.0		
Ridgeline Park		14.0		
Lakefront Park		45.0		
Poamoho Camp		32.0		
Pineapple Museum		6.0		
Kukaniloko Park		11.0		
Open Space/Circ.		58.0		
	Sub-total	432.0		
TOTAL		892.0 *		3,100

* Excludes reservoir, some gulch lands, Wahiawa Parcels and 1,200 acres north of Kamananui Road.

HELBER, HASTERT & FEE, Planners
September 14, 1992
Revised October 14, 1992

Soils

According to the U.S. Soil Conservation Service (Reference 1) the top soil in the area consist mostly of silty red clays (WaA and Wab) about 12 inches thick with approximately 48" of silty clay subsoil (see Figure 5). The underlying material is weathered basic igneous rock. The acidity of the soil is medium in the surface layer and medium to neutral in the sub soil. Permeability is moderately rapid, runoff is slow, and the erosion hazard is no more than slight.

II. DRAINAGE

Existing Conditions

Topographic maps indicate that runoff from about 87 percent of the site now flows in a southerly direction into Wahiawa Reservoir while runoff from the remainder of the site flows north into Poamoho Stream. Runoff from the existing pineapple fields generally follows the pattern of contour cultivation, along field roads and gullies. Ponding may occur in certain low areas; however, over the years ditches and culverts have been installed to enhance the flow of storm water runoff. The City's Storm Drainage Standards (Reference 5) include a design curve, Figure 6, which is to be used for estimating runoff for areas of over 100 acres in size and for a storm with a recurrence interval of 100 years. Using this design chart, the estimated peak runoff from the 892 acres to be developed is 4,400 cubic feet per second (cfs), (see Appendix C). Since the intensity of a 1-hr rainfall at the site is 3 inches for a 100-year storm and 2 inches for a 10 year storm, the runoff from the later would be 2,930 cfs.

Runoff from the northern 13 percent of the site flows towards the North into Poamoho Stream. The peak discharge into the stream for a 100-year recurrence storm is estimated to be 840 cfs (see Appendix C). For a 10-year storm, the estimated runoff from this area is 560 cfs. So the total 10-year storm runoff is 3,490 cfs.

Soil conditions allow moderately rapid permeability, thus runoff in most areas is slow. Erosion caused by runoff is also slight in most areas.

The Federal Emergency Management Agency, FEMA, which evaluates flood hazards and publishes flood insurance rate maps, has not determined if a flood hazard exists at the site of the proposed development.

The City's Storm Drainage Standards (Reference 5) prescribe the use of the Rational Formula for estimating runoff from areas of less than 100 acres in size and the use of this formula is applicable for estimating runoff from different land uses in the proposed development. The formula is, $Q = c*Cf*I*A$ in which c is a coefficient of runoff for various land uses, Cf is a correction factor to be applied to adjust the intensity of a storm with a recurrence interval of 10 years and a duration of one hour to that of a storm with the same recurrence interval but with a duration equal to the time of concentration of flow from the highest to the lowest elevation of the area under consideration.

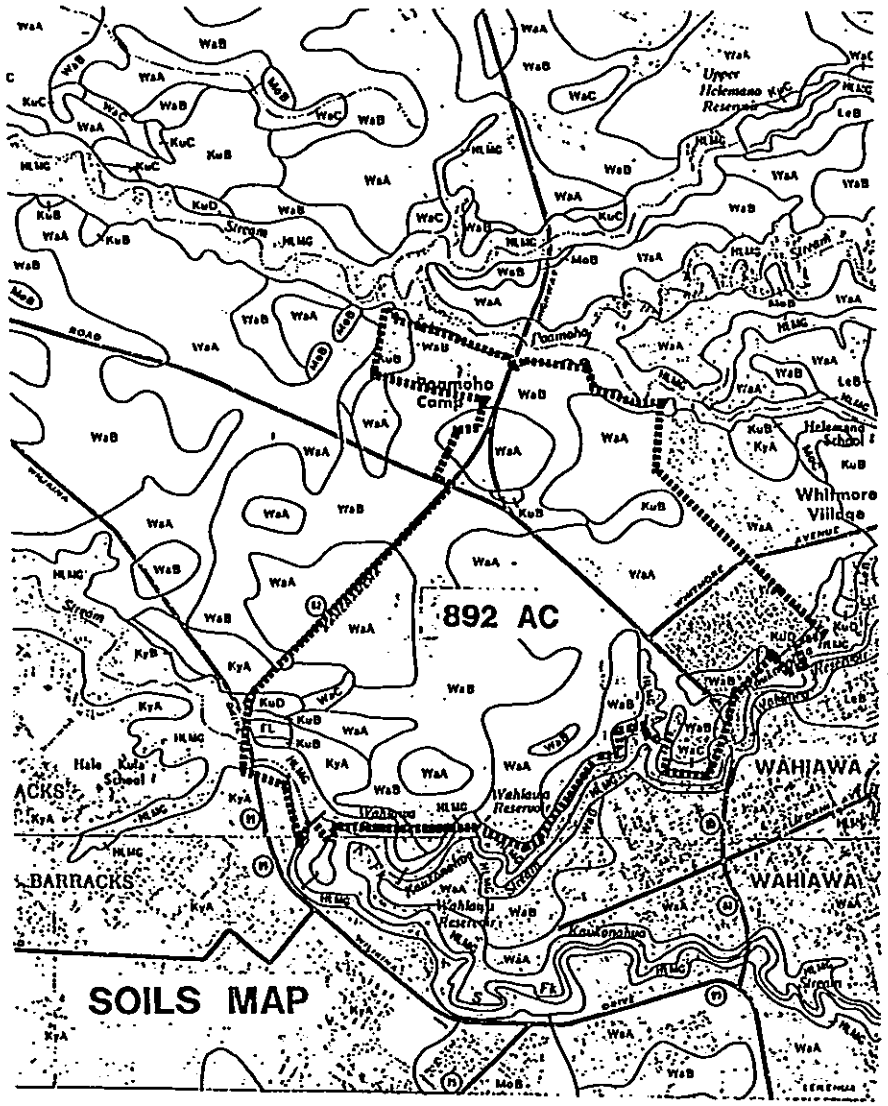

SOILS MAP
892 AC
Poamoho Camp
Whitmore Village
WAHIAWA
WAHIAWA
BARRACKS
Upper Helemano Reservoir
Helemano School
Hale Kula School
Wahiawa Reservoir
Kaukonahua
Stream
ROAD

FIGURE 5

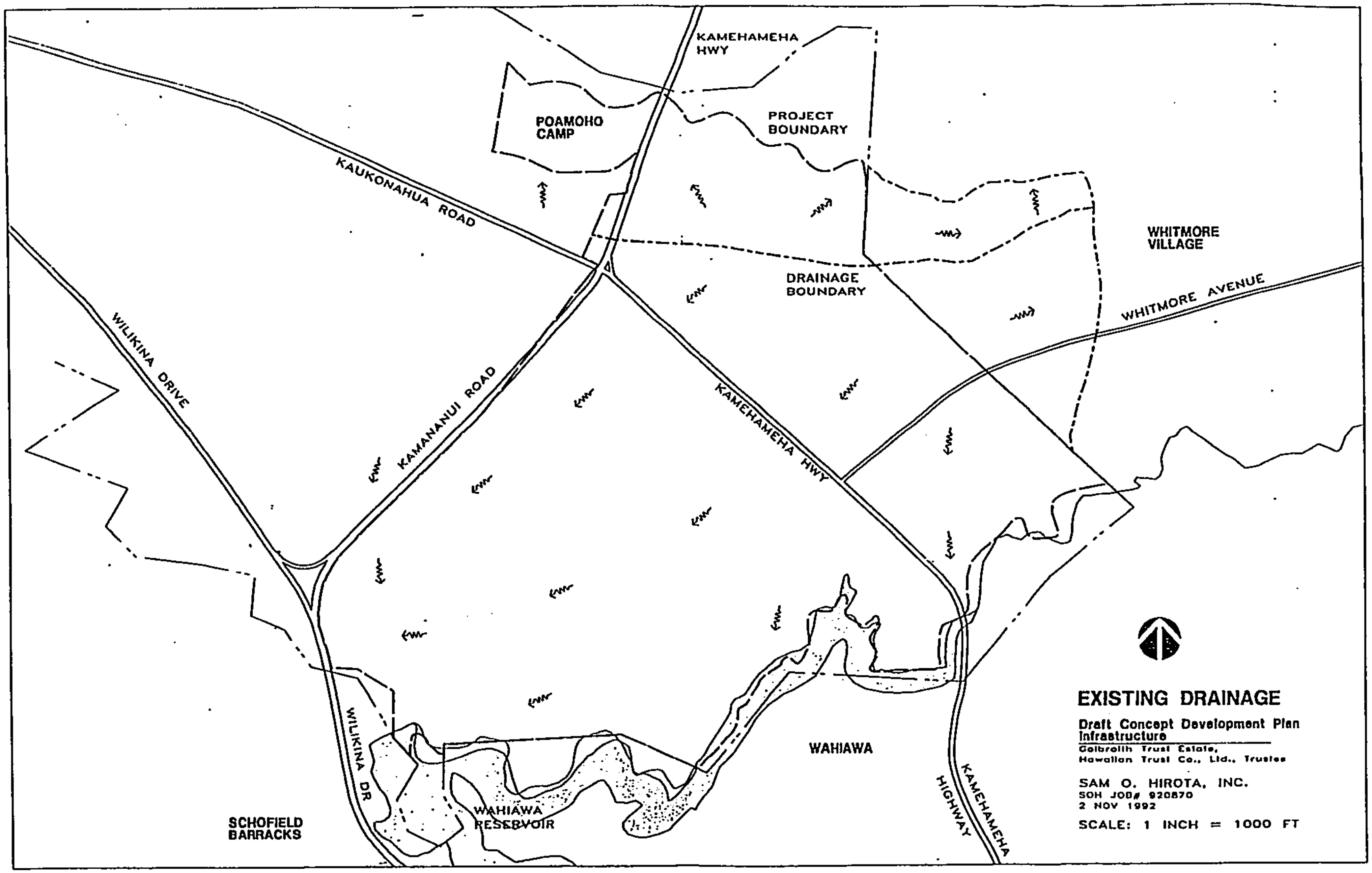

KAMEHAMEHA HWY
POAMOHO CAMP
PROJECT BOUNDARY
KAUKONAHUA ROAD
WHITMORE VILLAGE
DRAINAGE BOUNDARY
WHITMORE AVENUE
WILIKINA DRIVE
KAMANANUI ROAD
KAMEHAMEHA HWY
WILIKINA DR
WAHIAWA
WAHIAWA RESERVOIR
SCHOFIELD BARRACKS
KAMEHAMEHA HIGHWAY
EXISTING DRAINAGE
Draft Concept Development Plan
Infrastructure
Galbraith Trust Estate,
Hawaiian Trust Co., Ltd., Trustee
SAM O. HIROTA, INC.
SOH JOB# 920870
2 NOV 1992
SCALE: 1 INCH = 1000 FT

FIGURE 6

Proposed Development

On a comparable basis, the proposed improvements such as buildings, roadways, and parking lots will increase the total amount of runoff by only 6 percent (see Appendix C).

The golf course fairways and landscaped areas will incorporate low areas and about 30 acres of lakes which will act as holding ponds for some runoff. Drywells may be used in some areas to accommodate some of the runoff while excess runoff would continue to drain into Wahiawa Reservoir. Any drywells with a depth greater than their width would be subject to permitting as underground injection wells by Department of Health Regulations issued for the protection of underground sources of drinking water. Some of the runoff flowing into golf course ponds may be mixed with treated wastewater effluent and used for irrigation purposes.

The runoff from the proposed development was estimated (Appendix C) by applying the Rational Formula to the areas served by 15 possible drain lines (Figure 7)and to areas draining directly into golf course ponds, Wahiawa Reservoir and Poamoho Stream.

The total runoff from the proposed development is estimated to be 3,136 Cfs (Appendix C) or about nine percent more than the 2,890 cfs 10-year storm runoff from the undeveloped site.

Grading and drainage for the development will have to comply with the Department of Health Administrative Rules, and City and County ordinances and standards. In particular, it will be necessary to obtain a National Pollutant Discharge Elimination System (NPDES) permit or permits from the Department of Health, and a City and County of Honolulu grading permit. The latter requires approval of grading, drainage and erosion control plans. Construction of the drainage system must be in accordance with City standards and plans approved by the City.

III. ROADS

Existing Conditions

The portion of the Galbraith Trust Estate that is being considered for possible development is well situated with respect to highway transportation. Although the South boundary is along Wahiawa Reservoir, Kamehameha Highway traverses the site to the east and Kamananui Highway borders the site to the north. Also, Plantation Road crosses the site in an east-west direction from Kamananui Highway to the intersection of Kamehameha Highway and Whitmore Avenue. This highway intersects with Wilikina Drive, Kamehameha Highway and Kaukonahua Road. Kamehameha Highway, Kaukonahua Road and Wilikina Drive are State Highways while the others fall under the jurisdiction of the City and County of Honolulu.

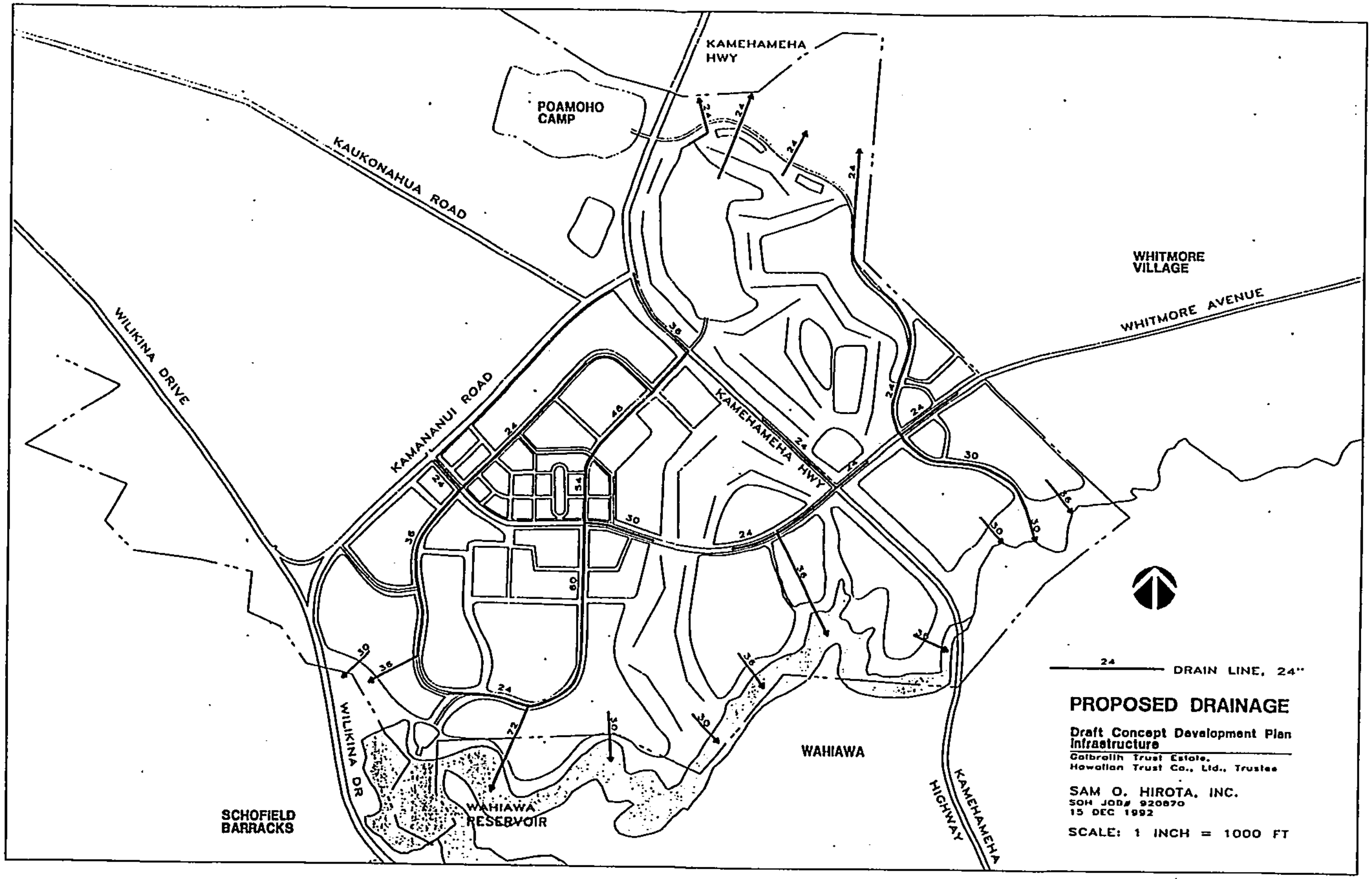
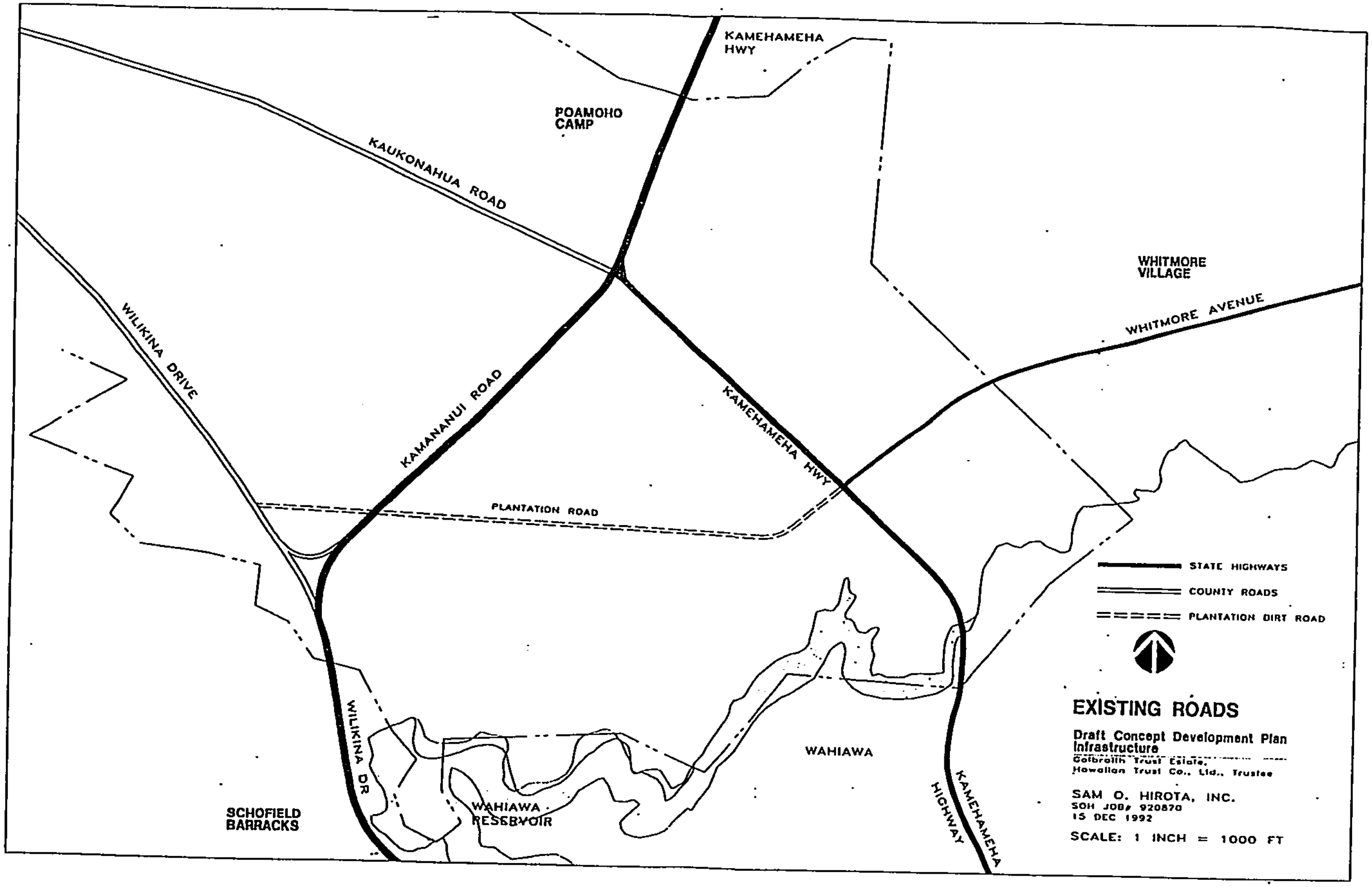

KAMEHAMEHA HWY
POAMOHO CAMP
KAUKONAHUA ROAD
WHITMORE VILLAGE
WHITMORE AVENUE
WILIKINA DRIVE
KAMANANUI ROAD
KAMEHAMEHA HWY
WAHIAWA
KAMEHAMEHA HIGHWAY
SCHOFIELD BARRACKS
WILIKINA DR
WAHIAWA RESERVOIR
24 DRAIN LINE, 24"
PROPOSED DRAINAGE
Draft Concept Development Plan
Infrastructure
Galbraith Trust Estate,
Hawaiian Trust Co., Ltd., Trustee
SAM O. HIROTA, INC.
SOH JOB# 920870
15 DEC 1992
SCALE: 1 INCH = 1000 FT

FIGURE 7


KAMEHAMEHA HWY
POAMOHO CAMP
KAUKONAHUA ROAD
WHITMORE VILLAGE
WHITMORE AVENUE
WILIKINA DRIVE
KAMANANUI ROAD
KAMEHAMEHA HWY
PLANTATION ROAD
STATE HIGHWAYS
COUNTY ROADS
PLANTATION DIRT ROAD
EXISTING ROADS
Draft Concept Development Plan
Infrastructure
Galbraith Trust Estate,
Hawaiian Trust Co., Ltd., Trustee
SAM O. HIROTA, INC.
SOH JOB# 920870
15 DEC 1992
SCALE: 1 INCH = 1000 FT
WILIKINA DR
WAHIAWA
KAMEHAMEHA HIGHWAY
SCHOFIELD BARRACKS
WAHIAWA RESERVOIR
FIGURE 8

Proposed Development

The conceptual development plan envisions a realignment of Plantation Road, and a pattern of collector and local streets to serve the new community. The intersection of the new streets with State highways would be designed to conform to State Department of Transportation Standards (Reference 6), while interior roadways will be designed to City standards (Reference 7) so that they can be dedicated to the State and City for traffic control and maintenance purposes.

The design of the highway intersections and interior roadways will reflect traffic data developed by the firm of Wilbur Smith Associates who have been engaged to analyze and forecast traffic to, from and within the proposed development.

Road construction is not expected to be difficult since the terrain has a fairly flat uniform slope. The terrain and soils are such that grading will be minimal and normal construction methods can be used. Furthermore, the soils on the site should provide a good sub-grade.

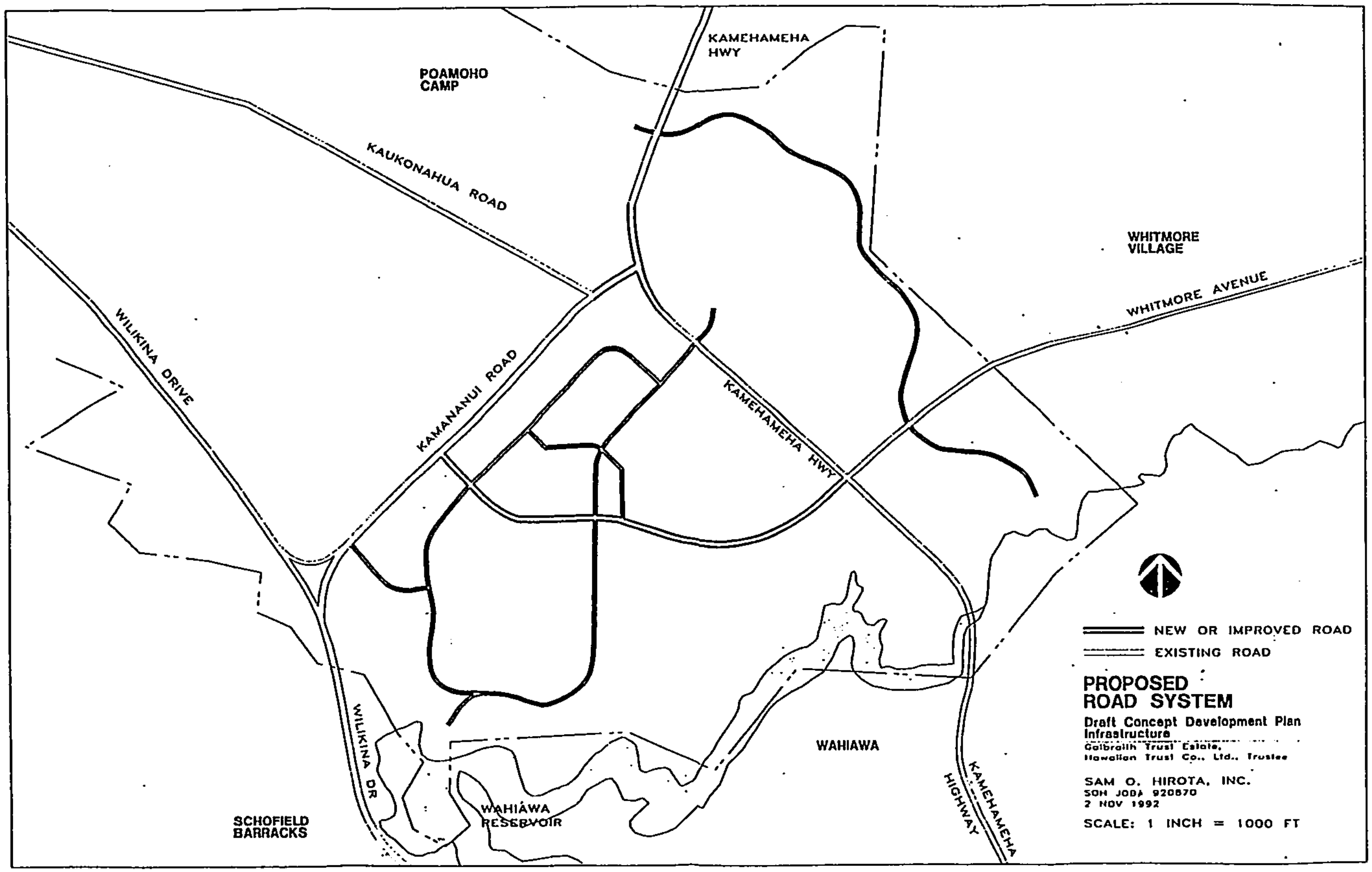
IV. WATER SUPPLY

Existing Domestic Potable Water Supply

There is no existing potable water service to the project site although a small pipe line of varying sizes crosses the area to serve Poamoho Village (Reference 8). The 12-inch BWS water main from Wahiawa to Whitmore Village passes to the east of the proposed site.

The water supply for the adjoining Wahiawa town and Schofield Barracks comes from deep wells and by piped distribution systems operated by the Board of Water Supply (BWS) and the U.S. Army, respectively. Reservoirs for water storage exist in both these areas. There are four reservoirs in BWS Wahiawa distribution system with a total capacity of 5.0 MG. The two 0.5 MG Brannen Tract Reservoirs are at an elevation of 1,326 feet, the 2.0 MG Wahiawa Reservoir is at 1,160 feet and the 2.0 MG Glen Avenue Reservoir is at an elevation of 1,045 feet.

Irrigation of the existing pineapple fields is usually accomplished by temporary or portable sprinkler systems. The water source is an artesian well located in the northeast part of the Estate lands outside of the project area. The capacity of this well is 2,000 gallons per minute (GPM). (Reference 8). The well is not in the area proposed for development.



POAMOHO CAMP
KAMEHAMEHA HWY
KAUKONAHUA ROAD
WHITMORE VILLAGE
WHITMORE AVENUE
WILIKINA DRIVE
KAMANANUI ROAD
KAMEHAMEHA HWY
NEW OR IMPROVED ROAD
EXISTING ROAD
PROPOSED ROAD SYSTEM
Draft Concept Development Plan
Infrastructure
Galbraith Trust Estate,
Hawaiian Trust Co., Ltd., Trustee
SAM O. HIROTA, INC.
SOH JOD# 920870
2 NOV 1992
SCALE: 1 INCH = 1000 FT
WILIKINA DR
WAHIAWA
WAHIAWA RESERVOIR
KAMEHAMEHA HIGHWAY
SCHOFIELD BARRACKS

FIGURE 9

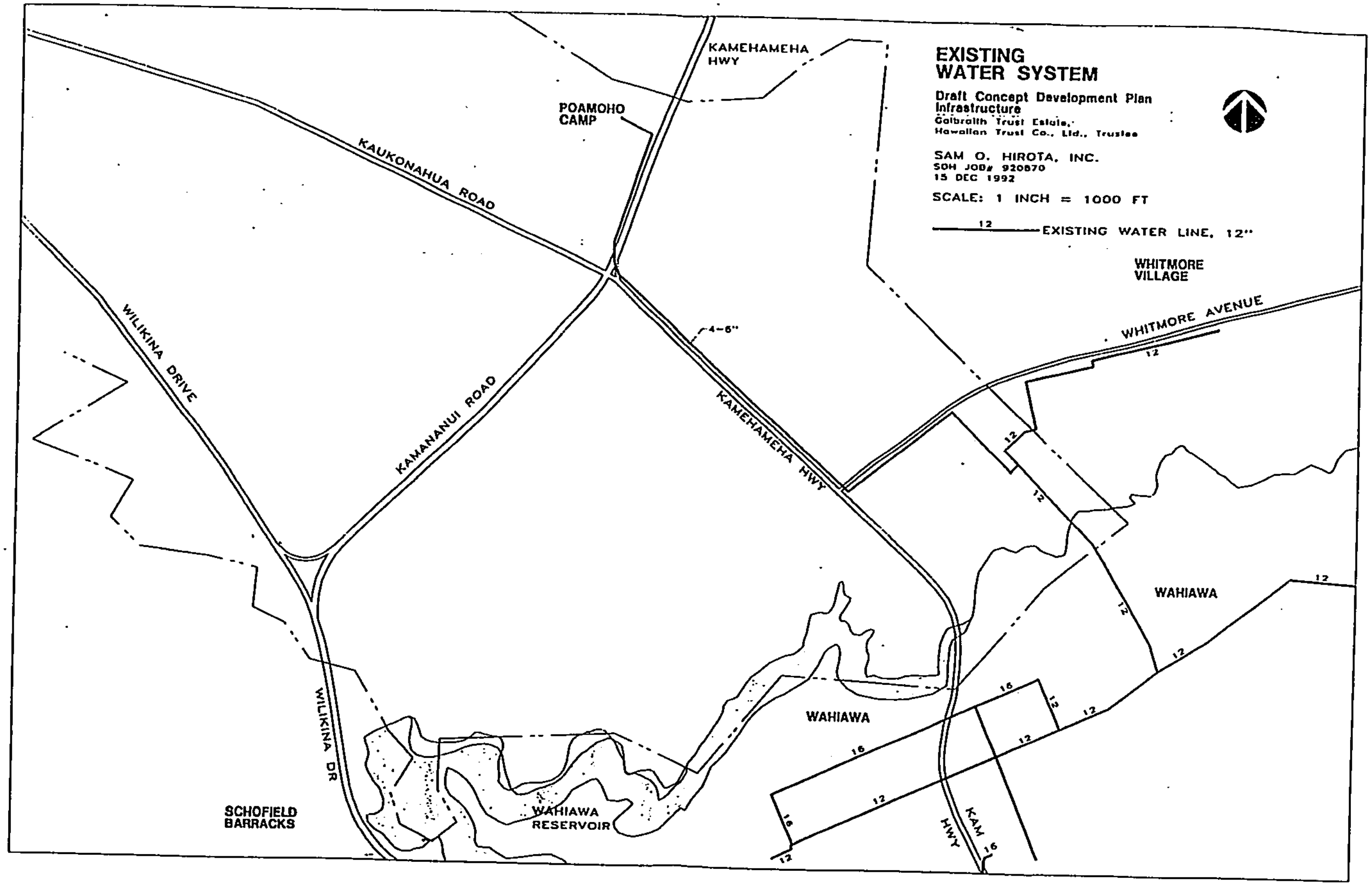

EXISTING
WATER SYSTEM
Draft Concept Development Plan
Infrastructure
Galbraith Trust Estate,
Hawaiian Trust Co., Ltd., Trustee
SAM O. HIROTA, INC.
SOH JOB# 920870
15 DEC 1992
SCALE: 1 INCH = 1000 FT
12 EXISTING WATER LINE, 12"
WHITMORE VILLAGE
WHITMORE AVENUE
KAMEHAMEHA HWY
POAMOHO CAMP
KAUKONAHUA ROAD
WILIKINA DRIVE
KAMANANUI ROAD
4-6"
WAHIAWA
WAHIAWA
WAHIAWA RESERVOIR
SCHOFIELD BARRACKS
WILIKINA DR
KAM HWY

FIGURE 10

Proposed Development

Domestic Potable Water Supply

The Board of Water Supply (BWS) has advised that the developer of the Galbraith Trust Lands at Wahiawa "will be required to install a complete new water system including a water source, reservoirs, and pipelines for the proposed development" (see Appendix A). Water Resource Associates, a consulting hydrology firm, has been engaged to prepare a report on the development of a new water source(s) for the development.

Potable water must be furnished to all dwelling units, commercial complexes, schools, civic center, clubhouse, parks and museum, and some landscape areas. The average daily potable water requirement for the proposed development is estimated by BWS standards to be 2.9 million gallons per day (MGD) (see Appendix D).

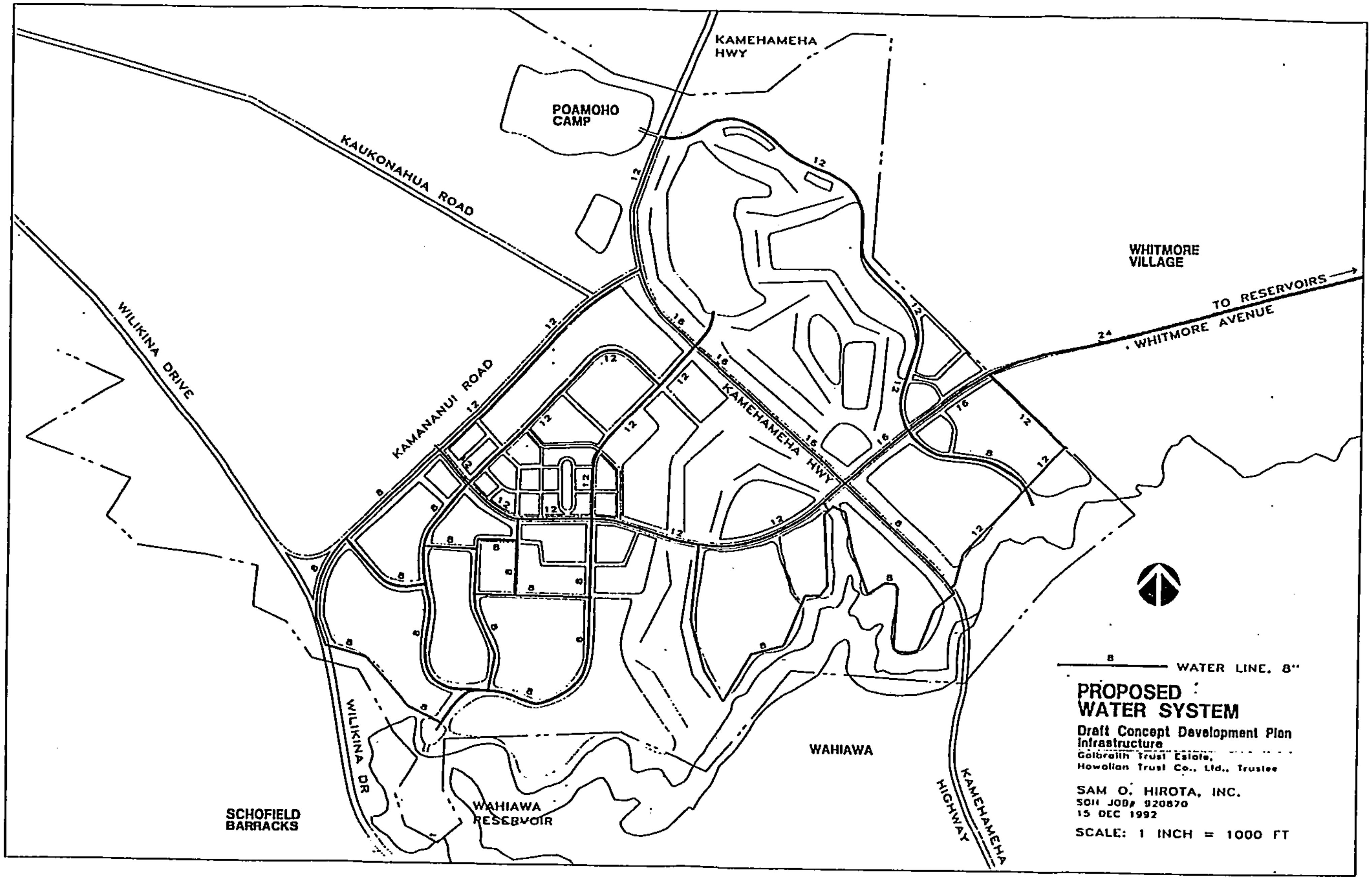
The potable water distribution system will have to be designed and installed with Department of Health Administrative Rules and BWS standards (References 4 and 9). It is anticipated that major phases of the water distribution system will be acceptable to the BWS for dedication to the City as they are completed.

BWS standards require that the distribution system carry, (1) the peak hour demand with a minimum residual pressure of 40 pounds per square inch (psi), and (2) the peak hour demand plus fire flow with a residual pressure of 20 psi at the critical fire hydrant location. The required fire flow for residential areas in this project is 1,000 GPM for a duration of thirty minutes with hydrants spaced at 350 feet. The required fire flow for other areas, i.e., commercial areas and civic centers, is 2,000 GPM for a duration of two hours with hydrants spacing not to exceed 250 feet.

It is anticipated that the potable water distribution system for the proposed development will include two reservoirs, one with a capacity of 2.0 Million Gallons (MG) and the other with a capacity of 1.5 MG. The BWS requires that reservoirs be located at least 100 feet higher than the highest elevation and 190 feet above the lowest elevation in the area to be served. Accordingly, both reservoirs would have to be located off-site, one at a minimum elevation of 1,085 feet and the other at an elevation of 1,070 feet. A possible location for these reservoirs would be on Whitmore Avenue east of Whitmore Village.

The two reservoirs would be interconnected to assure an uninterrupted water supply in case service is disrupted. Booster pumps would be provided to pump water from the source to the upper reservoir and where required to pump water from one reservoir to another. Booster pumps are not permitted in the distribution system (Reference 16).

The BWS will examine the need to inter-connect the existing Wahiawa distribution system with that of the proposed development when the development plans are submitted to the City.



KAMEHAMEHA HWY
POAMOHO CAMP
KAUKONAHUA ROAD
WHITMORE VILLAGE
TO RESERVOIRS
24 WHITMORE AVENUE
WILIKINA DRIVE
KAMANANUI ROAD
KAMEHAMEHA HWY
WAHIAWA
WILIKINA DR
SCHOFIELD BARRACKS
WAHIAWA RESERVOIR
KAMEHAMEHA HIGHWAY
8 WATER LINE, 8"
PROPOSED WATER SYSTEM
Draft Concept Development Plan
Infrastructure
Galbraith Trust Estate,
Hawaiian Trust Co., Ltd., Trustee
SAM O. HIROTA, INC.
SOH JOB# 920870
15 DEC 1992
SCALE: 1 INCH = 1000 FT

FIGURE 11

Irrigation Water Supply

It is contemplated that non-potable water will be used to irrigate the golf course fairways and large landscaped areas. The non-potable water would consist of storm water runoff and treated effluent from the wastewater treatment plant (WWTP).

As previously mentioned, the golf course could incorporate artificial lakes to improve aesthetics and provide storage for runoff and irrigation water. The lakes would be lined to prevent contamination of any ground water.

Some storm runoff would be directed into the artificial golf course lakes for storage and release as needed. The storm water in the lakes will mix with treated wastewater effluent to improve the quality of irrigation water.

The remaining stormwater runoff would drain directly into Wahiawa Reservoir.

The average rainfall in the project area is about 50 inches a year. Taking this into account the quantity of irrigation water required to irrigate the golf course fairways and landscaped areas may be estimated at 0.78 MGD (see Appendix D).

The domestic and irrigation water systems would be carefully designed and physically separated to prevent cross-connections and backflow conditions. As previously mentioned it is anticipated that the domestic (potable) water system would be dedicated to the City and County for operation and maintenance by the BWS. The operation and maintenance of the distribution system for non-potable irrigation water would remain the responsibility of the developer.

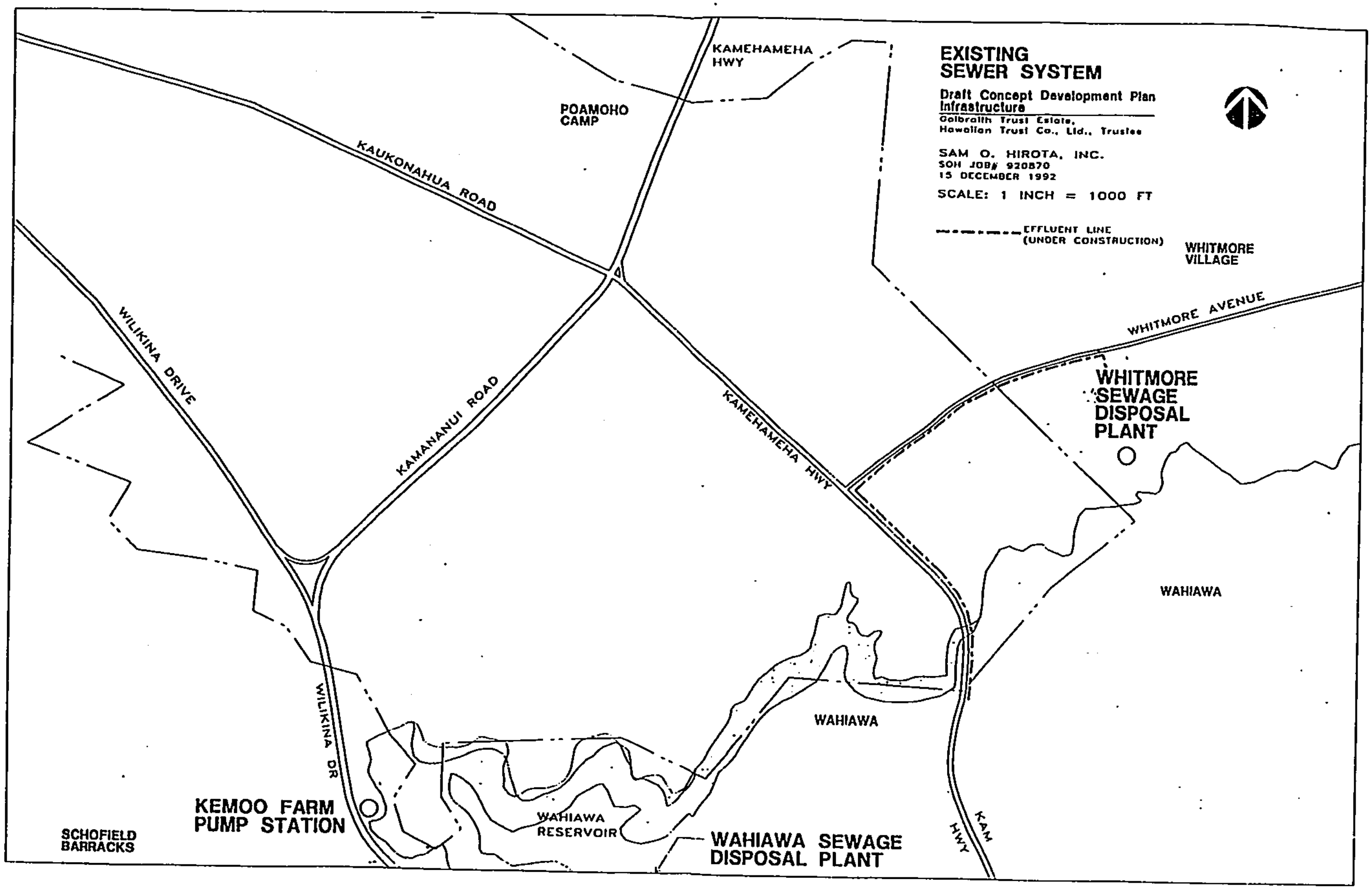
V. WASTEWATER

Existing Conditions

The project site is in pineapple cultivation and there are no wastewater collection systems or treatment facilities at the present time. However, the City is currently constructing a 15-inch sewer line to convey some of the effluent from the Whitmore Village wastewater treatment plant (WWTP) to the larger Wahiawa facility. This new sewer line is being laid along Whitmore Avenue and Kamehameha Highway, partly within the project site but on public property.

Collection and treatment facilities exist to serve the nearby Wahiawa town, Whitmore Village and Schofield Barracks. The Wahiawa and Whitmore Village treatment plants and collection systems are owned and operated by the City and County of Honolulu while the Schofield facilities belong to the Army.

The treated effluent from both the Wahiawa and Whitmore Village plants flow into the Wahiawa Reservoir, and the treated effluent from the Army WWTP is discharged in a Waialua Sugar Company irrigation ditch. This ditch receives its water from the reservoir so that sewerage effluent from all three plants is diluted with storm runoff and


EXISTING
SEWER SYSTEM
Draft Concept Development Plan
Infrastructure
Galbraith Trust Estate,
Hawaiian Trust Co., Ltd., Trustee
SAM O. HIROTA, INC.
SOH JOB# 920870
15 DECEMBER 1992
SCALE: 1 INCH = 1000 FT
EFFLUENT LINE
(UNDER CONSTRUCTION)
KAMEHAMEHA HWY
POAMOHO CAMP
KAUKONAHUA ROAD
WHITMORE VILLAGE
WHITMORE AVENUE
WILIKINA DRIVE
KAMANANUI ROAD
KAMEHAMEHA HWY
WHITMORE SEWAGE DISPOSAL PLANT
WAHIAWA
WAHIAWA
WILIKINA DR
KEMOO FARM PUMP STATION
SCHOFIELD BARRACKS
WAHIAWA RESERVOIR
WAHIAWA SEWAGE DISPOSAL PLANT
KAM HWY
FIGURE 12

used for the irrigation of sugar cane. The high level of nutrients in this irrigation water has, however, caused some concern in that it can cause premature tasseling of the sugar cane.

The Department of Health has issued a memorandum to the Wastewater Division of the City and County of Honolulu and to the Army requiring them to stop dumping effluent to the lake by 1994. In recognition of this edict, the City's Division of Wastewater Management has hired a consultant, Calvin Kim, to conduct a study of possible alternatives.

Proposed Development

The City Division of Waste Water Management (DWWM) has advised that they are not prepared to make any definite recommendations for handling wastewater from the proposed development at this time (Appendix B). They noted, however, that a private wastewater treatment system may be an option provided it is approved by the State Department of Health.

Wastewater from the proposed development will be generated at residences, commercial facilities, schools, the golf course clubhouse and maintenance facility, civic buildings, museum and at park restrooms. The average daily wastewater to be generated by the development estimated to be 1.5 MGD excluding groundwater infiltration (see Appendix E). The composition of this wastewater should be typical of that from any domestic source.

A private WWTP could be located along Kaukonahua Stream adjacent and west of Wilikina Drive which would allow gravity flow to the plant with a minimum requirement for sewage pumping stations. A lift (pump) station and force main will be required to move the wastewater collected from the most northern part of the development to a connection with a gravity system on higher ground (see Figure 13). The previously mentioned study to devise alternatives to dumping effluent into Wahiawa Reservoir is expected to recommend a treatment method, such as tertiary treatment, that would be acceptable for discharging effluent into Wahiawa Reservoir. This report assumes that tertiary treatment will be acceptable since piping effluent to WWTP with an ocean outfall does not seem to be a viable alternative. A 4.61 MGD tertiary treatment plant for processing the anticipated quantity of wastewater for the proposed development will require a 4 to 4-1/2 acre site.

The WWTP need not generate objectionable odor as long as it is properly designed, operated and maintained. Also enclosing the pumps, blowers and all or portions of the plant underground together with proper grading and landscaping would reduce the noise and visual impact of the facility.

The treated effluent from the WWTP that is deposited into Wahiawa Reservoir or used for irrigation purposes would have to meet strict DOH requirements, and the solids that are removed in the treatment process would have to be hauled to an approved disposal site. The quantity of effluent that could be used for project irrigation is estimated to be

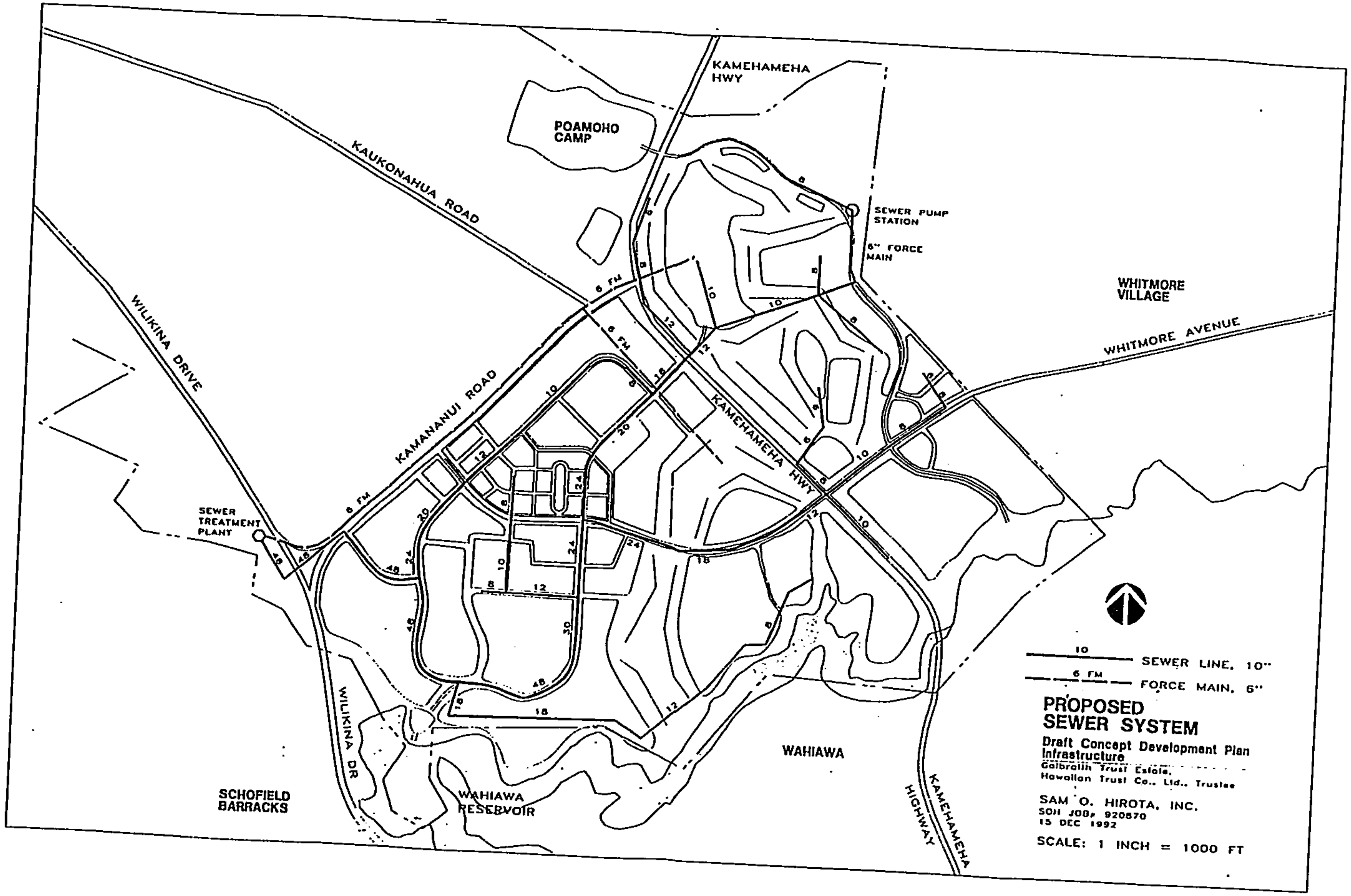

KAMEHAMEHA HWY
POAMOHO CAMP
KAUKONAHUA ROAD
SEWER PUMP STATION
6" FORCE MAIN
WHITMORE VILLAGE
WHITMORE AVENUE
WILIKINA DRIVE
KAMANANUI ROAD
KAMEHAMEHA HWY
SEWER TREATMENT PLANT
WILIKINA DR
SCHOFIELD BARRACKS
WAHIAWA RESERVOIR
WAHIAWA
KAMEHAMEHA HIGHWAY
SEWER LINE, 10"
FORCE MAIN, 6"
PROPOSED SEWER SYSTEM
Draft Concept Development Plan
Infrastructure
Galbraith Trust Estate, Hawaiian Trust Co., Ltd., Trustee
SAM O. HIROTA, INC.
SOH JOB# 920870
15 DEC 1992
SCALE: 1 INCH = 1000 FT

FIGURE 13

0.78 MGD which is considerably less than the estimated design maximum flow of 4.61 MGD. Del Monte has expressed interest in possibly using some of the excess effluent for irrigation purposes.

A collection system would have to be provided to convey wastewater to the sewage treatment plant from each lot of the proposed development. The sewer system could be designed to meet City standards so that they could be dedicated to the City. In this event, the City would become responsible for maintaining sewer lines located in dedicated streets or in easements granted to the City.

VI. ELECTRIC

Existing Conditions

The Hawaiian Electric Company, Inc. (HECO), now provides electric power required for pineapple operations at the site. They have a 12KV primary line along Kamehameha Highway. HECO also supplies power at Wahiawa community from a 12.47 - 138 KV substation, located at Wahiawa town (Reference 13).

Proposed Development

Hawaiian Electric Company, Inc. will provide residential electrical service to the proposed development via overhead power lines located within roadway rights-of-way or in utility easements.

The electric power requirement for the proposed development is estimated to be 30 MVA and the developer would be required to provide a site for a substation with this capacity. The developer would also be required to provide transformer pad sites where they are required and possibly participate in the cost for the electrical service. A possible site for the 30 MVA substation is shown in Figure 15.

It is expected that the design and construction of the proposed facilities will incorporate energy saving designs and devices in order to reduce operating cost.

VII. TELEPHONE AND CATV

Existing Conditions

GTE, Hawaiian Telephone Company, Incorporated (HTCO) provides telephone service to the adjoining areas of the project site via overhead lines located on public highways. Oceanic Cablevision provides cable television (CATV) service to the Wahiawa area and its vicinity. All the buried telephone cables shown in Figures 14 and 15 are owned by the military but are maintained by HTCO.

Oceanic Cable has CATV trunking facilities along Whitmore Avenue and Kamehameha Highway extending out to Poamoho Camp (Reference 17).

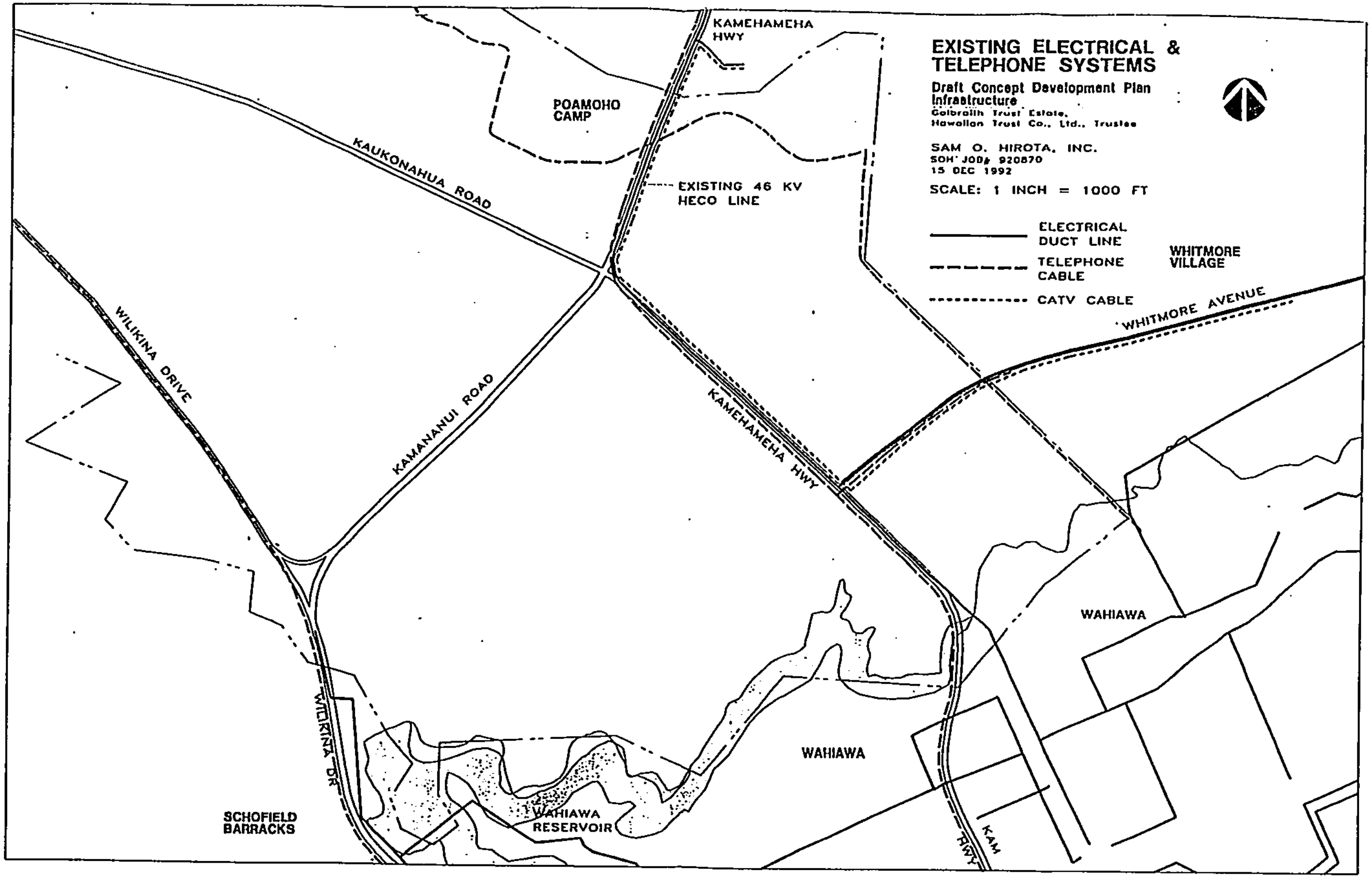

EXISTING ELECTRICAL &
TELEPHONE SYSTEMS
Draft Concept Development Plan
Infrastructure
Galbraith Trust Estate,
Hawaiian Trust Co., Ltd., Trustee
SAM O. HIROTA, INC.
SOH JOB# 920870
15 DEC 1992
SCALE: 1 INCH = 1000 FT
ELECTRICAL DUCT LINE
TELEPHONE CABLE
CATV CABLE
WHITMORE VILLAGE
WHITMORE AVENUE
KAMEHAMEHA HWY
POAMOHO CAMP
EXISTING 46 KV HECO LINE
KAUKONAHUA ROAD
WILIKINA DRIVE
KAMANANUI ROAD
KAMEHAMEHA HWY
WAHIAWA
WAHIAWA
WILIKINA DR
WAHIAWA RESERVOIR
SCHOFIELD BARRACKS
KAM HWY

FIGURE 14

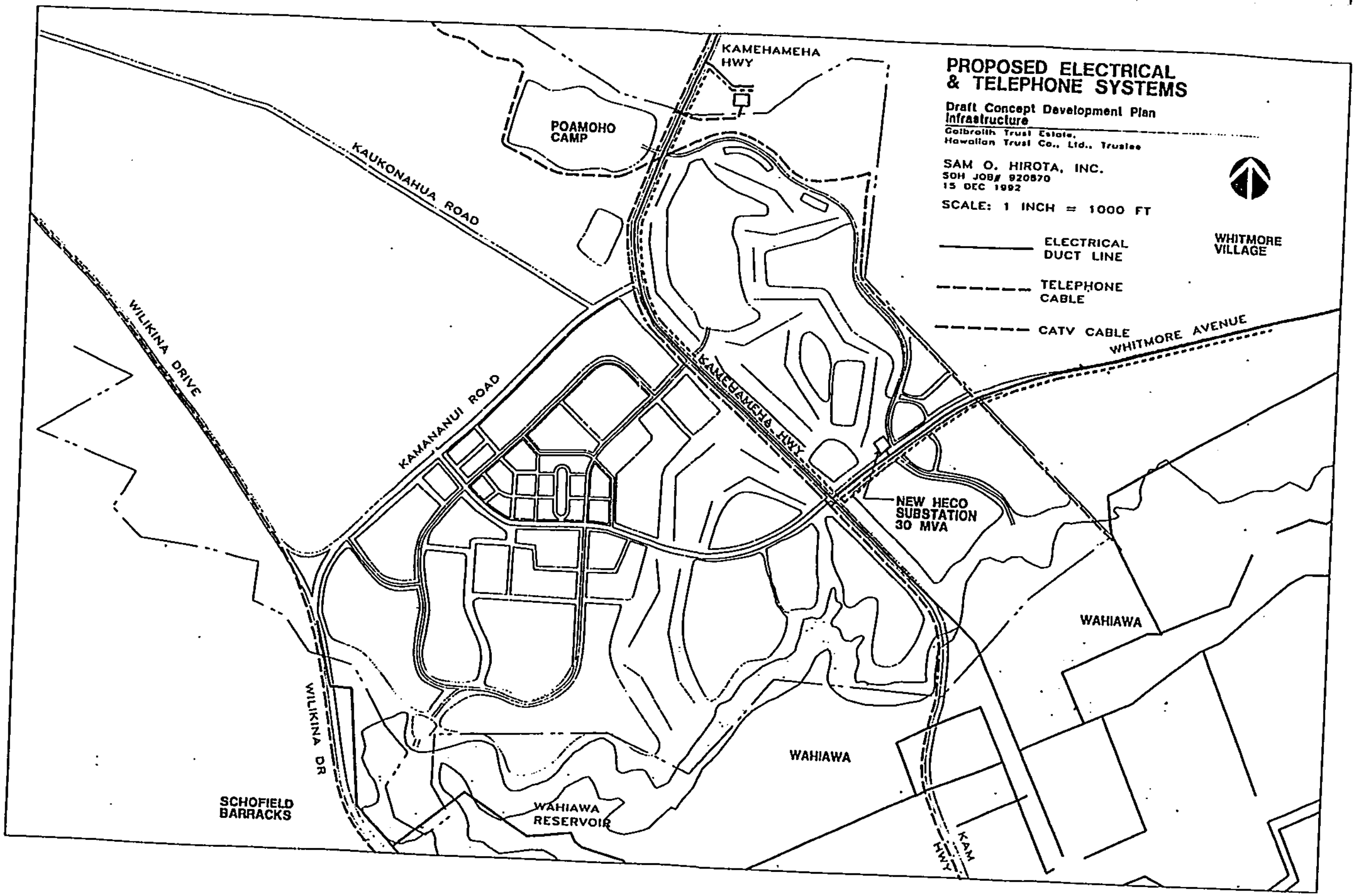

PROPOSED ELECTRICAL
& TELEPHONE SYSTEMS
Draft Concept Development Plan
Infrastructure
Galbraith Trust Estate,
Hawaiian Trust Co., Ltd., Trustee
SAM O. HIROTA, INC.
SOH JOB# 920870
15 DEC 1992
SCALE: 1 INCH = 1000 FT
ELECTRICAL DUCT LINE
TELEPHONE CABLE
CATV CABLE
WHITMORE VILLAGE
WHITMORE AVENUE
KAMEHAMEHA HWY
POAMOHO CAMP
KAUKONAHUA ROAD
WILIKINA DRIVE
KAMANANUI ROAD
NEW HECO SUBSTATION 30 MVA
WAHIAWA
WAHIAWA
WILIKINA DR
SCHOFIELD BARRACKS
WAHIAWA RESERVOIR
KAM HWY

FIGURE 15

Proposed Development

The proposed project will be provided with telephone service. Connection to the HTCO system will be made at Kamehameha Highway. If Kamehameha Highway is realigned, the costs of relocating that portion of the existing HTCO facilities will be borne by the appropriate governmental agency(ies) that would develop the land proposed to be dedicated by the applicant.

When the project enters the design phase, the appropriate governmental agency(ies) will coordinate with HTCO for the relocation of telephone facilities within public rights-of-way. The developer would have to work closely with HTCO to assure that telecommunication services are available in a timely manner. Existing buried communication cables would not be disturbed if at all possible.

Oceanic Cable does not foresee any problems in planning CATV service for the proposed development (Reference 17).

VIII. PHASE DEVELOPMENT

The initial first phase development consist of the 100-acre area as shown in Figure 16. It would include the following uses:

LAND USE	ACRES	UNITS
Residential		
Single Family	17	100
Multi-Family	33	500
Commercial		
Convenience	1	
Business Center	10	
Other		
Elementary School	8	
Civic	2	
Park & Ride	2	
Parks	6	
Open Space/Cir	17	
WWTP	4	
TOTAL	100	600

The infrastructure for the 1st Phase Development would include only the grading, drainage, roads and utilities that are required for the 100-acre development which could be incorporated in development envisioned in the 892-acre concept plan.

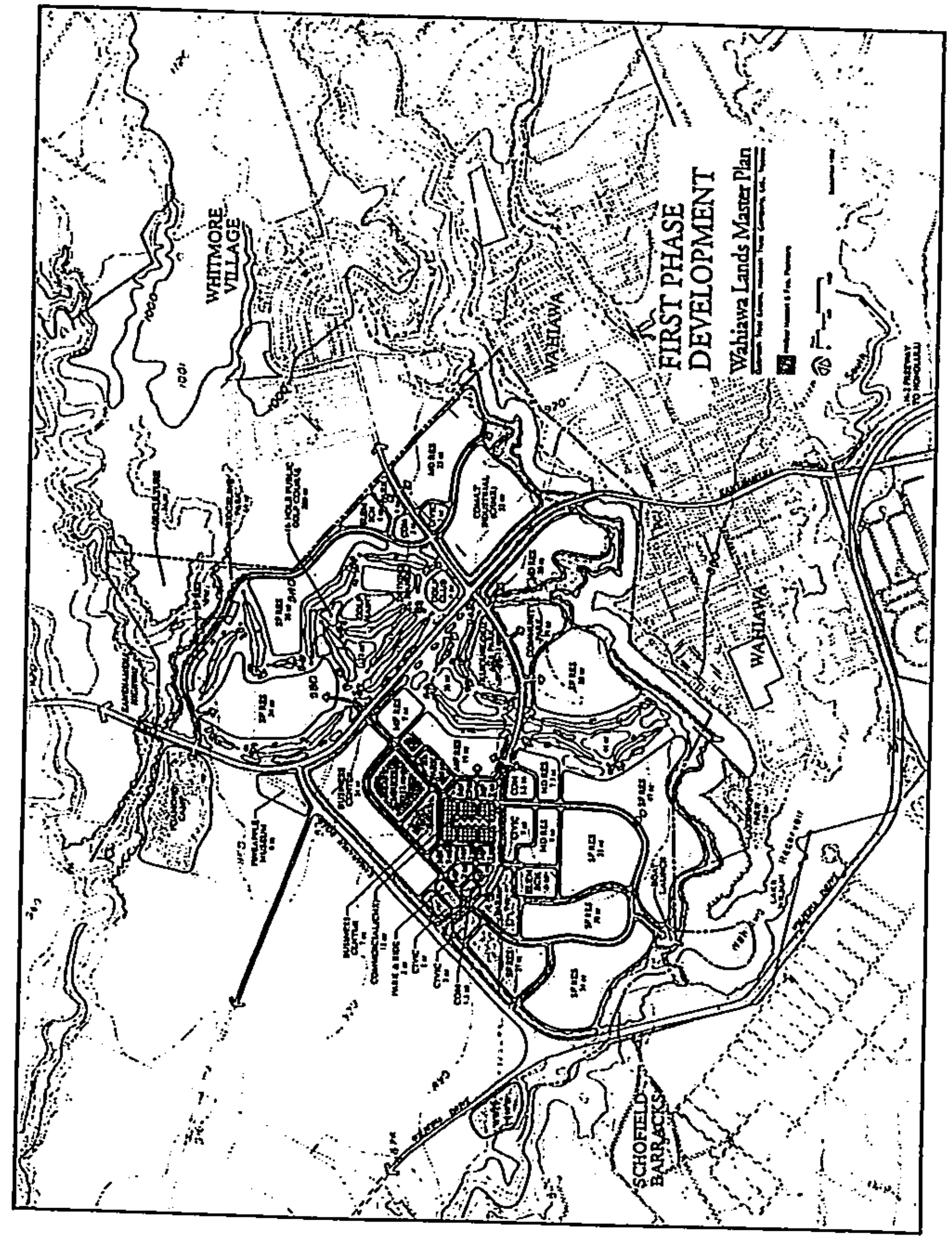


FIGURE 16

The peak runoff from the 1st Phase Development is estimated to be 1,300 cfs and this would be carried by drain lines into the Wahiawa Reservoir. The drain lines would vary in diameter from 24 inches to 60 inches.

Road work in the 1st Phase Development would include improvements to intersections with Kamehameha Highway and Kamananui Road and interior roads within the 100-acre site and some intersection traffic signals.

The maximum daily demand for domestic potable water for the 1st Phase Development is estimated according to BWS standards to be 0.56 MGD. The smaller 1.5 MG tank required for the 892-acre development would suffice for the initial development, but the distribution system would be sized for the full development.

The design maximum flow of wastewater that would be generated by the 1st Phase Development is estimated to be 1.14 MGD, about one fourth of that of the future 892-acre development. Accordingly, the WWTP for the initial development could be designed for a three-fold expansion in its capacity.

Electric, telephone and CATV facilities for the initial 1st Phase Development would similarly be sized to meet the requirements therefore and with the capability of additional capacity for the future development. The estimated power requirement for the first phase development is 8 MVA.

REFERENCES

1. Soil Survey of Islands of Kauai, Oahu, Maui, Molokai, and Lanai, State of Hawaii, U.S. Department of Agriculture, Soil Conservation Service.
2. Erosion and Sediment Control Guide for Hawaii, U.S. Soil Conservation Service, March 1981.
3. Soil Erosion Standards and Guidelines, Department of Public Works, City and County of Honolulu.
4. Title 11, Administrative Rules, Department of Health, State of Hawaii.
5. Storm Drainage Standards, Department of Public Works, City and County of Honolulu.
6. Hawaii Statewide Uniform Design Manual for Streets and Highways, Department of Transportation, State of Hawaii.
7. Public Works Design Standards, City and County of Honolulu.
8. Conversation with Rodger M. McCloskey, Plantation Manager, PPI Del Monte Fresh Produce (Hawaii) Inc., July 29, 1992.
9. Water System Standards, Board of Water Supply, City and County of Honolulu, et al, Volumes 1 and 2, 1985.
10. Conversation with Keith Tamura, Customer Clerk, Board of Water Supply, City and County of Honolulu.
11. Conversation with Albert Koga, Project Review Section, Board of Water Supply, City and County of Honolulu.
12. Design Standards, Division of Wastewater Management, City and County of Honolulu.
13. Telephone conversation with Stephanie Chun, Customer Clerk, Hawaiian Electric Company.
14. Telephone conversation with Kenneth Jen, Mapper, Hawaiian Electric Company.
15. Chapter 23, Grading, Soil Erosion and Sediment Control, Revised Ordinances, City and County of Honolulu.

16. Conversation with Albert Koga, Project Review, Division of Planning and Engineering, Board of Water Supply, City and County of Honolulu, October 26, 1992.

17. Letter from Oceanic Cable dated November 10, 1992 to Helber, Hastert & Fee.

APPENDIX A

Board of Water Supply Comments

APPENDIX B

Division of Wastewater Comments

BOARD OF WATER SUPPLY
CITY AND COUNTY OF HONOLULU
630 SOUTH BERETANIA STREET
HONOLULU HAWAII 96843

September 17, 1992

RECEIVED
SEP 22 1992
SAM O. HIROTA, INC.
By ____________

Mr. Dennis I. Hirota
Sam O. Hirota, Inc.
864 South Beretania Street
Honolulu, Hawaii 96813

Dear Mr. Hirota:

Subject: Your Letter of August 10, 1992 on Water Service for the Galbraith Trust Lands in Wahiawa, TMK: 7-1-01

Thank you for your letter regarding the proposed development in Wahiawa.

The developer will be required to install a complete new water system including a water source, reservoirs, and pipelines for the proposed development. The developer will have to obtain a permitted use from the State Commission of Water Resource Management to install wells and withdraw water for the development.

Please submit a water master plan for our review and approval. The master plan should show the layout of the development, contours, and the proposed water system facilities including the necessary calculations to verify the adequacy of the proposed water facilities.

If you have any questions, please contact Albert Koga at 527-6123.

Very truly yours,

KAZU HAYASHIDA
Manager and Chief Engineer

DEPARTMENT OF PUBLIC WORKS
CITY AND COUNTY OF HONOLULU
DIVISION OF WASTEWATER MANAGEMENT
650 SOUTH KING STREET
HONOLULU, HAWAII 96813

FRANK F. FASI
MAYOR

C. MICHAEL STREET
DIRECTOR AND CHIEF ENGINEER

GEORGE M. UYEMA
CHIEF

WPP 92-425

September 8, 1992

RECEIVED
SEP 14 1992
SAM O. HIROTA, INC.
By ________

Mr. Melvin E. Lepine, P.E.
Vice President
Sam O. Hirota, Inc.
864 South Beretania Street
Honolulu, Hawaii 96813

Dear Mr. Lepine:

Subject: Wahiawa Lands Master Plan
Galbraith Trust Lands
TMK: 7-1-01

This is in regards to your August 10, 1992 letter requesting guidance for wastewater treatment and disposal for the proposed Galbraith Trust Lands development.

The Division of Wastewater Management cannot make any definite recommendations for the proposed development at this time. Currently, the following factors are making planning for the Central Oahu area very complex:

1. The Whitmore Village and Wahiawa municipal sewer systems are adjacent to the proposed development. However, neither sewer system was planned and designed for, nor is capable of servicing at the present time, the development.

2. The State Department of Health has stated that wastewater effluent from the Wahiawa and Whitmore Village Wastewater Treatment Plants (WWTP) must be diverted out of Lake Wilson by March 1, 1994. Calvin Kim and Associates, Inc., an engineering consultant, has been contracted by the City to develop alternatives for treatment and disposal of the Wahiawa and Whitmore Village wastewater flows. Alternatives may include:

   a. Tertiary treatment of Wahiawa and Whitmore Village flows at the Wahiawa WWTP with continued effluent discharge into Wahiawa Reservoir or reuse/recharge in the Central Oahu area.

   b. Treatment of Wahiawa and Whitmore Village flows at the Wahiawa WWTP with effluent disposal through the Honouliuli WWTP's Barber's Point Ocean Outfall.

   c. Abandonment of the Wahiawa and Whitmore Village WWTP's with wastewater diversion to Honouliuli WWTP. This alternative is further complicated by the fact that the Honouliuli WWTP is currently the focus of a lawsuit by the Sierra Club and Hawaii's Thousand Friends. A trial in Federal Court to decide remedies has been scheduled for January 5, 1993. Until the remedies have been determined, plans for the expansion of the Honouliuli WWTP to possibly treat and dispose of Wahiawa and Whitmore Village flows cannot be made at this time.

   The most feasible alternative will be recommended at the completion of the Calvin Kim study which is tentatively scheduled for late 1993.

3. The City met with Army staff to study the feasibility of combining Central Oahu military and municipal flows for joint treatment and disposal. Thus far, no real commitment has been made by either party.

A private wastewater treatment system may be an option for the proposed Galbraith Trust Lands development since definite plans cannot be made at this time. However, please be aware that approval from the State Department of Health is required for private systems.

Please call Charles Yoshimoto of the Planning Section at 527-5388 if there are any question.

Very truly yours,

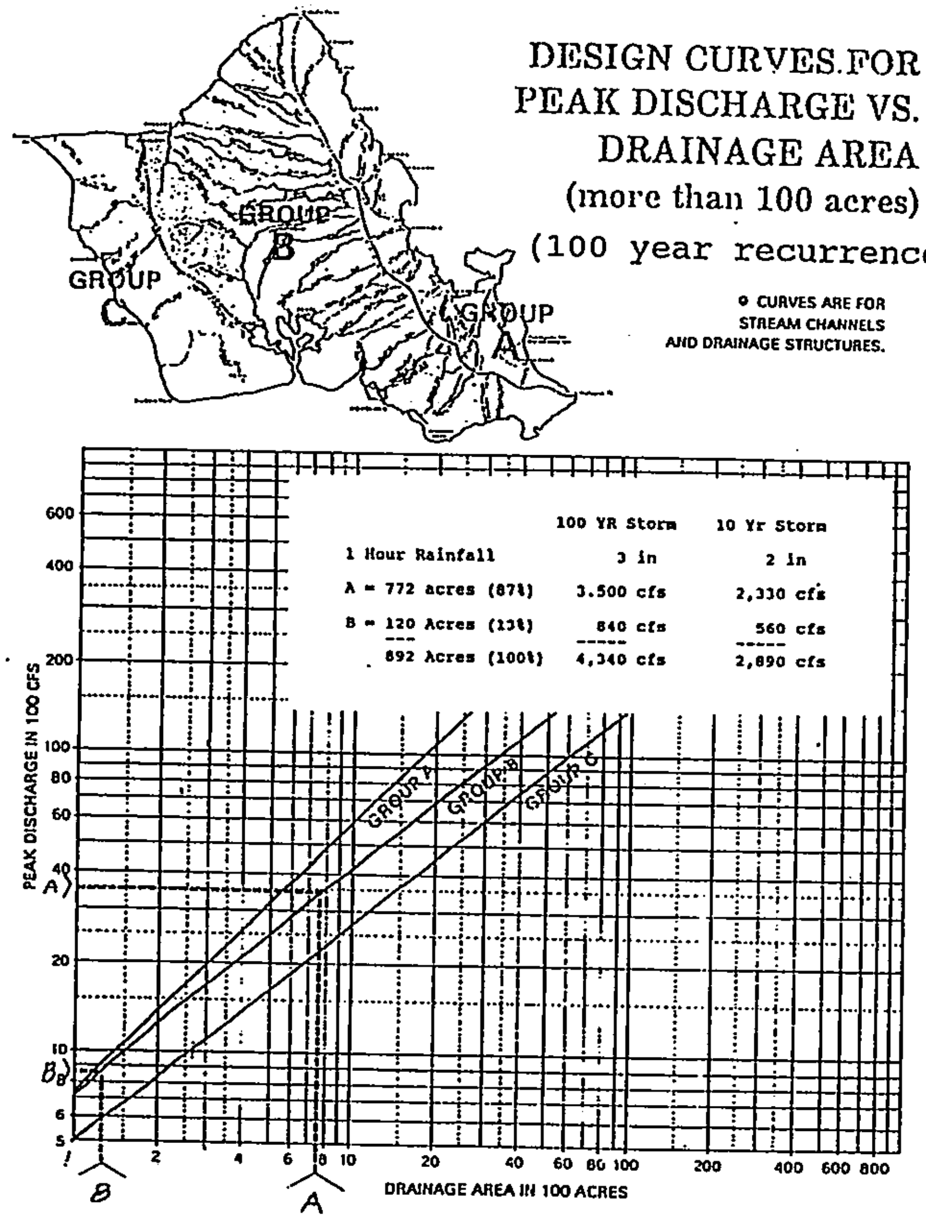
GEORGE M. UYEMA
Chief

APPENDIX C

Runoff Computations

DESIGN CURVES FOR PEAK DISCHARGE VS. DRAINAGE AREA
(more than 100 acres)
(100 year recurrence)

* CURVES ARE FOR STREAM CHANNELS AND DRAINAGE STRUCTURES.



	100 YR Storm	10 Yr Storm
1 Hour Rainfall	3 in	2 in
A = 772 acres (87%)	3,500 cfs	2,330 cfs
B = 120 Acres (13%)	840 cfs	560 cfs
892 Acres (100%)	4,340 cfs	2,890 cfs

SOURCE DATA FROM U.S. GEOLOGICAL SURVEY

WAHIDRAIN
WAHIAWA MASTER PLAN DRAINAGE . SOH 920870 MEL 24-OCT-1992

LAND USE	RUNOFF COEFF.	AREA Acres	DRAIN LINES 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	OTHER*
RESIDENTIAL	0.65	367.0	5.0	6.5	0.5	15.0	26.0	5.0	146.0	71.0	10.0		26.0	25.0		16.0	15.0	
COMMERCIAL	0.85	93.0					14.0		29.5	37.5		12.0						
ELEMENTARY SCHOOLS	0.80	12.0					6.0			6.0								
CIVIC	0.80	17.0					3.0		9.0	5.0								
PARK & RIDE	0.90	2.0								2.0								
GOLF COURSE	0.40	200.0			5.0			86.0							25.0			84.0
GOLF CLUBHOUSE	0.80	4.0						4.0										
PARKS	0.60	31.0					4.0	14.0	4.0	9.0								
RIDGELINE PARK	0.40	14.0																14.0
LAKEFRONT PARK	0.40	45.0																45.0
POMAHO CAMP	0.55	32.0																32.0
PINEAPPLE MUSEUM	0.60	6.0																6.0
KUKANILOKO PARK	0.40	11.0						11.0										
OPEN SPACE/CIRC.	0.80	58.0						1.0	1.0	17.0	10.0							29.0
TOTAL		892.0	5.0	6.5	5.5	15.0	53.0	121.0	189.5	147.5	20.0	12.0	26.0	25.0	25.0	16.0	15.0	210.0

* Golf course ponding and direct runoff into Poahomo Stream and Lake Wilson

RUNOFF CALCULATIONS

	DRAIN LINES 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	OTHER	TOTAL
C, Weighted Coefficient	0.65	0.65	0.42	0.65	0.72	0.45	0.69	0.73	0.73	0.85	0.65	0.65	0.44	0.65	0.65	0.48	
Cf, Correction Factor	3.00	3.00	3.00	3.00	3.00	3.00	2.65	2.93	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	
I, Rainfall Intensity, In/Hr, 10-Yr Storm	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	
A, Area, acres	5.0	6.5	5.5	15.0	53.0	121.0	189.5	147.5	20.0	12.0	26.0	25.0	25.0	16.0	15.0	210.0	892
Runoff, Cfs. Q=C*Cf*I*A	19.5	25.4	13.9	58.5	229.0	326.7	693.0	631.0	87.6	61.2	101.4	97.5	66.0	62.4	58.5	604.8	3,136

APPENDIX D

Water Requirement Computations

Draft Concept Development Plan
Wahiawa Lands Master Plan

POTABLE WATER REQUIREMENTS

LAND USE	ACRES	UNITS	STANDARDS *	AVERAGE FLOW, MGD **
Residential				
Single Family	247	1,482	500 gal/unit	0.741
Medium Density	66	660	500 gal/unit 80 gal/person/day	0.330
Multi-Family	54	810	400 gal/unit	0.324
Commercial				
Convenience	10		100 gal/1000 sq.ft. 43,560 sq.ft/acre	0.044
Mixed Use (Comm/Res)	12		120 gal/1000 sq.ft. 43,560 sq.ft/acre	0.063
Mixed Use (Comm/Ind)	33		100 gal/1000 sq.ft. 43,560 sq.ft/acre	0.144
Business Center	38		120 gal/1000 sq.ft. 43,560 sq.ft/acre	0.199
Other				
Elementary Schools	12		4,000 gal/acre	0.048
Civic	17		4,000 gal/acre	0.068
Park & Ride	2		4,000 gal/acre	0.008
18-Hole Golf Course	200	3	6,624 gal/unit ***	0.020
Golf Clubhouse	4		4,000 gal/acre	0.016
Parks	31		4,000 gal/acre	0.124
Ridgeline Park	14		4,000 gal/acre	0.056
Lakefront Park	45		4,000 gal/acre	0.020

LAND USE	ACRES	UNITS	STANDARDS *	AVERAGE FLOW, MGD **
Poamoho Camp	32		Existing facilities	0
Pineapple Museum	6		Existing facilities	0
Kukaniloko Park	11		4,000 gal/acre	0.044
Open Space/Cir	58			0
TOTAL	892			2.250

NOTES:
- * Water System Standards, Board of Water Supply, C&C of Honolulu.
- ** MGD (million gallons per day).
- *** 3 restrooms/drinking fountains on fairways, 12 fixture units per restroom (9.2 GPM).

Maximum Daily Demand = 2.25 x 1.5 = 3.38 MGD.

Peak Hour Flow = 2.25 x 3 = 6.75 MGD.

Fire Flow 2,000 GPM for 2 hours = 0.24 MGD.

Minimum Reservoir Capacity = 3.38 MGD.
(One 2 MG reservoir and one 1.5 MG reservoir.)

IRRIGATION REQUIREMENTS FOR GOLF COURSE AND LANDSCAPED AREAS

REQUIRED GOLF COURSE IRRIGATION: 0.75 inches to 2.5 inches per week. *

Assume 1.63 Inches Per Week	=	64.5 Inches Per Year
Deduct Rainfall Per Year	=	50.0 Inches Per Year
Irrigation Required	=	34.5 Inches Per Year
	=	2.88 Feet Per Year

Golf Course Area	=	200 Acres
Landscaped Areas	=	103 Acres
Total Irrigable Area	=	303 Acres

Total Volume Of Irrigation = 303 X 2.88 /365

= 779,160 Gals Per Day

* Source: Golf Course Design And Construction Manual Chapter 12

APPENDIX E

Wastewater Flow Estimates

WASTEWATER FLOW ESTIMATES

LAND USE	ACRES	POPULATION	STANDARDS *	AVERAGE FLOW, MGD **
Residential				
Single Family	247	5,928	4 persons/unit 80 gal/person/day	0.685
Medium Density	66	2,640	4 persons/unit 80 gal/person/day	0.211
Multi-Family	54	2,268	2.8 persons/unit 80 gal/person/day	0.181
Commercial				
Convenience	10	400	40 persons/acre 10 gal/person/day ****	0.004
Mixed Use (Comm/Res)	12	1,680	140 persons/acre 10 gal/person/day ****	0.017
Mixed Use (Comm/Ind)	33	3,300	100 persons/acre 10 gal/person/day ****	0.033
Business Center	38	1,400	25 persons/acre 10 gal/erson/day ****	0.008
Other				
Elementary Schools	12	5,179	25 gal/personday 5,179 persons ***	0.130
Civic	17	2,380	140 persons/acre 10 gal/person/day ****	0.024
Park & Ride	2	800	400 persons/acre 10 gal/person/day ****	0.008
18-Hole Golf Course	200	250	250 persons/day 10 gal/person/day ****	0.003
Golf Clubhouse	4	560	140 persons/acre 10 gal/person/day ****	0.006

LAND USE	ACRES	POPULATION	STANDARDS *	AVERAGE FLOW, MGD **
Parks	31	12,400	400 persons/acre 5 gal/person/day ****	0.062
Ridgeline Park	14	5,600	400 persons/acre 5 gal/person/day ****	0.028
Lakefront Park	45	18,000	400 persons/acre 5 gal/person/day ****	0.090
Poamoho Camp	32	0	Existing facilities	0
Pineapple Museum	6	0	Existing facilities	0
Kukaniloko Park	11	4,400	400 persons/acre 5 gal/person/day ****	0.022
Open Space/Cir	58	0		0
TOTAL	892	67,185		1.512

NOTES:
- * Design Standards of the Division of Wastewater Management, Department of Public Works, C&C of Honolulu, unless otherwise indicated.
- ** MGD (Million gallons per day).
- *** School populations are computed with the following assumptions: 2 students for single family & medium family and 0.8 students for multi-family, 1 employee/teacher/20 students
- **** Hawaii Administrative Rules, Chapter 11, Wastewater System.

SOH ESTIMATE
Maximum Wastewater Flow = 2.83 x Average Flow = 2.83 x 1.51 = 4.27 MGD.

Dry Weather Infiltration/Inflow (I/I) = 5 gallons/person = 5 x 67,185 = 0.34 MGD.

Design Average Flow = Average Flow+ Dry Weather I/I = 1.51 + 0.34 = 1.17 MGD.

Design Maximum Flow = Maximum Wastewater Flow + Dry Weather I/I Flow = 4.27 + 0.34 = 4.61 MGD.

Wet Weather I/I = 1,250 gal/sewered acre (493) =1,250 x 493 = 0.62 MGD.

Design Peak Flow = Maximum Flow + Dry Weather I/I + Wet Weather I/I = 4.27 + 0.39 + 0.62 = 5.28 MGD.

APPENDIX M

Proposed Text Amendments, DP Special Provisions

ARTICLE 5. CENTRAL OAHU

PART I

DEVELOPMENT PLAN
SPECIAL PROVISIONS FOR CENTRAL OAHU

SECTION 24-5.1. AREA DESCRIPTION

Central Oahu consists of the wide fertile plateau between the Waianae and the Koolau mountain ranges. The area includes the towns of Waipahu and Wahiawa, and the residential communities of Crestview, Waipio, Waipio Acres, Melemanu Woodlands, Whitmore Village and Wahiawa Lands. Adjacent to Wahiawa are the Schofield Barracks and Wheeler Air Force Base military reservations. Surrounding these suburban communities are some of the State's finest prime agricultural lands.

* * *

Wahiawa is a stable, low-density community bisected by Kamehameha Highway. It is closely associated with major military facilities and related housing. The Wahiawa Reservoir serves as a major visual focus and sharply defines the limits of Wahiawa town. Industrial, commercial, apartment, and public service uses form the center of the community surrounded by single-family residences. The adjacent residential communities of Wheeler Field, Schofield Barracks, Whitmore Village, Poamoho Camp and the proposed Wahiawa Lands development support the town of Wahiawa as Central Oahu's major urban center.

* * *

SECTION 24-5.2 URBAN DESIGN PRINCIPLES AND CONTROLS FOR CENTRAL OAHU

* * *

Principles and Controls for Special Areas

* * *

1. Wahiawa Lands Planned Community

The Wahiawa Lands Planned Community Special Area shall be developed with the urban uses generally identified in this subsection as an integral part of the larger Wahiawa community. The area planned for development shall contain the approximately 860 acres of land bisected by Kamehameha Highway. The area shall develop as a master planned residential community containing a mixture of residential uses; low-density apartment uses; commercial uses, including a village commercial center and office centers; public and quasi-public facilities; and park areas and facilities, all as generally shown on the Land Use Map of this Development Plan.

Development within the Wahiawa Planned Community shall be permitted in accordance with the Land Use and Public Facilities Maps of the Development Plan, and in accordance with the following development principles and standards:

a) A town center, which includes a village commercial center, office centers, a recreation center, and a mix of residential uses at various densities, shall be permitted to be developed to serve as the focus of community activities within the area.

b) Residential development within the area shall be permitted to be developed as generally shown on the Land Use Map in three density categories:

i) Low Density category containing not more than 6 units per acre and consisting of single-family detached and zero lot line housing units.

ii) Middle density category containing not more than 10 units per acre and consisting of single-family attached or clustered housing units, such as townhouses, duplexes, and fourplexes.

iii) High density category containing not more than 15 units per acre and including garden type apartments in buildings not exceeding three stories in height.

A total of about 3,100 residential units be permitted to be developed within the area.

c) Public parks and recreation facilities within the area, as shown on the Land Use Map and Public Facilities Map, as applicable, shall be developed. Public recreation facilities within the area shall include a golf course open to use by the general public. It shall be established and maintained as a major public, open space system and shall generally encompass steeply-sloped areas and natural drainageways within the area as a continuous greenbelt.

d) Supporting public facilities, infrastructure, roadways, utilities, and improvements thereto, shall be permitted to be developed in accordance with the Land Use Map and Public Facilities Map, as applicable.

e) Permitted land uses within the area, as shown on the Land Use Map, shall contain the following approximate acreages:

	Acres
Residential	347
Low Density Apartment	79
Commercial	18
Commercial Emphasis Mixed Use	64
Commercial Industrial Emphasis Mixed Use	41
Public and Quasi - Public	25
Parks and Open Space	93
Golf Course/Clubhouse	204
	871

f) Panoramic and other significant views from within and across the area shall be maintained and enhanced where possible.

APPENDIX N

View Corridor Study

KUKANILOKO BIRTHSTONES STATE MONUMENT VIEW CORRIDOR STUDY

Wahiawa Lands Master Plan

Prepared By: Helber Hastert & Fee, Planners
Prepared For: Hawaiian Trust Co., Ltd.

April 1993

I. PURPOSE

DLNR Division of State Parks (DSP) requested an analysis of view corridors from the State-owned Kukaniloko Birthstones State Monument to determine what, if any, visual impacts would be expected from the implementation of the proposed Wahiawa Lands Master Plan, and what, if any, mitigation would be required to mitigate visual impacts (DLNR letter dated March 12, 1993). The DSP request, and other concerns raised at community meetings, indicated a need to analyze potential impacts the proposed Wahiawa Lands development might have on view corridors from the State Monument. This study documents the analysis and findings of the view corridor study.

II. METHOD

A regional analysis was first conducted using the 1:62,500-scale USGS Island of Oahu map to determine the relevant view shed(s). The view sheds were determined to be confined to the east and west by the ridgelines of the Waianae and Koolau Ranges, respectively, to the north by local topographic ridges, and to the south by the trees along the north bank of Wahiawa Reservoir's North Fork. The view shed delineation was subsequently validated with a site visit. Precise azimuths and elevations between Kukaniloko and major distant viewpoints such as Kolekole Pass and Mt. Kaala were determined using the 1:62,500-scale USGS map.

The City & County of Honolulu's 1:2,400-scale, 5-foot contour aerial contour maps (1969) were used to determine local azimuths, elevations and high points. The 1:6,000-scale Wahiawa Lands Concept Plan was used to determine proposed land use locations. No adjustments were made for possible changes in ground elevations due to site grading, as it was assumed that moderate changes would not affect the order-of-magnitude findings of the analysis. Maximum building heights of all structures were assumed to be 25 feet. It is possible that during subsequent design and planning phases, the building heights and locations may change. Any significant changes should be subjected to a similar level of visual analysis to assess potential impacts to Kukaniloko Park.

A series of six "worst case" or representative sight lines were chosen for further analysis, essentially characterizing 360 degree visual impacts to the State Monument. Worst case sight lines were identified where proposed development would be placed on local high points such that proposed roof heights would extend into the view shed to a maximum extent.

Several common assumptions were made regarding the viewer's location. The viewer's "eyes" are assumed to be five feet above grade. All "views" were taken from the nearest point of the perimeter of the 0.5-acre parcel immediately surrounding the Birthstones (TMK 7-1-01:4) to the view object. This perimeter location was chosen over the perimeters of the State-owned five-acre parcel or the proposed 11-acre Kukaniloko Park as it would more accurately reflect potential impacts to the Birthstones, the principal feature of the monument.

To present the sightline analyses in a reproducible report format, it was necessary at times to compress the horizontal scale dimension on the distant views. This compression does not impair the analysis in any way, and graphic scales have been provided in all the sightlines to guide the reviewer.

III. DESCRIPTION OF EXHIBITS

Exhibit A

Exhibit A identifies the regional view sheds from Kukaniloko, based on the 1:62,500 USGS base information. Two view sheds are identified: the Waianae Range and the Koolau Range. As discussed, the western and eastern extent of the viewshed is limited by the respective mountain ridgelines. Views to the north and south are of open sky horizons, limited to the north by local ridgelines and to the south by trees along the north bank of Lake Wilson's North Fork. Exhibit A indicates the azimuths of three "distant" sight lines (2, 5 & 6), as well as the direction of Kolekole Pass and Mt. Kaala, identified by DSP and others as being important view corridors.

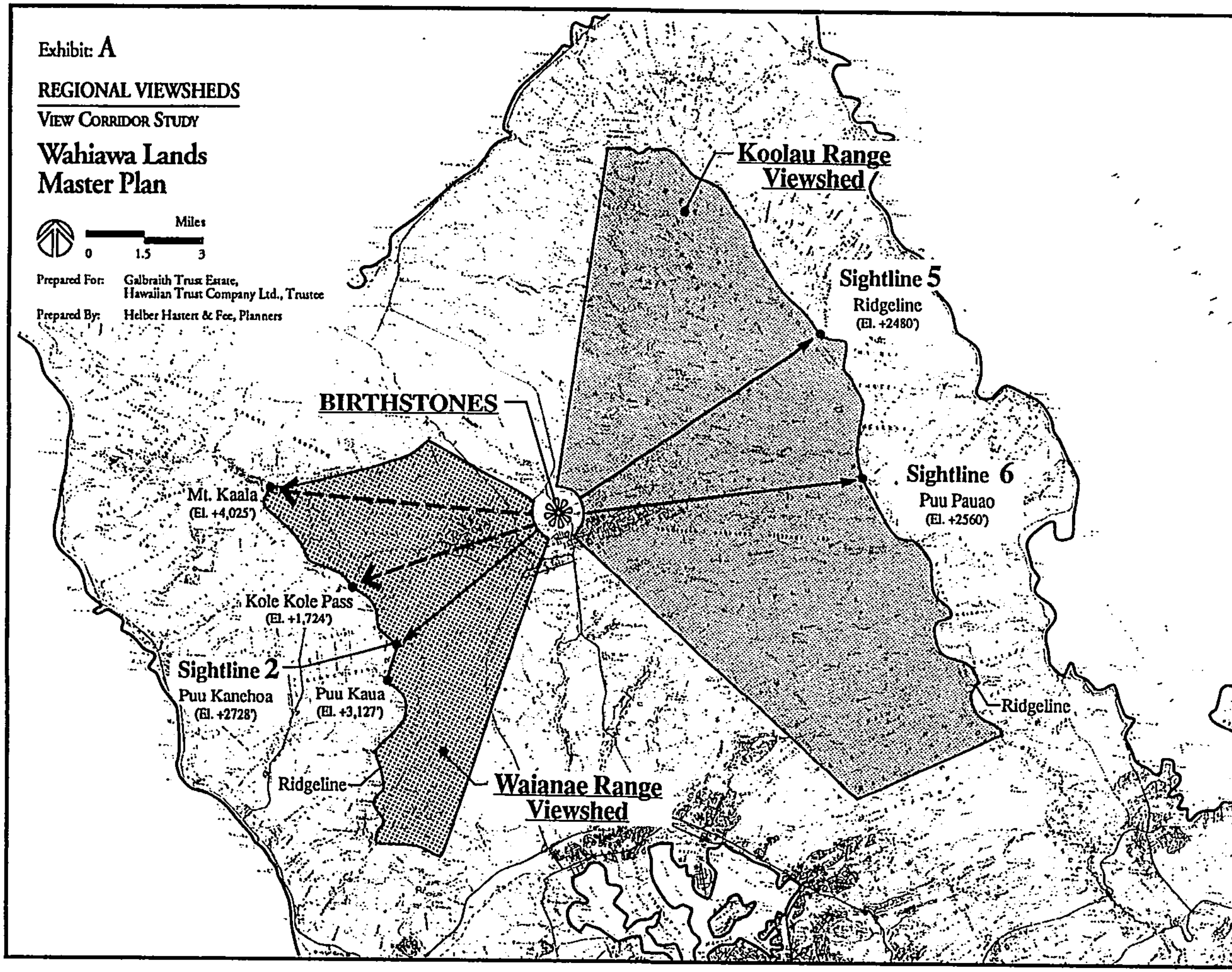


Exhibit: A
REGIONAL VIEWSHEDS
View Corridor Study
Wahiawa Lands
Master Plan
Miles
0
1.5
3
Prepared For: Galbraith Trust Estate, Hawaiian Trust Company Ltd., Trustee
Prepared By: Helber Hastert & Fee, Planners
Koolau Range Viewshed
Sightline 5
Ridgeline
(El. +2480')
BIRTHSTONES
Sightline 6
Puu Pauao
(El. +2560')
Mt. Kaala
(El. +4,025')
Kole Kole Pass
(El. +1,724')
Sightline 2
Puu Kanehoa
(El. +2728')
Puu Kaua
(El. +3,127')
Ridgeline
Ridgeline
Waianae Range Viewshed

Exhibit B

Exhibit B incorporates the distant view sightlines 2, 5 & 6, the precise directions of Kolekole Pass and Mt Kaala, and three additional sightlines 1, 3 & 4, onto the Wahiawa Lands Master Plan base map. The latter group of sight lines are to the north and south, and are confined by local topography and trees.

Exhibit C

Exhibit C presents Sightline 1 to the south-southeast. The view azimuth was selected as it cuts through the closest proposed residential development to the State Monument (see Exhibit B). As seen in the photograph, the view is confined by the tall trees along the north bank of Wahiawa Reservoir's North Fork. The Waianae Range enters the view to the west. The sightline uses a 10x vertical scale exaggeration. The viewpoint (or viewer's eyes) are identified at elevation +945 feet at the SSE perimeter of the 0.5-acre parcel surrounding the Birthstones. The nearest structures would be 550 feet away and consist of single-family homes with a maximum roof height of 25 feet. The extension of Whitmore Avenue and a Neighborhood Park are proposed to lie between the Monument and the single-family homes.

As seen in the sightline, the nearest edge of the single-family homes is the critical edge as the land slopes away from this point. The homes would obscure a significant portion of the trees lining the north bank of the North Fork as indicated, but would not obscure views of the horizon beyond. There are no views of either the Waianae or Koolau Ranges in this direction.

Mitigation of this view impact could be achieved by establishing a 7.4-foot high vegetative screen along the SSE perimeter of the proposed 11-acre Kukaniloko Park edge, in combination with planting and setback guidelines imposed on the referenced single-family residential area.

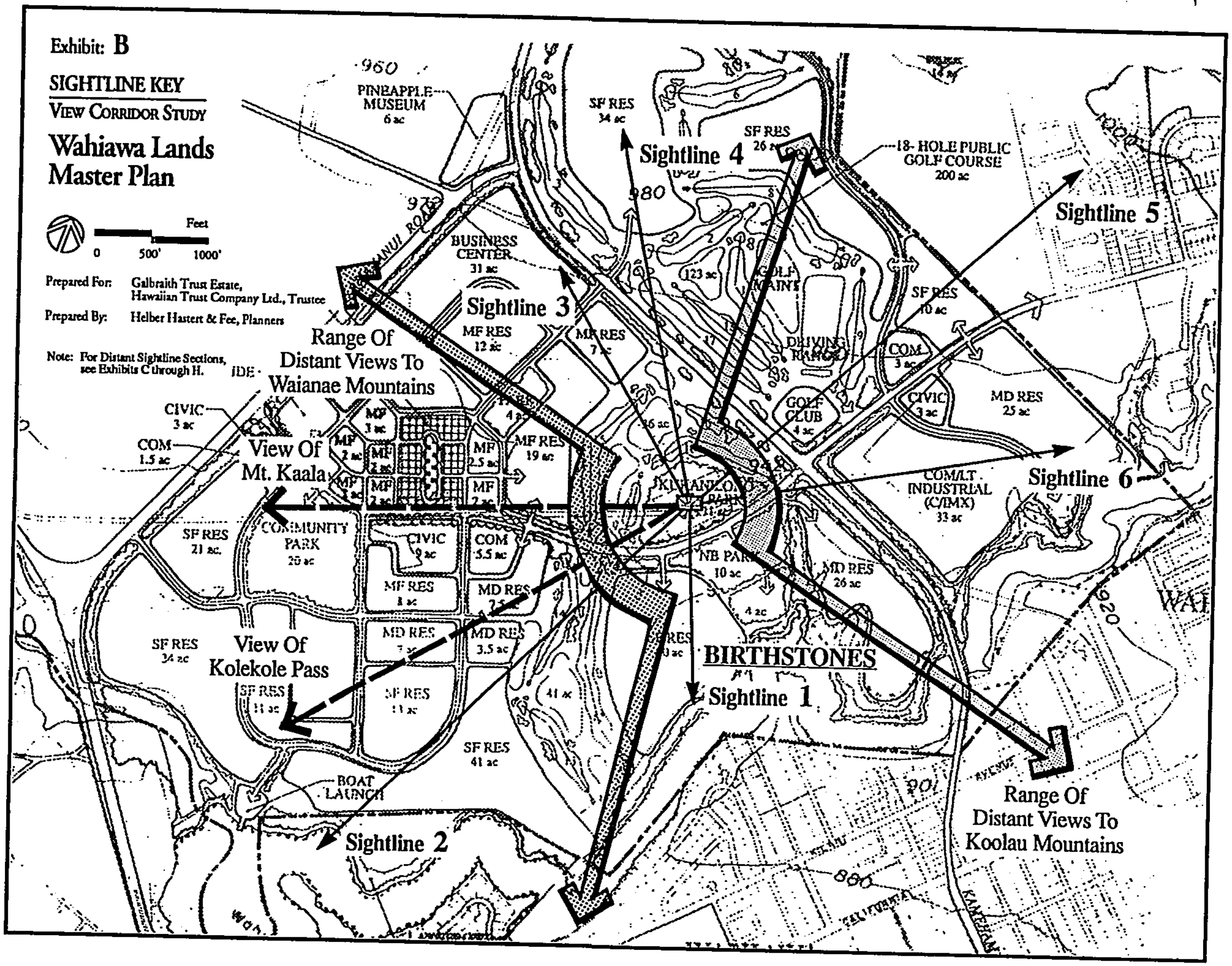


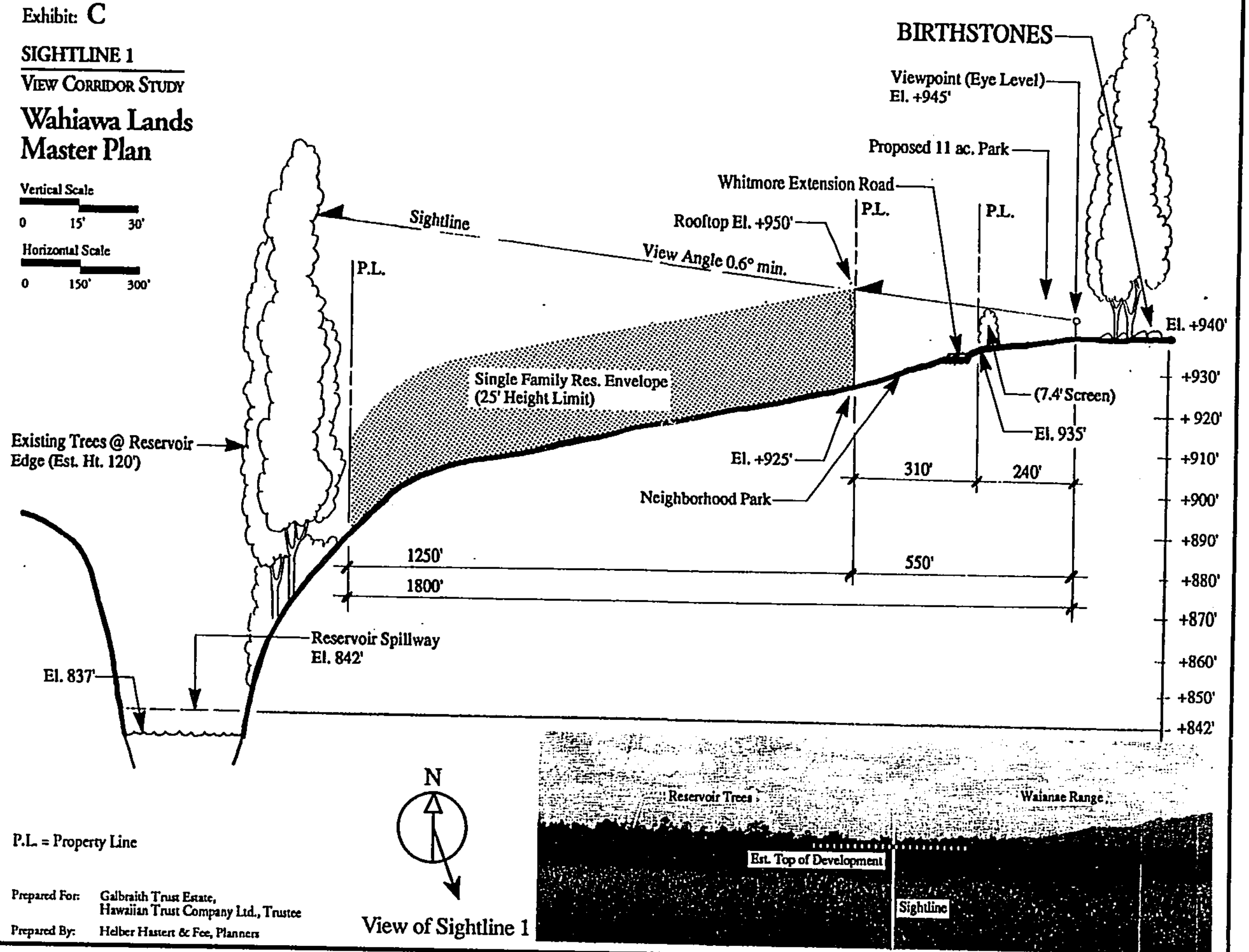
Exhibit: B
SIGHTLINE KEY
View Corridor Study
Wahiawa Lands Master Plan
Feet
0 500' 1000'
Prepared For: Galbraith Trust Estate, Hawaiian Trust Company Ltd., Trustee
Prepared By: Helber Hastert & Fee, Planners
Note: For Distant Sightline Sections, see Exhibits C through H.
Range Of Distant Views To Waianae Mountains
View Of Mt. Kaala
View Of Kolekole Pass
Range Of Distant Views To Koolau Mountains
BIRTHSTONES
Sightline 1
Sightline 2
Sightline 3
Sightline 4
Sightline 5
Sightline 6
PINEAPPLE MUSEUM 6 ac
BUSINESS CENTER 31 ac
18- HOLE PUBLIC GOLF COURSE 200 ac
SF RES 34 ac
SF RES 26 ac
SF RES 10 ac
SF RES 21 ac
SF RES 34 ac
SF RES 11 ac
SF RES 41 ac
MF RES 12 ac
MF RES 7 ac
MF RES 19 ac
MF RES 8 ac
MD RES 25 ac
MD RES 26 ac
MD RES 3.5 ac
COM 3 ac
COM 5.5 ac
COM 1.5 ac
CIVIC 3 ac
CIVIC 9 ac
GOLF CLUB 4 ac
DRIVING RANGE
COM/LT INDUSTRIAL (C/IMX) 33 ac
COMMUNITY PARK 20 ac
NB PARK 10 ac
BOAT LAUNCH
960
980
920
901
880

Exhibit: C

SIGHTLINE 1

VIEW CORRIDOR STUDY

Wahiawa Lands Master Plan



View of Sightline 1

P.L. = Property Line

Prepared For: Galbraith Trust Estate, Hawaiian Trust Company Ltd., Trustee

Prepared By: Helber Hastert & Fee, Planners

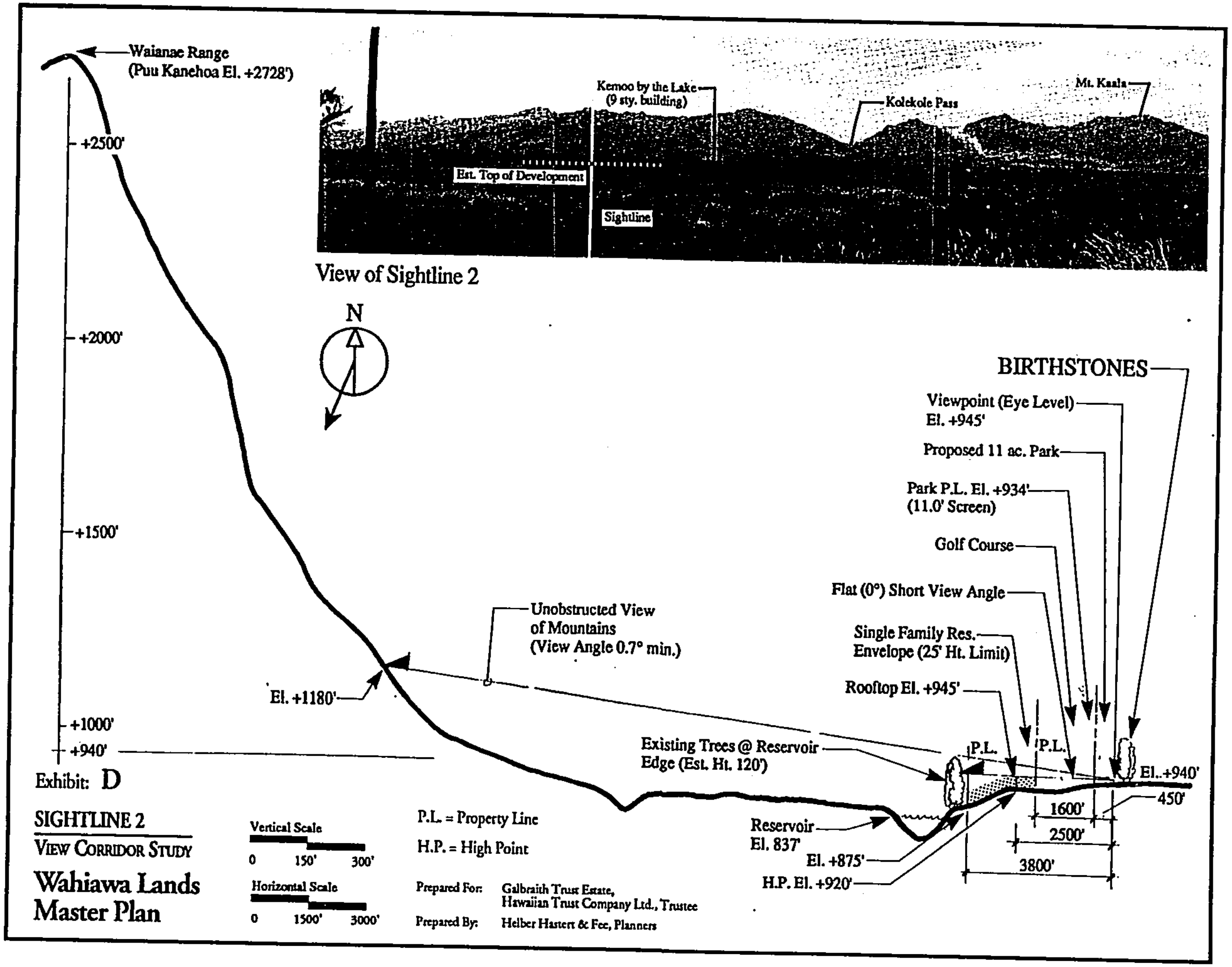
Exhibit D

Exhibit D presents Sightline 2, a distant view of the Waianae ridgeline to the west including Kolekole Pass and Mt. Kaala. The actual sightline azimuth was selected as it passed over a local project highpoint (el. +920 feet) proposed for single-family residential uses (see Exhibit B). Since the ground elevation of project lands in the direction of Kolekole Pass and Mt. Kaala are lower, and since there would be no significant changes in building heights in this general direction, analysis of the chosen sightline can be viewed as representative of that which might be expected in the Kolekole Pass and Mt. Kaala view corridors.

As shown in the sightline section, views of the lower Waianae Range foothills are obscured up to about the 1,180-foot elevation by the tall trees along the north bank of the North Fork (about a 0.7 degree view angle to the lowest visible spot on the Waianae Range). With regard to the local views, proposed single-family homes, with the nearest located approximately 2,500 feet from the viewer, would obscure most of the reservoir trees, although the roof heights are not projected to intrude above a 0.0 degree view angle, or above the reservoir tree back drop.

Golf fairways and the proposed Whitmore Avenue extension would occupy the area between the Monument and the homes.

Mitigation of the local view impacts could be achieved by establishing a 11.0-foot high vegetative screen along the SW perimeter of the proposed 11-acre Kukaniloko Park edge, perhaps in combination with planting and setback guidelines imposed on the single-family residential area, and strategic placement of trees and shrubs within the golf fairways and along the roadway right-of-way.


Waianae Range
(Puu Kanehoa El. +2728')
+2500'
+2000'
+1500'
+1000'
+940'
Kemoo by the Lake
(9 sty. building)
Kolekole Pass
Mt. Kaala
Est. Top of Development
Sightline
View of Sightline 2
N
BIRTHSTONES
Viewpoint (Eye Level)
El. +945'
Proposed 11 ac. Park
Park P.L. El. +934'
(11.0' Screen)
Golf Course
Flat (0°) Short View Angle
Single Family Res.
Envelope (25' Ht. Limit)
Rooftop El. +945'
Unobstructed View
of Mountains
(View Angle 0.7° min.)
El. +1180'
Existing Trees @ Reservoir
Edge (Est. Ht. 120')
P.L.
P.L.
El. +940'
450'
1600'
2500'
3800'
Reservoir
El. 837'
El. +875'
H.P. El. +920'
Exhibit: D
SIGHTLINE 2
VIEW CORRIDOR STUDY
Wahiawa Lands
Master Plan
Vertical Scale
0 150' 300'
Horizontal Scale
0 1500' 3000'
P.L. = Property Line
H.P. = High Point
Prepared For: Galbraith Trust Estate,
Hawaiian Trust Company Ltd., Trustee
Prepared By: Helber Hastert & Fee, Planners

<u>Exhibit E</u>

Exhibit E presents Sightline 3 to the northwest. The view azimuth was selected as it cuts through the closest proposed upslope residential development to the park in this direction (see Exhibit B). As seen in the photograph, the view is of an open horizon with pineapple occupying the foreground and with utility poles running along Kamehameha Highway in the distance. There are no views of either the Waianae and Koolau Ranges in this direction. The sightline section indicates the horizon is defined by a 952-foot ground elevation contour located about 250 feet away from the viewer with approximately three feet of pineapple cover which effectively acts as a buffer to distant views. The sightline identifies the Del Monte maintenance building located adjacent within the "pineapple triangle" intersections of Kamananui and Kaukonahua Roads with Kamehameha Highway. This structure, assumed to be approximately 20 feet tall and located about 2,700 feet from the viewer, lies just below the horizon at the five-foot viewing height. The sightline uses a 10x vertical scale exaggeration and identifies the viewer's eye level at elevation +950 feet at the NW perimeter of the 0.5-acre parcel surrounding the Birthstones. The nearest proposed structures would be 1,100 feet away and consist of two-story town homes with a maximum roof height of 25 feet. Proposed golf fairways would lie between the residential uses and the park.

The nearest edge of the multi-family homes is identified as the critical edge due the local topographic features. The sightline section indicates that the horizon is now visible at about a 1.1 degree minimum view angle, and that the town homes would intrude into that horizon by about 0.2 degrees (for comparison purposes, a 0.5 degree angle would be similar to the distance between the upper and lower edges of a dime from over six feet away).

Mitigation of this view impact could be achieved by establishing a 3.5-foot high vegetative screen along the NW perimeter of the proposed 11-acre Kukaniloko Park edge, in combination with planting and setback guidelines imposed on the single-family residential area and strategic placement of trees and shrubs within the golf course.

Exhibit: E

SIGHTLINE 3

VIEW CORRIDOR STUDY

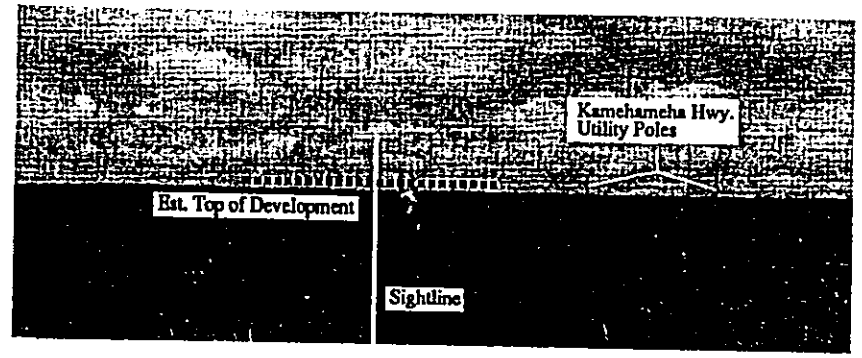
Wahiawa Lands Master Plan

Vertical Scale: 0 15' 30'

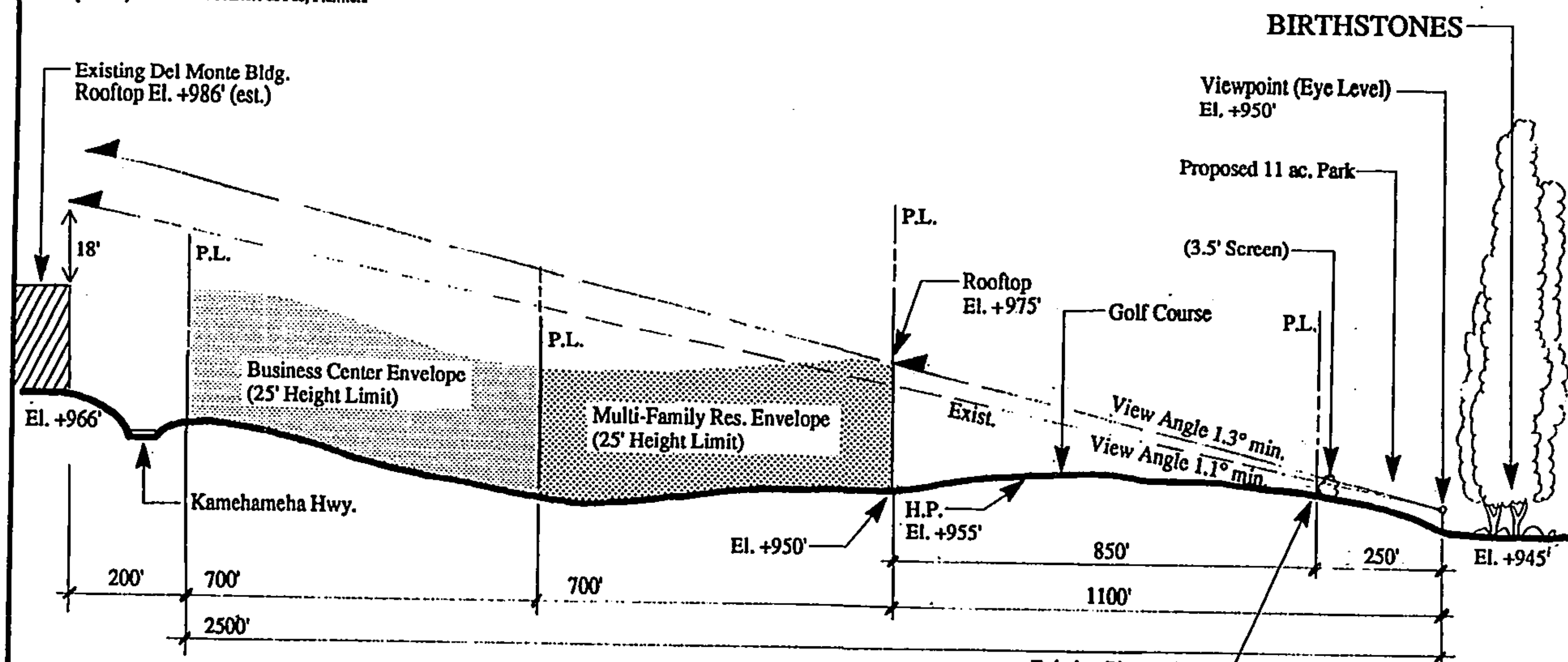
Horizontal Scale: 0 150' 300'

Prepared For: Galbraith Trust Estate, Hawaiian Trust Company Ltd., Trustee

Prepared By: Helber Hastert & Fee, Planners



View of Sightline 3



P.L. = Property Line

H.P. = High Point

Exhibit F

Exhibit F presents Sightline 4 to the north-northwest. The view azimuth was selected as it cuts through a local high point at elevation +997.5 feet (mauka of Kamehameha Highway) planned for single-family homes (see Exhibit B). As seen in the photograph, the view is similar to Sightline 3, consisting of an open horizon with pineapple occupying the foreground and utility poles running along Kamehameha Highway in the distance. The northern reaches of the Koolau Range begin to come into view to the east. There are no views of the Waianae Ranges in this direction. The sightline section indicates the horizon is defined by a 954-foot ground elevation contour with approximately 3 feet of pineapple cover, about 270 feet away from the viewer. The sightline uses a 10x vertical scale exaggeration and identifies the viewer at elevation +950 feet at the NNW perimeter of the 0.5-acre parcel surrounding the Birthstones. The nearest structures would be 2,300 feet away and consist of single-family homes with a maximum roof height of 25 feet. Proposed golf fairways would lie between the residential uses and the park.

The sightline section indicates that the horizon is now visible at about a 1.5 degree view angle, and that the proposed single-family homes would be below that horizon by about 0.2 degrees.

Once the existing pineapple cover is removed, continued mitigation of this view impact could be achieved by establishing a modest 2.2-foot high vegetative screen along the NNW perimeter of the proposed 11-acre Kukaniloko Park edge, in combination with planting and setback guidelines imposed on the single-family residential area and strategic placement of trees and shrubs within the golf course. A 100-foot landscaped setback is also planned along both sides of Kamehameha Highway to buffer adjacent urban uses.

Exhibit: F

SIGHTLINE 4

VIEW CORRIDOR STUDY

Wahiawa Lands Master Plan

Vertical Scale: 0, 15', 30'

Horizontal Scale: 0, 150', 300'

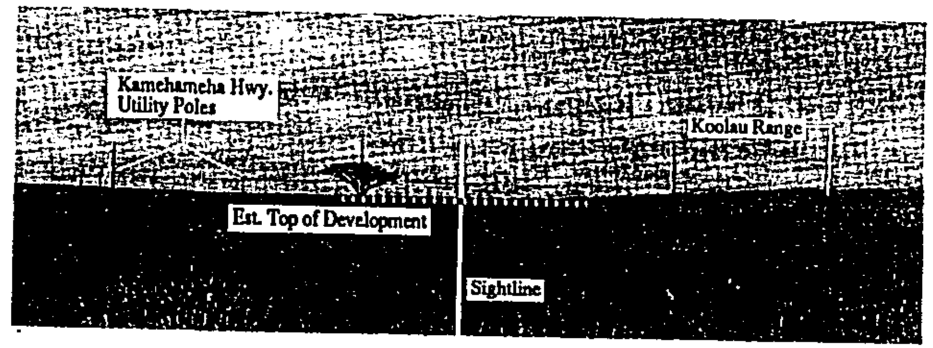
Prepared For: Galbraith Trust Estate, Hawaiian Trust Company Ltd., Trustee

Prepared By: Helber Hastert & Fee, Planners

P.L. = Property Line

H.P. = High Point

View of Sightline 4



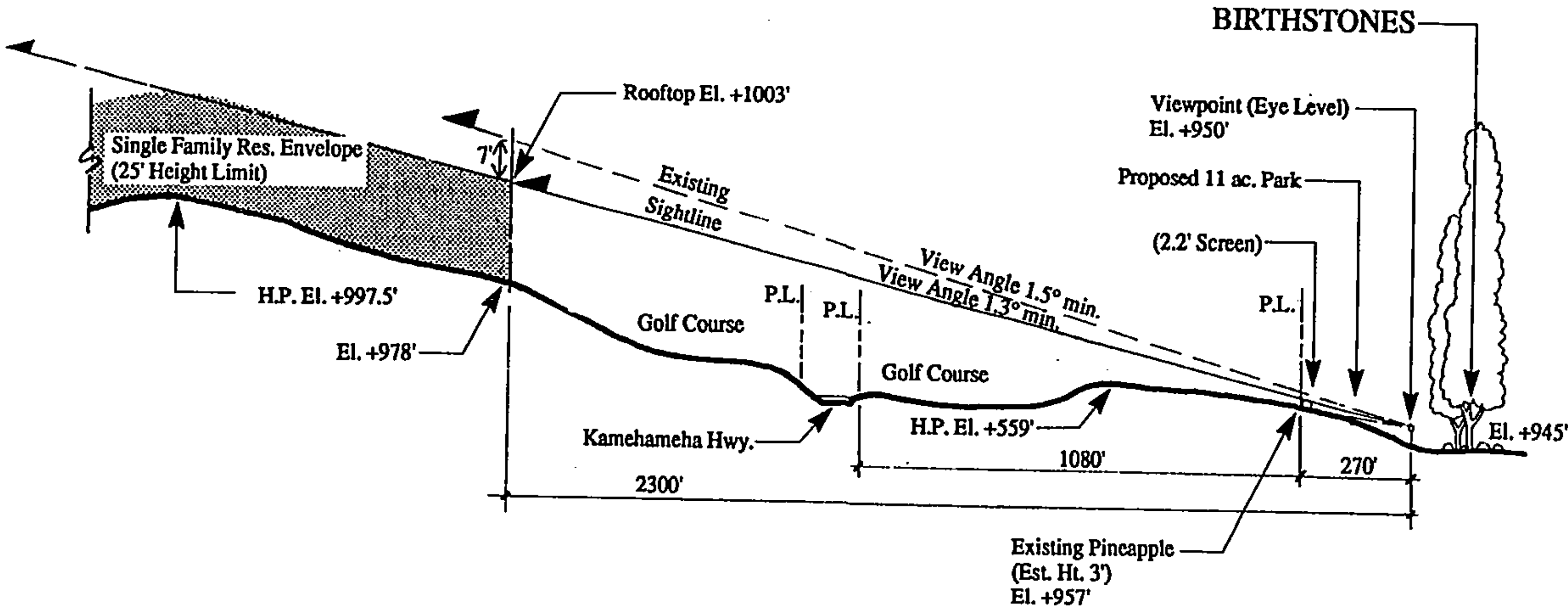


Exhibit G

Exhibit G presents Sightline 5 to the north-northeast. The view azimuth was selected as it cuts through the proposed golf club house planned for construction across Kamehameha Highway from the Park (see Exhibit B). As seen in the photograph, the view is occupied by the Koolau Range in the background with the urban uses of Whitmore Village and utility poles along Kamehameha Highway in the foreground. The main sightline uses a 10x vertical scale exaggeration while the inset uses equal vertical and horizontal scales. The sightline identifies the viewer at elevation +945 feet at the NNE perimeter of the 0.5-acre parcel surrounding the Birthstones. The nearest structure would be the golf course clubhouse about 930 feet away with a maximum roof height of 25 feet. Proposed golf fairways and Kamehameha Highway would lie between the clubhouse and the park.

The sightline section indicates that the Koolau Range above Whitmore Village is now visible above a 1.5 degree view angle, and that the proposed clubhouse would intrude into that horizon by about 0.3 degrees.

Mitigation of this view impact could be achieved by a 7.0-foot high vegetative screen along the NNE perimeter of the proposed 11-acre Kukaniloko Park edge, in combination with planting and setback guidelines imposed around the perimeter of the clubhouse area and strategic placement of trees and shrubs within the golf course. It should be noted that a 5.5-foot high screen would be needed to screen out the existing urban uses. A 100-foot landscaped setback is also planned along both sides of Kamehameha Highway to buffer adjacent urban uses.

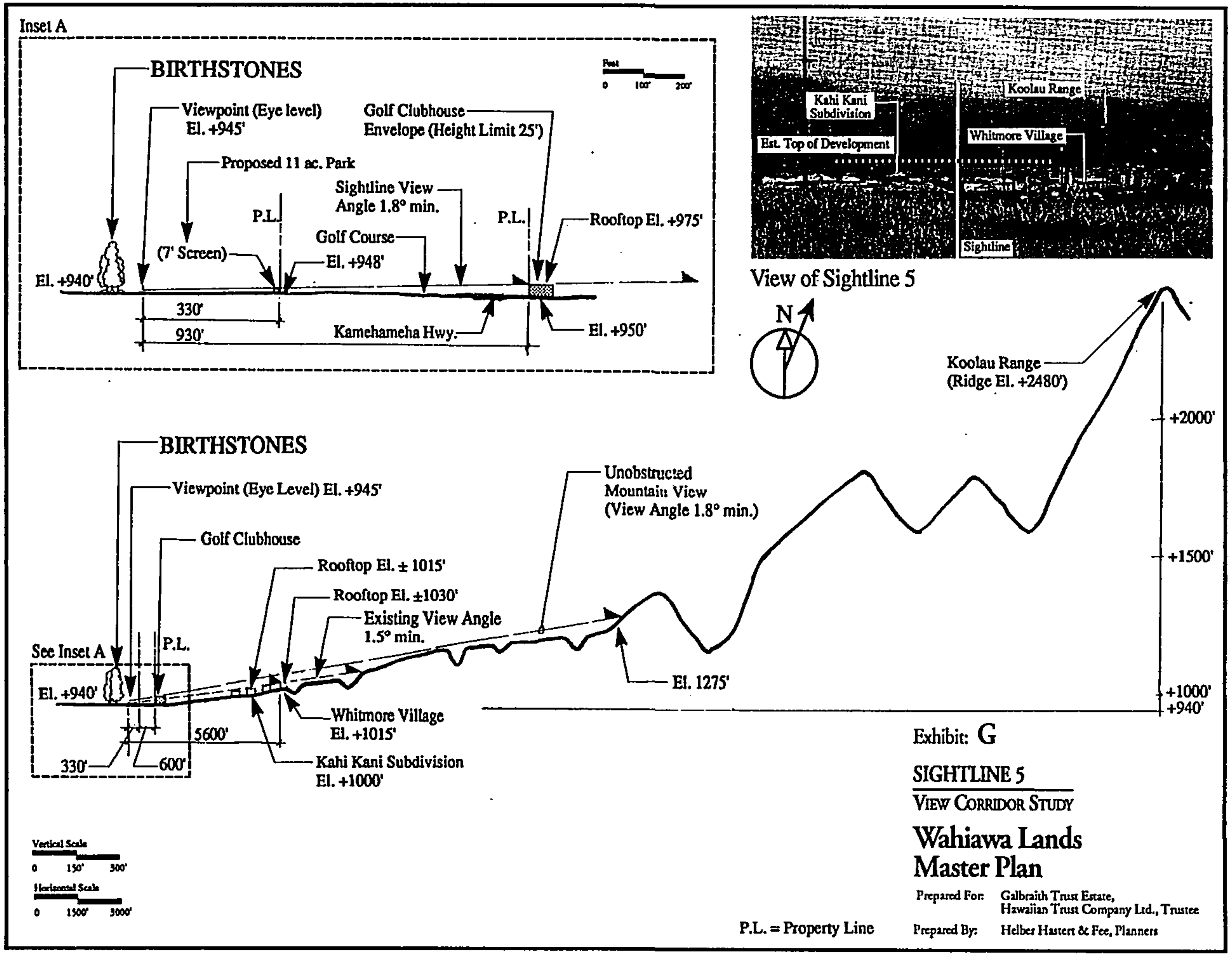


Exhibit: G

SIGHTLINE 5

VIEW CORRIDOR STUDY

Wahiawa Lands Master Plan

Prepared For: Galbraith Trust Estate, Hawaiian Trust Company Ltd., Trustee

Prepared By: Helber Hastert & Fee, Planners

Exhibit H

Exhibit H presents Sightline 6 to the northeast. The view azimuth was selected as it cuts through the proposed commercial/light industrial mixed use area (C/IMX) across Kamehameha Highway from the Park (see Exhibit B). As seen in the photograph, the view is similar to Sightline 5 in that it is occupied by the Koolau Range in the background with the urban uses of Whitmore Village and utility poles and traffic signal lights along Kamehameha Highway in the foreground. Wahiawa can be seen in the middle ground to the east. The main sightline uses a 10x vertical scale exaggeration while the inset uses equal vertical and horizontal scales. The sightline identifies the viewer at elevation +949 feet at the NE perimeter of the 0.5-acre parcel surrounding the Birthstones. The nearest structure would be the C/IMX area about 1,300 feet away with a maximum roof height of 25 feet. The proposed Whitmore Avenue extension and Kamehameha Highway would lie between the C/IMX area and the park.

The sightline section indicates that the Koolau Range above Whitmore Village is now visible above a 0.6 degree view angle, and that the proposed C/IMX area would intrude into that horizon by about 0.3 degrees.

Mitigation of this view impact could be achieved by a 15-foot high vegetative screen along the NE perimeter of the proposed 11-acre Kukaniloko Park edge, in combination with planting and setback guidelines imposed around the perimeter of C/IMX area, and the Whitmore Extension and Kamehameha Highway ROWs. It should be noted that a 12.6-foot high screen would be needed to screen out the existing urban uses. A 100-foot landscaped setback is also planned along both sides of Kamehameha Highway to buffer adjacent urban uses.

Exhibit I

Exhibit I presents a plan view of proposed land uses surrounding the proposed 11-acre Kukaniloko Park, illustrating the open space uses buffering the park comprising close to 100 acres. The buffering uses consist of parks, golf fairways and existing and proposed roadway rights-of-way.

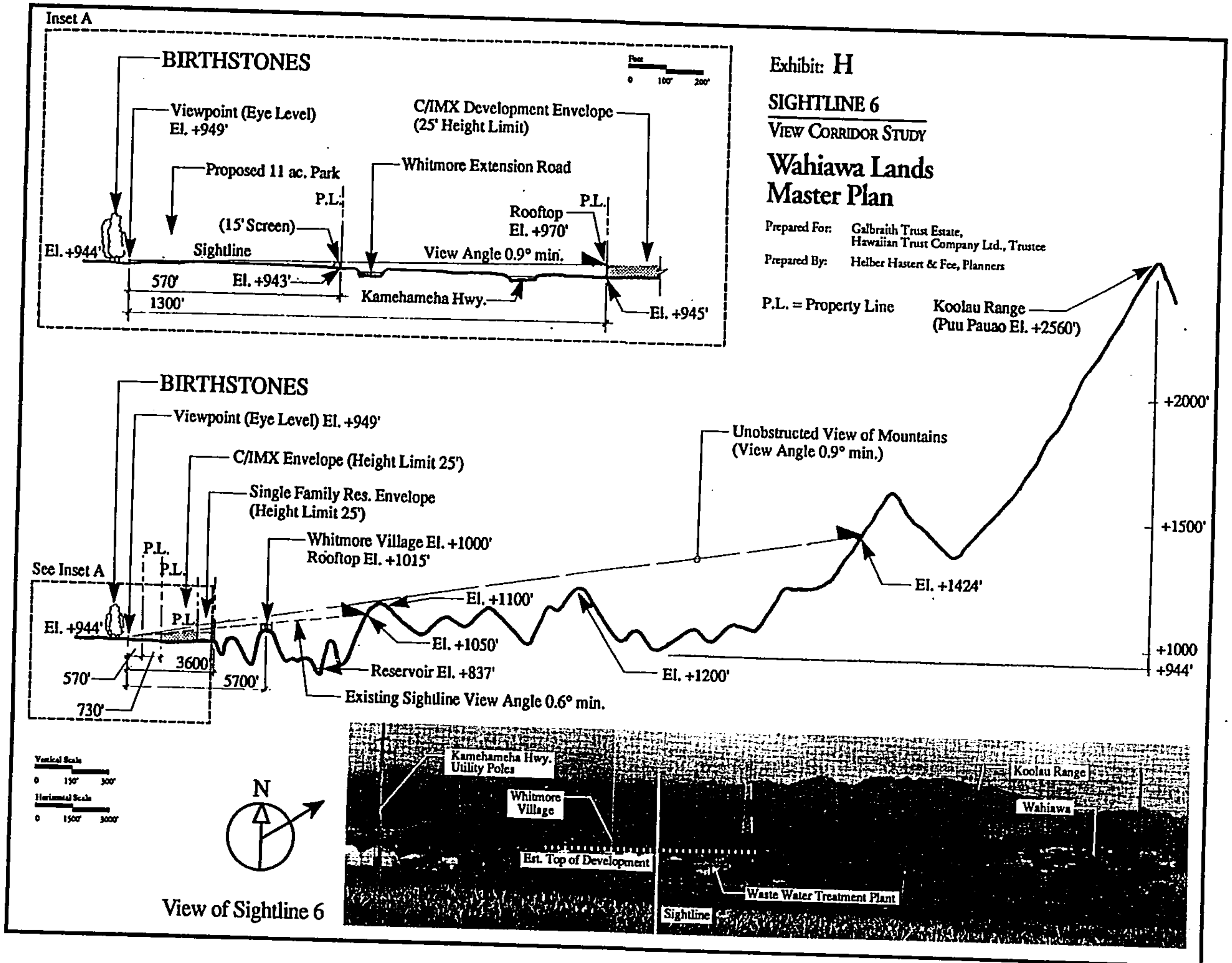


Exhibit: H
SIGHTLINE 6
View Corridor Study
Wahiawa Lands Master Plan
Prepared For: Galbraith Trust Estate, Hawaiian Trust Company Ltd., Trustee
Prepared By: Helber Hastert & Fee, Planners
P.L. = Property Line
Koolau Range (Puu Pauao El. +2560')
Inset A
BIRTHSTONES
Viewpoint (Eye Level) El. +949'
Proposed 11 ac. Park
(15' Screen)
Sightline
El. +944'
570'
1300'
El. +943'
P.L.
Whitmore Extension Road
Kamehameha Hwy.
C/IMX Development Envelope (25' Height Limit)
Rooftop El. +970'
View Angle 0.9° min.
El. +945'
BIRTHSTONES
Viewpoint (Eye Level) El. +949'
C/IMX Envelope (Height Limit 25')
Single Family Res. Envelope (Height Limit 25')
Whitmore Village El. +1000' Rooftop El. +1015'
See Inset A
El. +944'
570'
730'
3600'
5700'
El. +1100'
El. +1050'
Reservoir El. +837'
Existing Sightline View Angle 0.6° min.
El. +1200'
Unobstructed View of Mountains (View Angle 0.9° min.)
El. +1424'
+2000'
+1500'
+1000
+944'
Vertical Scale
Horizontal Scale
N
View of Sightline 6
Kamehameha Hwy. Utility Poles
Whitmore Village
Est. Top of Development
Sightline
Waste Water Treatment Plant
Koolau Range
Wahiawa

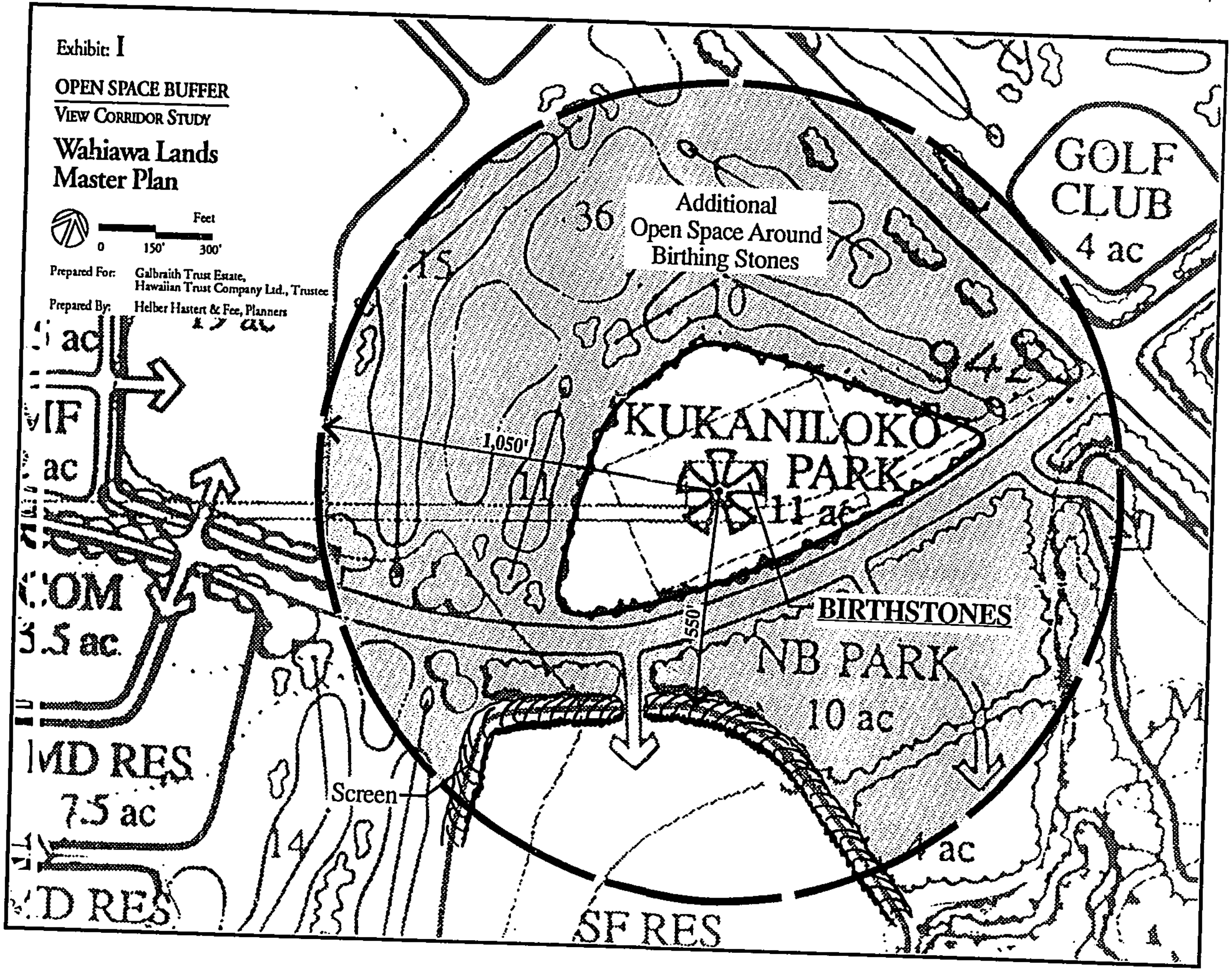


Exhibit: I
OPEN SPACE BUFFER
VIEW CORRIDOR STUDY
Wahiawa Lands
Master Plan
Feet
0 150' 300'
Prepared For: Galbraith Trust Estate, Hawaiian Trust Company Ltd., Trustee
Prepared By: Helber Hastert & Fee, Planners
GOLF CLUB
4 ac
Additional Open Space Around Birthing Stones
36
KUKANILOKO PARK
11 ac
1,050'
550'
BIRTHSTONES
NB PARK
10 ac
COM
3.5 ac
MD RES
7.5 ac
Screen
SF RES

IV. FINDINGS

A. Potential Impacts

The following table summarizes the various attributes discussed in the foregoing sightline analysis.

Sight Line	Azimuth	View Content (near/far)	Degree Intrusion	Screen Height (feet)	Closest Structure (feet) (1)
1	SE	Wilson Res/ Open Horiz.	0.0	7.4	550/310
2	SW	Wilson Res/ Waianae Rnge	0.0	11.0	2050/1600
3	NW	Open Horiz.	0.2	3.5	1100/850
4	NNW	Open Horiz.	0.0	2.2	2300/2030
5	NNE	Whitmore/ Koolau Rnge	0.3	7.0 (2)	930/600
6	NE	Whitmore/ Koolau Rng	0.3	15.0 (3)	1300/730

Notes:
(1) Distance from: 0.5-ac. Park/11-ac. Park
(2) 5.5-foot screen needed for existing conditions
(3) 12.6-foot screen needed for existing conditions

Based on the sightline analysis, potential impacts can be summarized as follows:

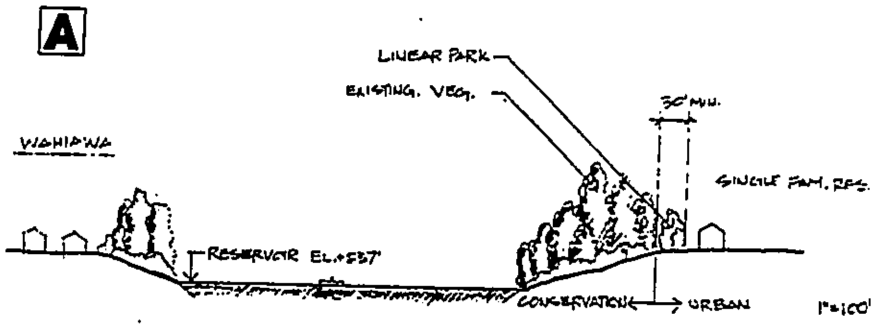
- Distant views of the Waianae and Koolau Mountain Ranges will not be adversely impacted by the proposed development.
- Approximately 0.2 degrees of open horizon would be obscured in the northwest direction.
- Approximately 0.3 degrees of the lower Koolau Range would be obscured in the north-northwest direction.
- Local views to the nearby pineapple fields and to the trees along Wilson Reservoir would be obscured by proposed development.

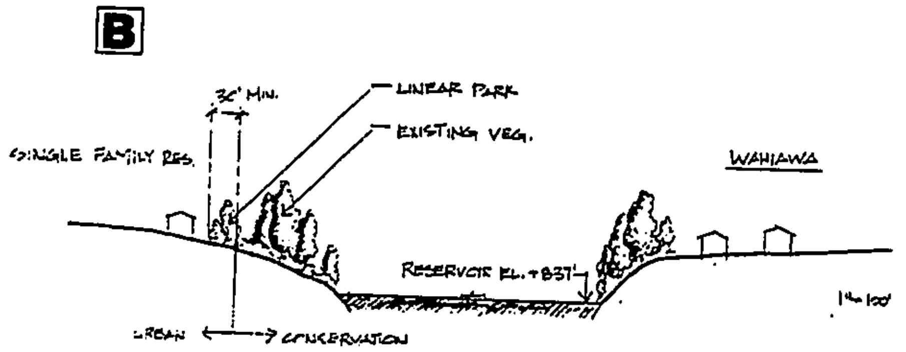
B. Mitigation Measures

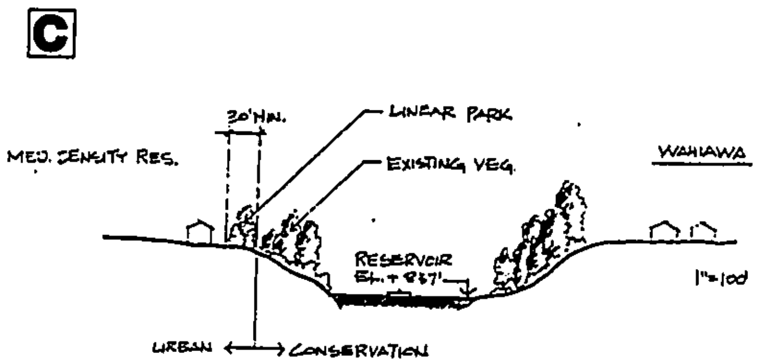
The sightline analysis has determined that vegetative screening at the perimeter of the 11-acre Kukaniloko Park and within adjacent land uses would mitigate project impacts. Site grading within the Park boundaries should also be considered as a complementary approach to perimeter landscaping to mitigate against visual intrusions into the Park. A 100-foot landscaped setback is also planned along both sides of Kamehameha Highway to further buffer adjacent urban uses.

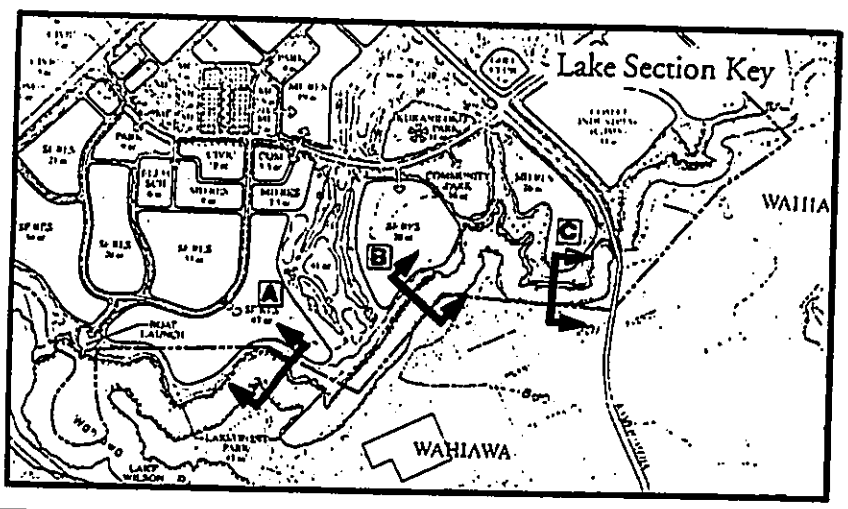
APPENDIX O

Wahiawa Reservoir (North Fork) Project Edge Treatment









Wahiawa Reservoir (North Fork) Project Edge Treatment

April 1993

Prepared For: Galbraith Trust Estate,
Hawaiian Trust Company, Ltd., Trustee

Prepared By: Helber Hastert & Fee, Planners

Not to Scale