‘O‘OMA II

NORTH KONA, HAWAII

VOLUME II - APPENDICES

FINAL SUPPLEMENTAL
ENVIRONMENTAL IMPACT STATEMENT
November 1991

Prepared For: KAHALA CAPITAL CORPORATION
Prepared By: HELBER HASTERT & FEE, PLANNERS
For Submittal To: STATE LAND USE COMMISSION

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APPENDIX A

SHORELINE ACCESS AGREEMENT

CADES SCHUTTE FLEMING & WRIGHT
ATTORNEYS AT LAW

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SUITE B-303
HUALALAI CENTER
75-170 HUALALAI ROAD
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TELECOPIER: (808) 326-1175
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November 2, 1990

WRITER'S DIRECT DIAL NUMBER

Kevin R. Seiter, Esq.
Kona Inn Village
75-5744 Alii Drive
Suite 245
Kailua-Kona, HI 96740

Re: Friends of Kohanaiki, et al., v. Nansay Hawaii, et al., Civil No. 90-255K

Dear Kevin:

The purpose of this letter is to memorialize the terms of the settlement agreement between our respective clients. As of my October 9, 1990 letter, I will try to set out the basic terms of our settlement agreement in a non-legalistic manner. Both parties anticipate the need to enter a formal stipulation and settlement agreement or stipulated judgment which recites, in detail, the full terms of our agreement. At the same time, it is intended that this letter agreement is binding on the parties with respect to the terms and conditions it contains.

1. Kohanaiki: Nansay Hawaii, Inc. ("Nansay") will not interfere with public vehicular access or use of the shoreline "jeep trail" for recreational purposes as defined in H.R.S. Chapter 520 from the northern boundary of the Kohanaiki property (where it abutts on the O'oma property) to the southern boundary of the Kohanaiki property (where it abuts on the National Park Service's Kaloko property) until such time as improved public vehicular accesses (A) and (B) as set out below have been constructed and opened to the public. When the improved public accesses (A) and (B) as described hereinbelow have been completed and opened to the public, Nansay will grant a nonexclusive easement, access right, or right-of-way to the State of Hawaii, Department of Land and Natural Resources, Na Ala Hele program, to incorporate that section of the trail in Na Ala Hele's Ala Kahakai demonstration trail as outlined in the attached letter dated October 15, 1990 from the Department of Land and Natural Resources Director, William W. Paty and addressed to Mr. Duane Kanuha, Planning Director (Exhibit "B"). The portion of the Kohanaiki property not included in the pending SMA application will be referred to as the "southern portion" of the Kohanaiki property.

Access point "B" will provide vehicular access to the shoreline of the southern portion of the Kohanaiki property, and Nansay will agree to not interfere with public vehicular access and use of the shoreline "jeep trail" within the southern portion of the Kohanaiki property for recreational purposes as defined by H.R.S. Chapter 520 until such time as Nansay undertakes construction of improvements in that area pursuant to appropriate governmental permits.

Nansay will agree that as part of construction of improvements in the southern portion of the Kohanaiki property, Nansay will provide mauka-makai vehicular access to the shoreline in this area, including parking, bathroom facilities, and shower facilities as set out as improved public access (C) hereinbelow and on Exhibit "A."

At the time access point (C) is constructed and open to the public, a nonexclusive easement, access, or right-of-way over the shoreline trail will be granted by Nansay to the State of Hawaii, Department of Land and Natural Resources, Na Ala Hele program for inclusion in the Ala Kahakai demonstration trail.

At the time access point (C) is completed and open to the public, access point (B) will remain as a mauka-makai public access point (subject to relocation) which will provide access from the paved road system in the Kohanaiki development to (but not along) the shoreline in the vicinity of the northern boundary of the southern portion of the Kohanaiki property.

The improved public vehicular access points will be:

a) a paved mauka-makai vehicular access road to "Pine Trees" beach, including parking, bathrooms, showers; (Exhibit "A" Number 1)

b) a four-wheel drive access road from the paved road system in the Kohanaiki development to the shoreline in the vicinity of the northern boundary of the southern portion which will permit the public to utilize the "jeep trail" within the southern portion until such time as Nansay undertakes construction of improvements in that area and which after construction of improvements in the southern portion have been completed will be limited to vehicular access to but not along the shoreline in the vicinity of the northern boundary of the southern portion of the Kohanaiki property (Exhibit "A" number 2); and

c) a paved mauka-makai vehicular access road to the southern portion of the Kohanaiki property, including parking, bathrooms, and showers (Exhibit "A" number 3).

Nansay and/or its successors or assigns will agree to provide unrestricted 24-hour access to the Kohanaiki shoreline along access points designated in Exhibit "A" hereto subject to reasonable rules and regulations as reviewed and approved by the Planning Department of the County of Hawaii. Nansay further agrees to keep public vehicular access to "Pine Trees" beach open during all phases of construction.

2. <u>O'oma</u>: Kahala Capital Corporation ("Kahala"), its successors and assigns, will agree not to interfere with public vehicular access along the shoreline "jeep trail" for recreational purposes as defined by H.R.S. Chapter 520 from the northern boundary of the O'oma property (where it abuts with State-owned HOST Park property) to the southern boundary of the O'oma property (where it abuts on Kohanaiki) until such time as improved, paved mauka-makai public access improvements are completed and opened to the public providing public vehicular access to both the northern and southern shoreline portions of the O'oma property.

Specifically, Kahala, its successors and assigns, agree to include in any plans submitted to the State of Hawaii Land Use Commission and/or County of Hawaii Planning Commission or County Council two vehicular mauka-makai public shoreline access points (north and south) including adequate parking, showers, and changing and bathroom facilities.

The south shoreline access point will be located as near as practicable to the southern boundary of the O'oma property (where it abuts on Kohanaiki) and the north as near as practicable to the HOST Park. Kahala will agree not to interfere with shoreline vehicular access to the existing "jeep trail" until such time as improved public access points are constructed and opened to the public. At the time improved accesses and facilities are open, Kahala Capital will grant a nonexclusive easement, access, or right-of-way to the State of Hawaii, Department of Land and Natural Resources, for inclusion of the shoreline trail in the Na Ala Hele Ala Kahakai demonstration trail as outlined in the attached letter for use consistent with the description as outlined in the attached letter dated October 15, 1990 from the Department of Land and Natural Resources Director, William W. Paty and addressed to Mr. Duane Kanuha, Planning Director (Exhibit "B").

Kahala, its successors and assigns, will agree not to interfere with continued public mauka-makai access along the unimproved (unpaved) roadway which leads from Kaahumanu Highway to the shoreline "jeep trail" along the southern portion of the O'oma property. [This road will be referred to as the "Old O'oma Road."] The Old O'oma Road intersects the shoreline "jeep trail" on the O'oma property just north of Puhili Point. Kahala will agree to permit use of the road by the public until such time as the alternative mauka-makai access road is constructed and opened to the public. In no event will Kahala, its successors and assigns, dedicate the portion of the longshore "jeep trail" on its property to the State of Hawaii prior to completion of vehicular access and facilities described herein.

Kahala Capital Corporation, Nansay Hawaii, Inc., the Friends of Kohanaiki, Inc., West Hawaii Surfing Association, and Surfrider Foundation will agree to consult with the County and State governments and enter a formal written agreement, stipulated settlement agreement, and/or stipulated judgment (as deemed appropriate by the parties) memorializing the agreement reached between the parties. Nansay agrees that the terms of this agreement insofar as they relate to Nansay and Kohanaiki may be included as conditions in Nansay's Special Management Area use permit (if granted). Kahala agrees that the terms of this agreement may be included in any Land Use Commission decision and order, Conservation District Use Permit, zoning ordinance, and/or SMA permit which may issued to Kahala or its successors or assigns with respect to future development of the O'oma property.

In exchange for the above-described undertakings on the part of Nansay and Kahala, plaintiffs will agree to withdraw their request for contested case consideration with respect to Nansay's SMA application currently pending before the County of Hawaii Planning Commission and will either 1) dismiss the above-entitled action (Civil No. 90-255K) with prejudice or 2) enter into a stipulated judgment in said action incorporating the terms and conditions of this settlement. If a stipulated judgment is to be entered, the parties will stipulate to certification of the plaintiffs' class described in the Complaint and notice of this settlement shall be provided to the public as required by the Court. The plaintiffs will agree that the statute of limitations with respect to prescriptive vehicular access rights of any description with respect to both the mauka-makai and longshore accesses discussed in this agreement both on the O'oma and Kohanaiki properties is tolled or interrupted effective on the date of this agreement.

It is also agreed between Nansay Hawaii, Kahala Capital Corporation, and the plaintiffs that the undertakings of Nansay under this proposed agreement would be subject to Nansay receiving approval of its petition for a Special Management Area permit, approval of its public access plan, final plan approval as necessary for Nansay to complete construction of improvements on the Kohanaiki property. It is also understood that the undertakings of Kahala under this proposed agreement are subject

to Kahala's obtaining appropriate reclassification, zoning, and/or Conservation District Use Permits from the State of Hawaii and/or County of Hawaii to enable Kahala to construct improvements on the O'oma property.

It is agreed that this agreement may be executed in counterparts with the various counterparts taken together to constitute a complete agreement.

I will be submitting this agreement to my clients today for their review and signatures. If they have any changes or corrections, I will so inform you immediately. I ask that you do the same so that we move with all deliberate speed to execution of this letter agreement and preparation of a final stipulated settlement agreement or stipulated judgment in consultation with the State of Hawaii and County of Hawaii.

As always, if you have any questions or need any further information, please contact me at 329-5811.

Very truly yours,

Gino L. Gabrio for

Roy A. Vitousek III
for
CADES SCHUTTE FLEMING & WRIGHT

APPROVED AND AGREED:

NANSAY HAWAII, INC.

By ____________________

KAHALA CAPITAL CORPORATION

By Toni Fortin

FRIENDS OF KOHANAIKI, INC.

By ____________________

WEST HAWAII SURFING ASSOCIATION

By ____________________

SURFRIDER FOUNDATION

By ____________________

to Kahala's obtaining appropriate reclassification, zoning, and/or Conservation District Use Permits from the State of Hawaii and/or County of Hawaii to enable Kahala to construct improvements on the O'oma property.

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As always, if you have any questions or need any further information, please contact me at 329-5811.

Very truly yours,

Roy A. Vitousek III
for
CADES SCHUTTE FLEMING & WRIGHT

APPROVED AND AGREED:

NANSAY HAWAII, INC.

By_______________

FRIENDS OF KOHANAIKI, INC.

By_______________

KAHALA CAPITAL CORPORATION

By_______________

WEST HAWAII SURFING ASSOCIATION

By_______________

SURFRIDER FOUNDATION

By Mark A Massara

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As always, if you have any questions or need any further information, please contact me at 329-5811.

Very truly yours,

Roy A. Vitousek III
for
CADES SCHUTTE FLEMING & WRIGHT

APPROVED AND AGREED:

NANSAY HAWAII, INC.

By_______________________

FRIENDS OF KOHANAIKI, INC.

By_______________________

KAHALA CAPITAL CORPORATION

By_______________________

WEST HAWAII SURFING ASSOCIATION

By_______________________

SURFRIDER FOUNDATION

By_______________________

KEVIN SEITER
ATTORNEY AT LAW
KONA INN VILLAGE
75-5744 ALII DRIVE
SUITE 245
KAILUA-KONA, HI 96740

November 8, 1990

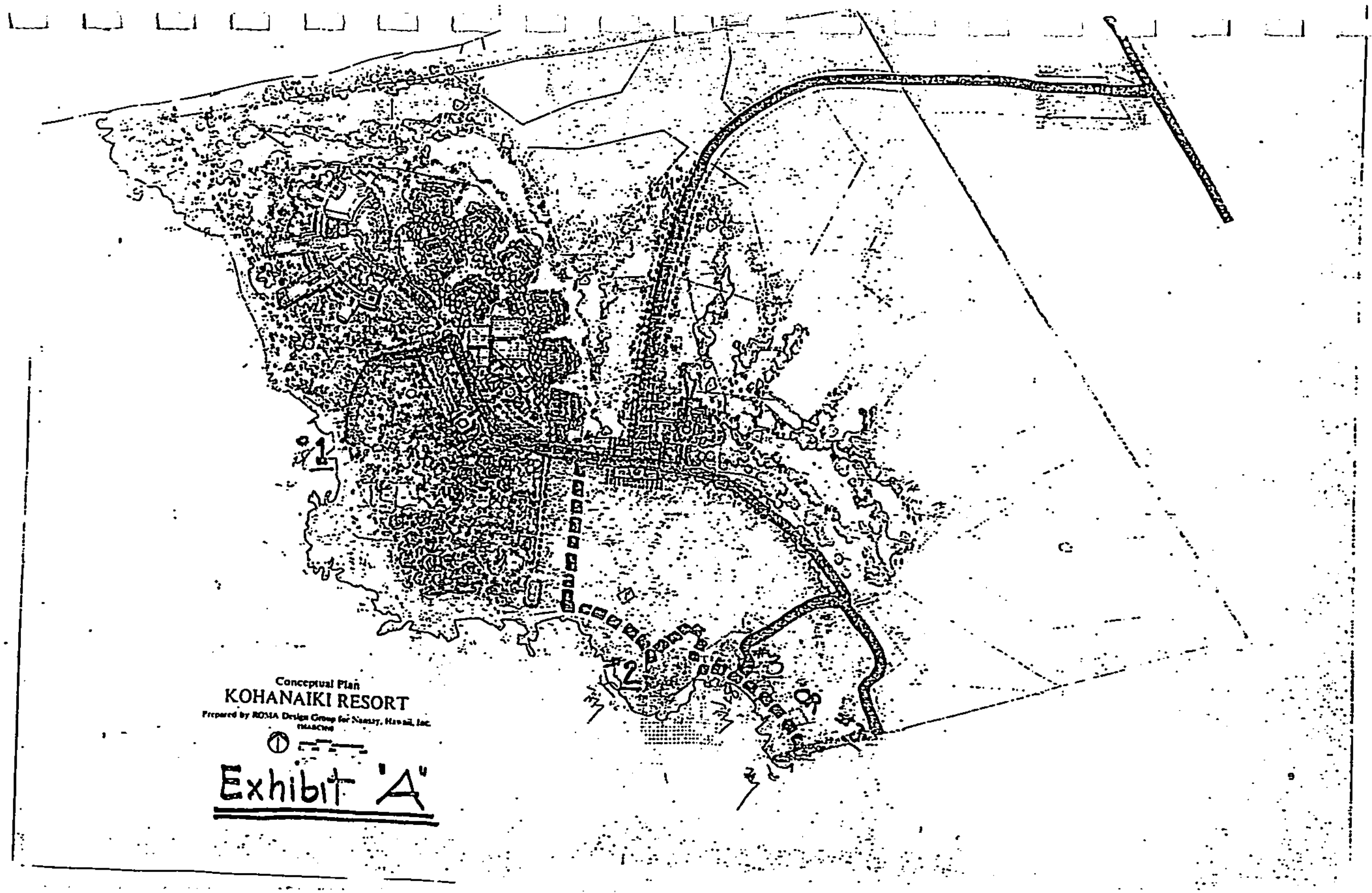
Mr. Roy A. Vitousek, III
Attorney at Law
Cades Schutte Fleming & Wright
Suite B-303
75-170 Hualalai Road
Kailua-Kona, Hawaii 96740

Dear Mr. Vitousek,

This is to inform you and your clients, Nansay Hawaii, Inc. and Kahala Corporation that I received authority from my clients: Friends of Kohanaiki, West Hawaii Surfing Association and the Surfrider Foundation to substitute their signature page (page 5 of the agreement dated November 2, 1990) to the revised agreement. My authority is based on my clients accepting the reference to Exhibit "B" which is currently referred to and attached to the revised agreement.

Sincerely,

KEVIN SEITER
Attorney at Law


Conceptual Plan
KOHANAIKI RESORT
Prepared by ROMA Design Group for Nansay, Hawaii, Inc.
Exhibit "A"

WILLIAM W. PATY, CHAIRPERSON
BOARD OF LAND AND NATURAL RESOURCES

DEPUTIES
KEITH W. AHUE
MANABU TAGOMORI
RUSSELL N. FUKUMOTO

AQUACULTURE DEVELOPMENT PROGRAM
AQUATIC RESOURCES
CONSERVATION AND ENVIRONMENTAL AFFAIRS
CONSERVATION AND RESOURCES ENFORCEMENT
CONVEYANCES
FORESTRY AND WILDLIFE
LAND MANAGEMENT
STATE HISTORIC PRESERVATION
STATE PARKS
WATER RESOURCES MANAGEMENT

In reply, please refer to:
REF: DOFAW

STATE OF HAWAII
DEPARTMENT OF LAND AND NATURAL RESOURCES
P. O. BOX 621
HONOLULU, HAWAII 96809

DOFAW:ks

October 15, 1990

Mr. Duane Kanuha
Planning Director
Hawaii County Planning Department
25 Aupuni St., Rm. 109
Hilo, HI 96720

Dear Mr. Kanuha

The Division of Forestry and Wildlife's Na Ala Hele Statewide Trail and Access Program is aware of the public controversy over the vehicular, lateral coastal access road fronting the proposed Kohanaiki Resort. As the State program focusing on Hawaii's trail and access concerns, it has been studying the issue and is taking the following position.

The Na Ala Hele Program opposes motorized vehicular access along that coastal stretch because:

1. Na Ala Hele's priority trail project, the "Ala Kahakai", first planned and proposed by the State in 1973, is intended to be a continuous, pedestrian lateral shoreline trail from the Old Kona Airport in Kailua to Kawaihae. As much as possible the trail is to incorporate existing, historic Hawaiian shoreline trails and maintain a trail experience that is preferably removed from motorized vehicles and conducive to enjoyment and protection of the coast's rich natural and historic resources. This trail concept is consistent with the Kaloko-Honokohau National Historical Park's plan adjacent to Kohanaiki, and other sections of the Ala Kahakai which are currently in place or being restored at Kaupulehu, Kiholo, Waikoloa, Kalahuipuaa, and from Puukohola Heiau, to Spencer Park, and to Mauumae Beach in Kawaihae. Thus, continued use of motorized vehicles in and along the Kohanaiki shoreline would be contrary to the Ala Kahakai's basic objectives.

2. Continued public vehicular-use of the coastal road at Kohanaiki, in combination with the future mauka-makai accesses and parking lots required of the resort by Hawaii County, would result in major management responsibilities and concerns which include:

   a. Potentially unsafe conditions when uncontrolled amounts and types of motorized vehicles share the same route with pedestrians of all ages;

EXHIBIT B

b. Potential overcrowding and overuse of coastal resources, resulting from increases in the numbers of people accessing the coastline and no controls over commercial enterprises wanting to use the road (e.g. dirt bike rentals, scuba diving, snorkeling and scenic tours, etc.); and

c. The State does not presently have the regulatory and back-up enforcement capabilities that would be required to manage the resources and the expanded public use of the coast that can be expected if the subject road were to remain open to motor vehicle use by the public.

We note that the current impacts of public access use of the road demonstrate the need for active management, even before the anticipated access "improvements" by the planned resort. Biologically sensitive anchialine ponds along the coastal road were closed at the recommendation of the Department of Health following confirmation of pond contamination by human and animal fecal matter. People are apparently using the ponds as toilets and dumping garbage which is boosting the mongoose population.

Na Ala Hele considers the ancient Hawaiian coastal trail that pre-existed the 4-wheel drive access to be owned by the State and prefers that the traditional Hawaiian coastal trail system be restored in that area to become another increment of the Ala Kahakai demonstration trail.

If you have questions regarding this position statement please call the Division of Forestry and Wildlife's Administrator, Mr. Michael Buck, in Honolulu (548-8850) or Ms. Deborah Chang Abreu, Na Ala Hele's Program Coordinator in Kona (325-7381).

Sincerely,

WILLIAM W. PATY

cc: Mr. Michael G. Buck
Mr. Roger Evans
Mr. Fred Fujimoto
Mr. Ralston Nagata
Mr. Kevin Seiter
Mr. Roy A Vitousek III
Mr. Charles Wakida
Mr. Mason Young

APPENDIX B

MARINE ENVIRONMENT BASELINE ASSESSMENT

Marine Research Consultants

BASELINE ASSESSMENT OF THE MARINE ENVIRONMENT IN THE VICINITY OF THE O'OMA II RESORT DEVELOPMENT

PREPARED FOR

HELBER, HASTERT, VAN HORN & KIMURA, PLANNERS

JULY, 1986

STEVEN DOLLAR

Marine Research Consultant

44-130-5 Mui Place / Kaneohe, Hawaii 96744 / 808 247-2440

INTRODUCTION

Coral reefs and other marine environments are often some of the most valuable aesthetic and recreational features of coastal tropical and sub-tropical communities. Thus, addressing the potential for degradation of marine environments that might arise during construction, and the ensuing operation, of coastal developments is a matter of critical concern in early planning stages.

On the Big Island of Hawaii, Kahala Capital Corporation is proposing to develop an intermediate resort on 313 acres of open land situated just south of the Keahole Airport (see Figure 1). The development concept for the subject property, called "O'oma II", incorporates a variety of land uses comprising a resort community centered around one 600-room hotel, 600 resort condominiums and an 18-hole golf course. In addition, the development may provide space for high-technology users to complement the neighboring Hawaii Ocean Science and Technology (HOST) Park facility currently being developed on adjacent property by the State of Hawaii.

With such development scenarios there is inevitably the potential for undesirable habitat changes and possible irreversible destruction of marine ecosystems. In the case of O'oma II the need for caution in recognizing the potential for environmental degradation may be especially important owing to the proximity of the Natural Energy

Laboratory of Häwaii (NELH), which relies on clean ocean water. Such degradational processes, if they exist, can be minimized if the proper information is assembled early on in the development scheme. Environmental data can serve to identify areas that may be particularly susceptible to man-induced stresses, or conversely, particularly resistant to such stresses. Comparison of the magnitude of natural environmental impacts to anticipated anthropogenic (man-induced) stresses can serve to put into perspective the ultimate effects of the activities of man. In the present study, alteration of the marine ecosystems from waves generated from a recent winter storm in the North Pacific presents a dramatic example of the forces that naturally affect marine community structure.

One objective of the proposed study is to establish quantitative baseline information to accurately depict the community structure of the indigenous marine populations inhabiting the areas offshore of O'oma II. Marine community structure can be defined as the abundance, diversity, and distribution of stony and soft corals, other attached benthic fauna and flora such as algae and sponges, motile benthos such as echinoderms, molluscs, and crustacea, and pelagic species such as reef fish and sea turtles. This information will serve to identify any living marine resources that may be of significant commercial or recreational value, or that represent rare or unique ecological features that may be especially susceptible to human-induced stress.

The emphasis of this report is not, however, directed at a compilation of either lists of organisms inhabiting the area, or extensive tabulation of chemical measurements, as is often the case with environmental assessments. Rather, emphasis is placed on characterizing the offshore environments as integrated communities that are under the influence of specific physio-chemical processes. Describing the cause and effect relationship of these processes in shaping biotic community structure is the major intent of the survey.

A quantitative data set can also serve as a baseline from which actual changes that may result from construction can be ascertained. If such changes are identified, remedial action can be applied to eliminate the stress factors causing environmental alteration after a minimum of change has occurred. With such management practices optimal utilization of marine resources may occur, while at the same time preserving a high level of environmental integrity.

With these ideas in mind, permanent baseline stations or "benchmarks" were established in order to allow monitoring of the same stations in the future. This provision is in accordance with the State of Hawaii (Department of Health) Chapter 54 of Title 11, Administrative Rules entitled "Water Quality Standards", which specify that permanent benchmark stations be established for monitoring of marine biological communities. Water quality standards shall be deemed met if time-series surveys of benchmark stations indicate no relative changes in the relevant biological communities, as noted by biological community indicator organisms which may be applicable to the specific site.

In the context of time-series surveys, the most useful biological communities for direct evaluation of environmental impacts are benthic (bottom dwelling) communities. Because benthos are generally long-lived, immobile, and intimately affected by exogenous input of sediments and other potential pollutants, these organisms must either tolerate the surrounding conditions within the limits of adaptability or die. As members of the benthos, stony corals are of particular importance in nearshore Hawaiian environments. They contribute a large portion of the reef biomass and their skeletal structures are vital in providing a complex of habitat space, shelter, and food for other species. Since corals serve in such a keystone function, coral community structure is considered the most "relevant" group in the use of reef community structure as a means of evaluating past and potential impacts associated with land development. For this reason, and because alterations in coral communities are easy to identify, observable change in coral population parameters is a practical and direct method for obtaining the information that is required to meet existing environmental regulations.

The most important, objective of this assessment is to evaluate the potential for impact to the marine environment resulting from the proposed development. In order to accomplish this objective it is first necessary to evaluate the adaptation of nearshore benthic communities to natural stress (sedimentation, wave scour, etc.). Because impacts caused by the development would be superimposed on natural effects, it is necessary to estimate cause and effect by comparing the existing community structure of stations subjected to varying degrees of natural disturbance to the conditions that would exist if the development proceeds.

METHODS

All field work was carried out on July 11-13, 1986, and was conducted from a 19 foot boat. Several methods were employed in the collection of qualitative and quantitative data. Qualitative reconnaissance surveys covering the entire area fronting the development parcel were conducted by slowly towing a diver behind a small boat. These surveys were useful in making relative comparisons between areas, identifying any unique or unusual biotic resources, and providing a general picture of the physiographic structure and benthic assemblages occurring throughout the region of study.

Following the preliminary survey, four quantitative transect sites were selected offshore of the development area (see Figure 1). In addition, a control site was selected at a location south of the development parcel at a site protected form north swells. The control sites serves as a reference station for subsequent time-series surveys to identify if observed changes are the result of man-induced or natural environmental perturbations. Because the control site was protected from winter storm waves, it also serves as a reference from which it is possible to estimate the effects of natural disturbance at the development site.

All site locations were accurately determined and recorded using a hand-bearing compass and triangulation sightings of distinguishable landmarks. At each site, line transects were conducted at depths of approximately 20, 30, and 60 feet. These depths correspond to the three generalized major West Hawaii reef zones described by Dollar (1975) (see Figure 2).

Transects were 200 feet long and were oriented parallel to the shoreline in areas deemed to be representative of community structure. The ends of each transect were permanently marked for possible future monitoring studies by pounding steel stakes into the substrate (see Plate 1). A surveying tape was laid out over the reef surface parallel to depth contours between two marker stakes. An aluminum quadrat frame with dimensions of one meter by two-thirds meter was sequentially placed over ten random marks on the transect tape so that the tape bisected the long

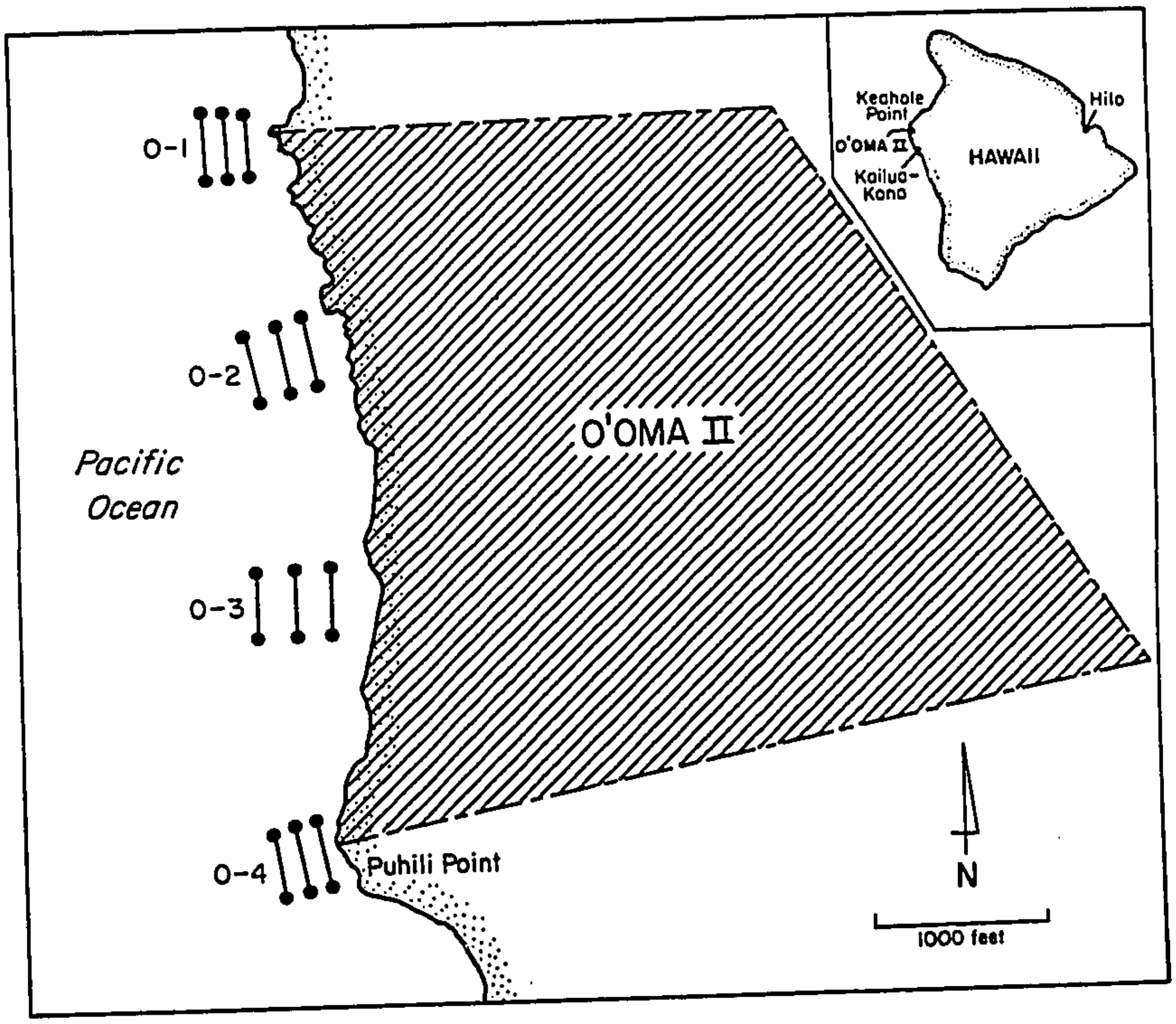


FIGURE 1. Map showing location of O'oma II development site, and locations of four transect sites, used to quantify marine community structure.

axis of the frame. At each quadrat location a color photograph recorded the segment of reef area enclosed by the quadrat frame. In addition, a diver with knowledge of the taxonomy of resident species visually estimated the percent cover and occurrence of organisms and substrata types within the quadrat frame. Only macrofaunal species greater in size than approximately 2 cm were noted; no attempt was made to identify or enumerated cryptic species dwelling within the reef framework.

Following the period of field work, quadrat photographs were projected onto a grid enabling units of bottom cover for each species and bottom type to be calculated. This information was combined with the in-situ cover estimates and the combined assessment provided the data base for the benthic community structure analysis. Species diversity was calculated using the Shannon-Wiener index, and can be equated with the equitability, or dominance, of distribution of the species occurring on each transect.

The practical advantages of photo-transects are numerous: most species can be easily and accurately identified from transparencies, and the transparencies provide a permanent record for subsequent time-series comparisons. Also, photo-quadrat sampling is rapid and efficient with respect to time and data collected - an important consideration under conditions where underwater time is restricted by cost, depth and exposure.

Quantitative assessment of reef fish community

PLATE 1. Diver pounding transect stake into reef substrate at the origin of a 30 ft. transect station.

structure was conducted in conjunction with the benthic surveys. As the transect tape was being laid along the bottom, all fishes observed within a band approximately three meters wide along the transect path were identified to species and enumerated. Care was taken to conduct the fish surveys so that the minimum disturbance by divers was created, ensuring the least possible dispersal of fish. Only readily visible individuals were included in the census. No attempt was made to seek out cryptic species or individuals sheltered within coral.

RESULTS AND DISCUSSION

Shoreline Area

The main structural feature of approximate one mile of shoreline of the O'oma II development is a basaltic ledge of pahoehoe lava with interspersed pockets of white calcareous sand (see Plate 2). The intertidal platform, which is constantly subjected to the wash of waves, is flooded in places to form tide pools. However, none of these pools appeared to be separated from the ocean on a permanent basis so they do not constitute unique or rare habitats. Rimming many of pools formed in the basalt bench are dense bands of the intertidal seaweeds *Ahnfeltia concinna* and *Ulva fasciata* (see Plate 3). The submerged portions of the intertidal pools are lined with various forms of encrusting red algae, and contain numerous sea

PLATE 2. Basaltic bench that typifies the shoreline of the O'oma II property. Small sand beach to the left of the trees at the northern border of the property constitutes the best shoreline access to the water for swimmers.

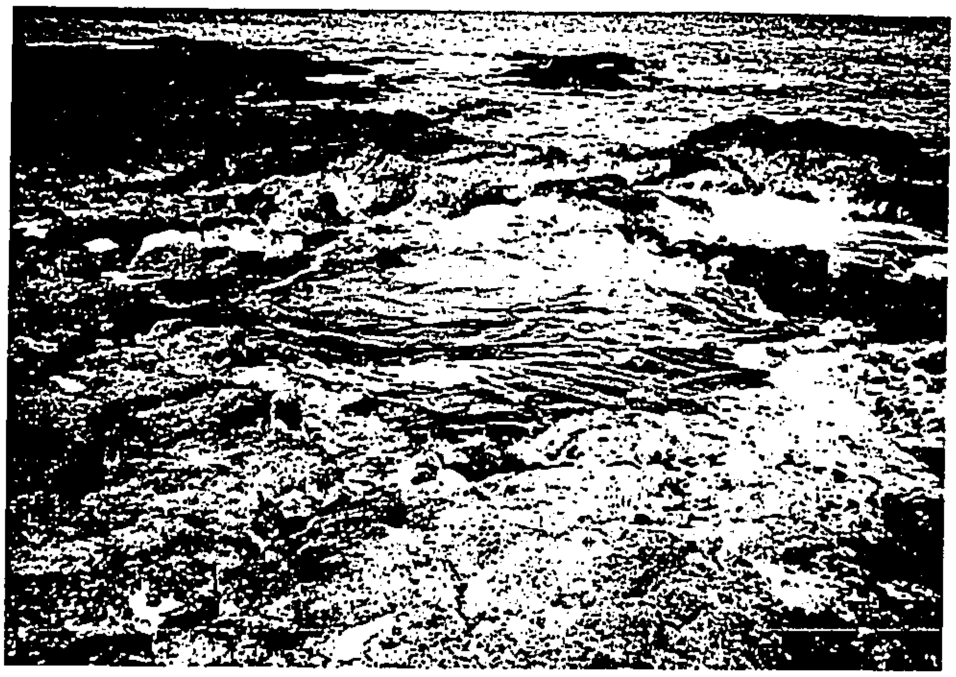


Plate 3. Typical tidepool in the basalt shoreline bench. Pool is connected to the ocean and is filled by wave action.

urchins Echinometra matheai, Echinostrephus aciculatus and Colobocentrotus atratus, as well as numerous juvenile reef fish. The seaward edge of the lava shoreline is composed either of basaltic boulder "beaches" or vertical shoreline sea-cliffs 2 to 5 feet in height. Access to the water from the basaltic bench is difficult, and potentially dangerous. The one exception is a small area at the northern border of the property where a small sandy beach reaches the waterline.

Offshore Marine Environments

Water Quality

A comprehensive water quality sampling program was not part of the present investigation. Such a sampling during the three days of field work would be relatively meaningless owing to the natural variability typical of the chemistry of surface ocean waters. There does exist, however, a very comprehensive data set of surface water chemical parameters, collected near the NELH site located just to the north of the O'oma II property. This data set consists of weekly measurements spanning the last 4 years. In summary, surface waters near the O'oma II site contain relatively low concentrations of dissolved nutrients (nitrogen and phosphorus), but exhibit a natural cyclic variability that is apparently related to seasonal influences. This data set could serve as a excellent preliminary baseline to monitor changes in water chemistry resulting from development activities.

Descriptively, the nearshore waters off the O'oma II property are classed by the State Department of Health as AA, and can be considered pristine. Lack of suspended material results in extreme water clarity. There are no streams entering the sea along the development frontage, and ground water seepage of fresh water appears to be relatively minimal. Present usage is restricted primarily to shoreline fishing.

Coral Community Structure

In general, the geologically young age of the Island of Hawaii results in very undeveloped true "coral reefs". Rather, the majority of the offshore environments can be called "coral communities". The distinction is that, for the most part, corals are growing on substrata composed of basement rock, rather than on calcareous rock of organic (reef) origin.

The typical coral community structure of the west coast of Hawaii, has been described in detail by Dollar (1975). The community structure of the O'oma II property corresponds well with the typical pattern. Three zones, each characterized by a distinctive substratum type, depth range, range of physical conditions, and single dominant coral species make up the coral community. Figure 2 shows

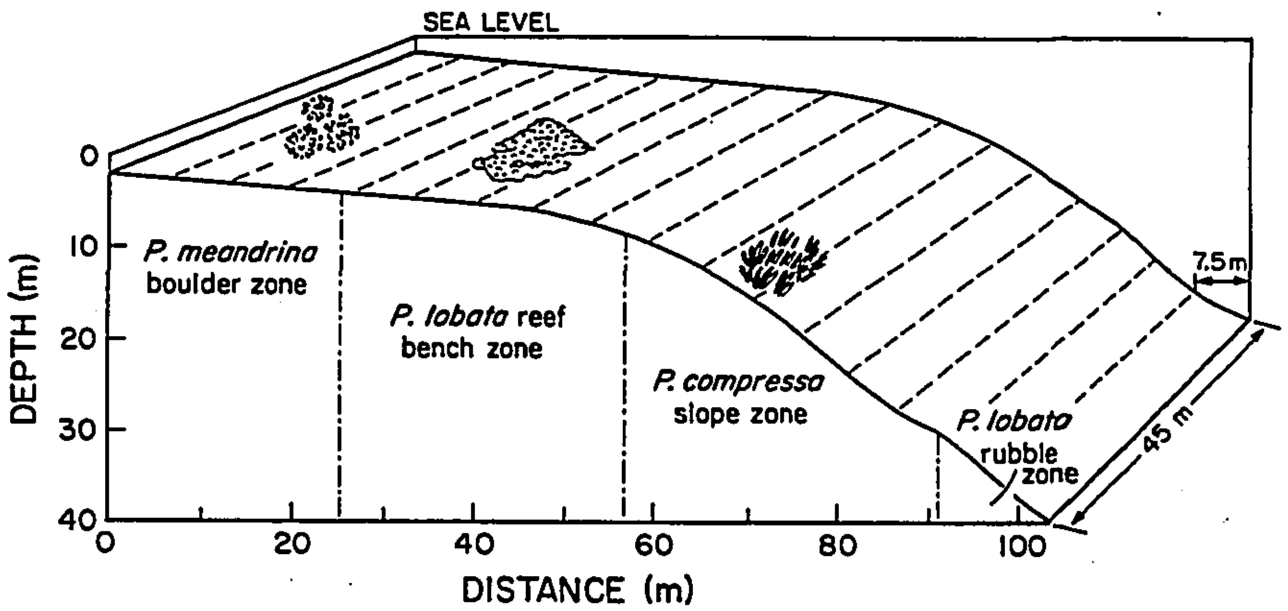


FIGURE 2. Schematic diagram of typical reef zonation pattern off West Hawaii. For the O'oma II survey, 20 ft. transects were conducted in the P. meandrina-boulder zone, 30 ft. transects in the P. lobata-reef bench zone, and the 60 ft. transects in the P. compressa-slope zone.

a diagramatic representation of the west Hawaii coral community structure, while Figure 3 and Tables 1 and 2 summarize quantitatively the results of the benthic community transects off O'oma II and the control station. The relative uniformity of the shoreline off the entire O'oma II property results in a fairly uniform marine environmental structure. Therefore, the zonation pattern described below represents the environment fronting the entire development.

The most shoreward zone is comprised of the seaward continuation of the basaltic shoreline bench and scattered basaltic boulders (see Plates 4 and 5). Seaward of the shoreline, the basaltic bench becomes a shallow submarine terrace, which receives most of the force of breaking waves. Pocillopora meandrina, a sturdy hemispherical branching species is the dominant coral colonizer of the near-shore areas. This species rapidly colonizes newly cleared surface, has a small adult colony size of short densely packed branches, and is able to flourish in areas that are physically too harsh, particularly in terms of wave scour, for other species. The 20 ft. transects conducted off O'oma II all traversed the Pocillopora meandrina-boulder zone.

Seaward of the edge of the boulder field the reef bench is predominantly a flat basaltic pavement, interspersed with lava extrusions and sand channels (see Plate 6). Porites lobata is the dominant coral in this area, and

TABLE 1. Percentage of non-coral substrata on O'oma II benthic transects.

		TRANSECT STATION				
SUBSTRATA TYPE	TRANSECT DEPTH (ft)	0-1	0-2	0-3	0-4	CON
Sand	20	0	30.0	0	0	0
	30	0	0	0	0	9.5
	60	0	6.5	9.7	0	0
Limestone	20	21.0	24.9	10.8	4.3	14.3
	30	2.4	10.0	5.7	2.3	23.2
	60	0	8.3	11.2	0	0
Coral rubble	20	6.9	0	10.0	23.9	1.0
	30	50.9	27.5	70.2	10.8	13.6
	60	59.5	47.5	57.4	54.5	30.0
Basalt	20	52.3	23.5	77.2	63.4	58.6
	30	35.4	28.7	13.3	64.2	18.1
	60	59.5	0	1.1	38.6	0

TABLE 2. Percent cover of individual coral species, total coral cover, number of coral species, and coral species diversity on benthic transects at O'oma II.

CORAL SPECIES	TRANSECT DEPTH (ft)	TRANSECT STATION 0-1	0-2	0-3	0-4	CON
Porites lobata	20	19.3	20.2	14.9	9.7	23.0
	30	11.2	13.7	3.0	8.7	34.5
	60	4.4	24.8	14.5	4.2	0
Porites compressa	20	0	0.6	0	0	0
	30	0	1.6	1.5	0	0
	60	31.2	10.0	4.3	1.1	65.5
Pocillopora meandrina	20	0.1	0.6	7.6	1.7	3.0
	30	0.4	1.5	1.2	15.3	1.0
	60	0.6	1.8	0.7	1.4	0
Montipora patula	20	0.2	0	0	0	0.1
	30	0	0.2	0	0	0
	60	0	0	0	0	0.1
Montipora verrucosa	20	0.2	0.1	0.2	0.6	0
	30	0	0.1	0	0.1	0.1
	60	0	0	0	0.1	0
Leptastrea purpurea	20	0	0	0.1	0.7	0
	30	2.1	0	0	0	0
	60	0.2	0	0	0.1	0
Sarcothelia edmondsoni	20	0	0	0	0	0
	30	2.1	0	0	0	0
	60	4.1	1.6	1.1	0.1	3.5
Pavona varians	20	0	0.1	0	0	0.1
	30	0	0	0	0	0
	60	0	0	0	0	0
TOTAL CORAL COVER	20	19.8	21.6	22.8	12.7	26.1
	30	13.7	17.1	5.7	25.0	35.6
	60	40.5	37.6	20.6	6.9	70.0
NUMBER OF CORAL SPECIES	20	5	5	3	4	4
	30	4	5	3	3	3
	60	5	4	4	6	3
CORAL SPECIES DIVERSITY	20	0.144	0.311	0.779	0.779	0.403
	30	0.842	0.695	1.017	0.639	0.147
	60	0.762	0.906	0.845	1.102	0.221

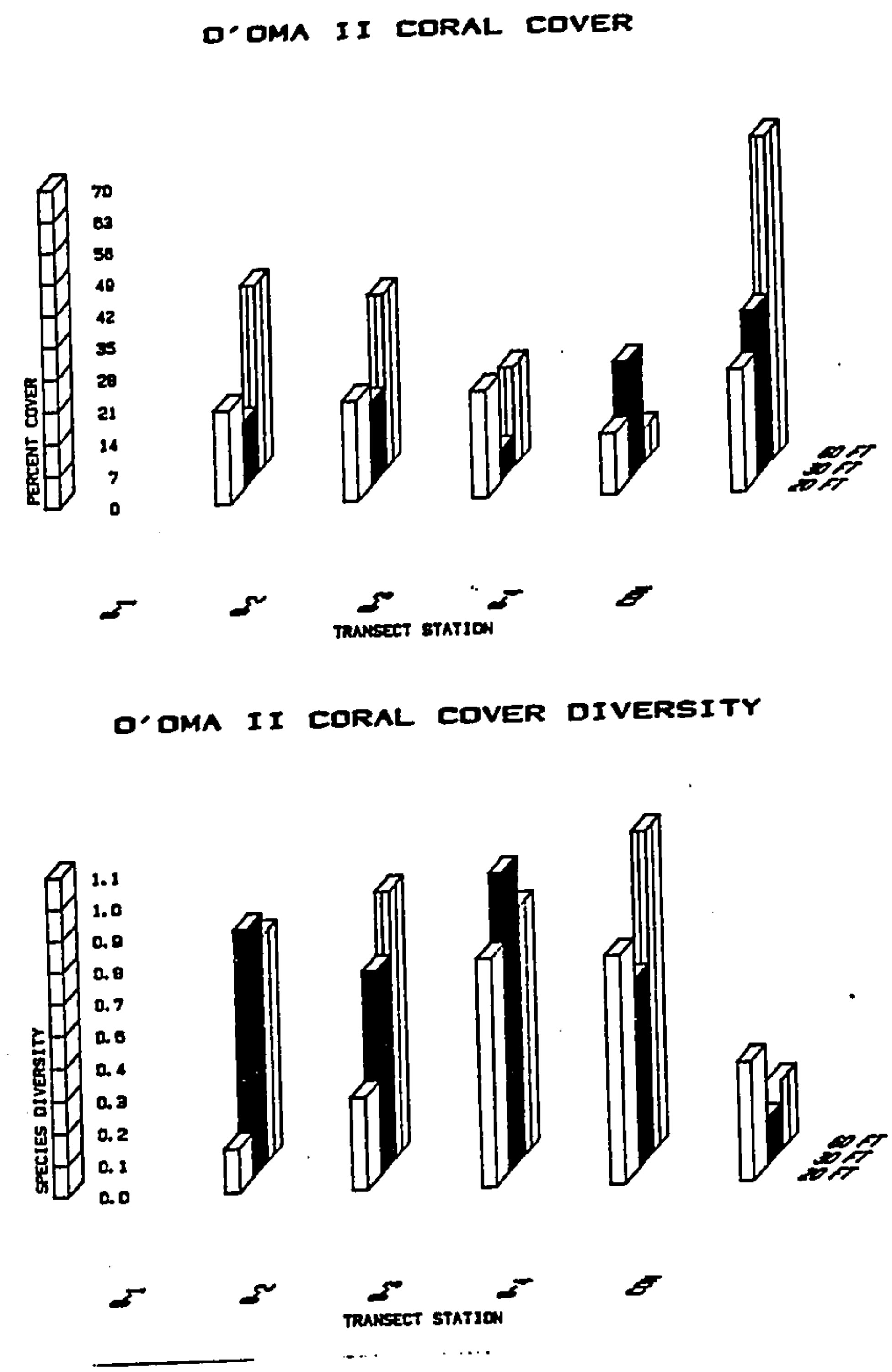


FIGURE 3. Bar graphs showing total coral cover and coral cover diversity on O'oma II transects.

occurs in a variety of growth forms, but predominantly takes the shape of short, thick lobed colonies (see Plate 7). Because of increased water depth and distance offshore, reduced wave scour results is greater proportions of coral cover on the reef bench. It is in this zone that the most number of corals occur, and where "reef formation" is occurring. The 30 ft O'oma II transects bisect the Porites lobata-reef bench zone.

At the seaward edge of the basaltic bench, the slope of the bottom increases sharply to approximately 40°, and the substratum consists primarily of unconsolidated rubble and sand (see Plate 8). Porites compressa, commonly called "finger coral" typically covers the reef slope in the form of dense interconnected thickets that extend to a depth of approximately 90 ft. (see Plates 8 and 9). The 60 ft. transects off O'oma II traversed the Porites compressa-slope zone.

The most significant result of the transects data, as well as the qualitative appearance of the reef communities, is that coral cover on all of the O'oma II transects is reduced compared to the control (see Figure 3, Table 2). The decrease is attributed to the physical destruction of coral colonies brought on by a severe winter storm that occurred in February of 1986. The direction of wave propagation (from the northwest) was such that breaking waves estimated at 15-20 ft in height impacted directly the O'oma II site, but not the control site.

Average coral cover for the four O'oma II transects was 6.8% less than the control at the 20 ft. deep transects, 20.2% less at the 30 ft. transects and 43.6% less at the 60 ft. transects. It is apparent from these differences that the greatest effects of the storm waves occur at the deepest reef zones, which normally exist under very calm conditions. As described above, the dominant coral to inhabit this zone, Porites compressa is extremely delicate and susceptible to breakage and re-distribution down the reef slope. In contrast, the shallow boulder zone, which routinely is subjected to water motion of sufficient velocity to prevent coral growth of all but Pocillopora meandrina exhibits relatively small changes at the O'oma sites compared to the control. In corresponding fashion, coral species diversity is greater at the O'oma sites compared to the control. The lower diversities at the control site are the result of community domination by a single species within each zone. Storm damage preferentially reduces the cover of that species, resulting in a more equitable distribution, and hence higher diversity, following the storm damage. These storm events of moderate intensity seem to prevent dominance and resource monopolization by differentially affecting both th most abundant species or the species highest in competitive ability.

In contrast, infrequent storm events with forces capable of totally destroying all coral cover, effectively

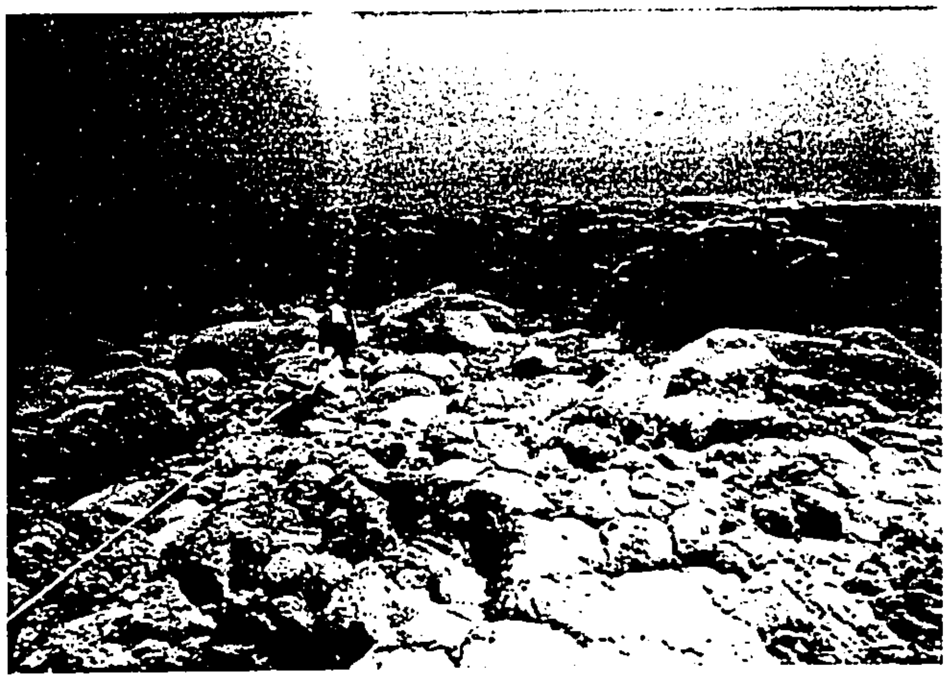


PLATE 4. Nearshore boulder zone. Basaltic terrace in the background is the seaward extension of the shoreline reef bench.

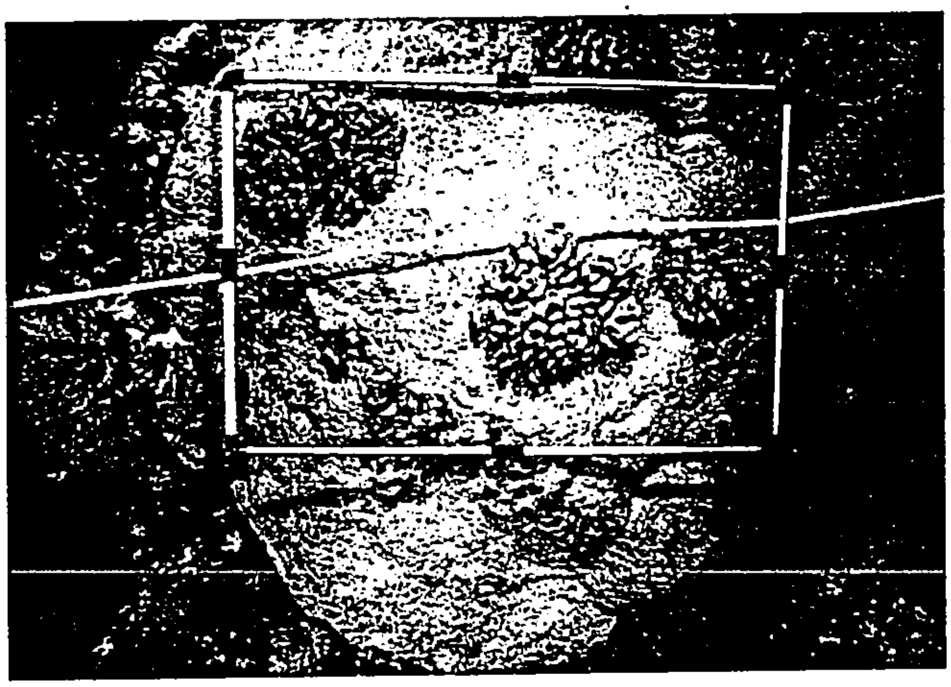


PLATE 5. Typical quadrat photograph on a 20 ft. transect. Round coral colonies growing on boulders are Pocillopora meandrina.

PLATE 6. View of diver laying transect line on reef bench zone.

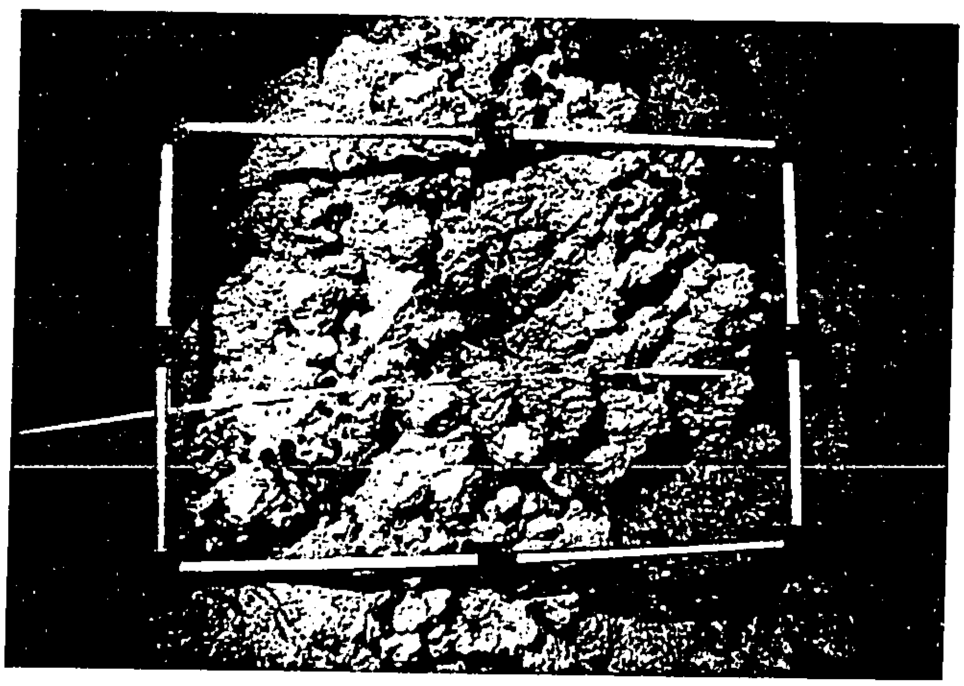


PLATE 7. Typical quadrat photograph on 30 ft. transect on reef building zone. Coral colonies in center of photograph are Porites lobata.

PLATE 8. Transect station in the reef slope zone.

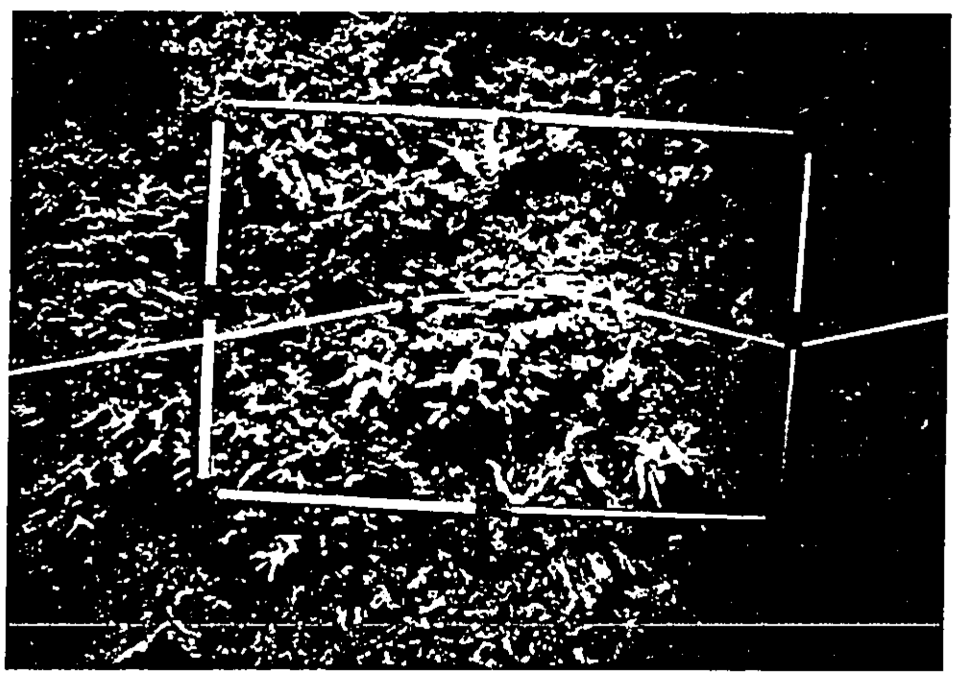


PLATE 9. Typical quadrat photograph at 60 ft. transect. Entire reef surface is composed of lattice of finger coral, *Porites compressa*.

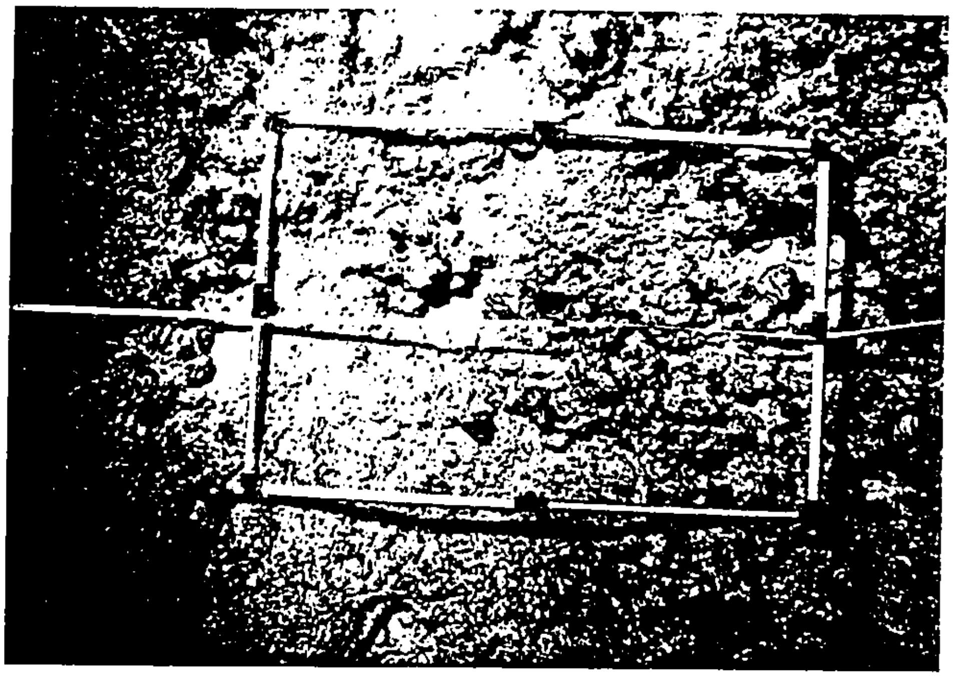


PLATE 10. Typical quadrat photograph at a 30 ft. transect in an area that received the full destructive force of winter storm waves. When compared to Plate 6 the extent of damage to coral cover is evident.

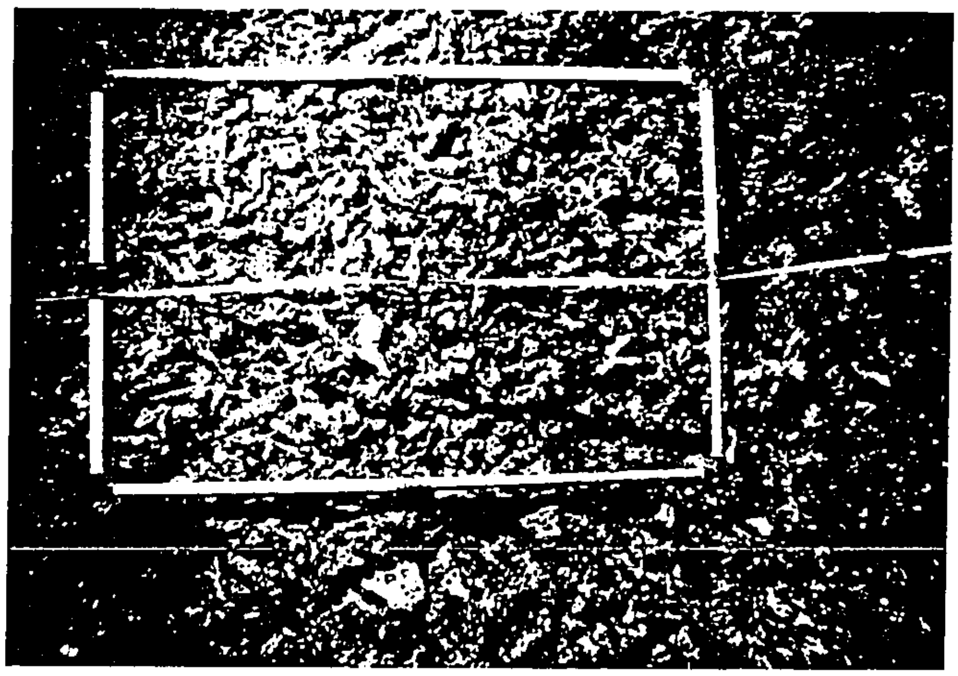


PLATE 11. Typical quadrat photograph at 60 ft. transect that received the full force of wave stress in February, 1986. Extent of coral damage is evident when compared to Plate 9

wipe out the entire zonation pattern and return the entire reef to an essentially pioneering stage. A more complete account of the effects of storm waves on coral community structure is described by Dollar (1982).

Other Benthic Invertebrates

The major taxa of benthic organisms occurring on the O'oma II reefs, other than corals, are sea urchins (Echinoidea) and sea cucumbers (Holothuroidea). By far the most abundant urchins are the two species that bore into limestone surfaces, Echinometra mathaei and Echinostrephus aciculatus. In the reef bench zones, densities of these urchins is often of the order of 30 individuals per square meter. Less abundant, but ubiquitous across the entire reef, are the larger species Tripneustes gratilla and Heterocentrotus mammillatus. Most common of the sea cucumbers are the species Holothuria atra and H. mauritiana, which occurred mainly in the P. lobata-reef building zone. None of the assemblages of these organisms constituted any unusual or rare community.

The design of the reef survey was such that no cryptic organisms or species living within interstitial spaces of the reef surface were enumerated. Since this is the habitat of the majority of mollusks and crustacea, detailed species counts were not included in the transecting scheme. No dominant communities of these classes of biota were observed during the reef surveys at any of the study stations.

Frondose benthic algae are conspicuously rare on the reefs of West Hawaii. Several plants were observed, however, off the O'oma II development. These included the brown algae Turbinarea ornata, and Padina spp.. The encrusting red coralline algae, predominantly Porolithon spp. and Peysonellia rubra were commonly observed on the deeper reef slope on the Porites compressa reef framework. None of the red algae communities associated with early successional stages of recolonization following denudation of substrate by wave action were observed.

Reef Fish Community Structure

Reef fish community structure was largely determined by the topography and composition of the benthos. Transect results are presented in Table 3 and Figure 4.

The reef fish community bordering the proposed O'oma II development can be grouped into six general categories: juveniles, planktivorous damselfishes, herbivores, rubble-dwelling fishes, swarming tetrodonts, and surge-zone fishes.

Juvenile fishes were especially abundant at the deepest transect site in areas of finger coral (Porites compressa). It is important to note that while storm damage to the deep slope zone substantially lowered the percentage of living finger coral, the coral framework was not completely

TABLE 3. Reef fish community structure at O'oma II.

	D-1 40'	D-1 30'	D-1 20'	D-2 40'	D-2 30'	D-2 20'	D-3 40'	D-3 30'	D-3 20'	D-4 40'	D-4 30'	D-4 20'	CONT 40'	CONT 30'	CONT 20'
MURAENIDAE															
Gymnothorax meleagris	1	1	1				1		1						
AULOSTOMIDAE															
Aulostomus chinensis	1	1											1	1	1
HOLOCENTRIDAE															
M. berndti									15						4
CIRRHITIDAE															
Cirrhitus pinnulatus												2			
Paracirrhites arcatus	1		1	1	2	1	1		5		3	3	1	3	1
P. forsteri	2		1							2				1	
MULLIDAE															
Mulloidichthys flavolineatus		2											68		5
M. vanicolensis	3					3		1				2			
Parupeneus multifasciatus	2	7	1	13	12	12	3	15	3	7	6	4	5	3	7
P. bifasciatus			3						1	3	1	1			
P. cyclostomus				4											2
LETHRINIDAE															
Monotaxis grandoculis															1
SERRANIDAE															
Cephalopholis argus		1													
CARANGIDAE															
Caranx melampygus												1			
CHAETODONTIDAE															
Chaetodon lunula										2					8
C. quadrimaculatus			2		1	1			7						
C. miliaris			1		7	1		2							
C. ornatissimus				1		2	2		1	2	3			3	
C. multicinctus	4	2	5	8	4	7	5	6	9	4	6	3	7		10
C. reticulatus															
C. auriga			1												
Forcipiger flavissimus	2	3	7	5		2	5	1	1	3	2	4	7	4	3
Heniochus diphreutes										6					
POMACANTHIDAE															
Centropyge potteri	7	26		8			8	3		1			3	3	4
Holacanthus arcuatus															
POMACENTRIDAE															
Abudefduf sordidus									13			9			
Plectro. johnstonianus			1	1		1								2	1
Stegastes fasciolatus	7					7			1				1		
Dascyllus albisella				3											
Chromis agilis	44	77		30	3		69		7	25			60	25	10
C. hanui	4	9		12			31			17			15	6	
C. vanderbilti	90	55	89		112	48		95	120	58	55	85		110	105
C. ovalis			7		13										
LABRIDAE															
Novaculichthys taeniourus	1							7			1				
Cheilinus unifasciatus	8													2	1
C. bimaculatus											1				
Pseudocheilinus octotaenia	6			3	2	3	1			5		1	3	3	
P. tetrataenia	4			4	4		7			7	2		3	5	
Bodianus bilunulatus					1										
Coris gaimard		3	5	6	7		1	6	7	11	1	1		2	7
C. flavovittata		1										1			
Anampses chrysocephalus				2									1		
Thalassoma duperreyi	3	11	6	8	13	15	8	9	25	15	6	13	9	7	12
Gomphosus varius								1						3	
Labroides phthirophagus				2			3			1					
Macropharyngodon geoffroy	3	3				7		2		1				1	1
Pseudojuloides cerasinus	1			6			1			1	1		2	1	
Stethojulis balteata			2		2			3						10	9
Halichoeres ornatissimus	6	7	4	4	4	8	3	2	1	3	1		4	1	7
SCARIDAE															
Calotomus sp.								1	1						
Scarus sordidus	3	1					3				4	3	7	2	
S. perspicillatus						6						1		1	
S. psittacus		1							1				1		
S. rubroviolaceus												3			
Juvenile Scarus	2	3	3	7				12	7	8		3			
ACANTHURIDAE															
Zebrasoma flavescens	45	41	21	22	21	18	22	9	60	22	14	49	37	36	31
Acanthurus achilles		1	1			2						9	7		4
A. sandvicensis									18			1			
A. leucopareius												27			11
A. thompsoni													90		
A. olivaceus			3	2				11	4	2	1	5			
A. mata											1				
A. nigrofuscus	13	31	15	16	9	14	20	4	10	11	13	8	12	18	12
A. nigroris		5	3		4	8	4		4	1	2	2	3	2	2
Ctenochaetus strigosus	21	40	21	40	2	10	11	6	12	42	12	12	26	37	36
C. hawaiiensis							2					2			
Naso lituratus	5	11	3	3			5	2	3		3	11	4	1	7
N. unicornis												1		1	
ZANCLIDAE															
Zanclus cornutus	3	1	2	3		2			21			3	2	4	
MONOCANTHIDAE															
Pervagor spilosoma	45	37	31	37	27	45	40	35	22	40	41	37	27	45	39
BALISTIDAE															
Sufflamen bursa	3	3	2		3	2	3			6	2	1	2		2
Melichthys vidua					2				2		3			1	
M. niger	1	2	5						7					2	
Xanthichthys auromarginatus		2								3	3			1	
TETRAODONTIDAE															
Arothron meleagris	2	3	1	2	1		1	5	2	1	1		1	1	
NUMBER SPECIES	32	31	30	29	23	26	28	23	31	30	21	32	29	35	29
NUMBER INDIVIDUALS	337	342	255	249	251	207	271	231	364	318	191	305	275	355	353
SPECIES DIVERSITY	2.522	2.480	2.482	2.818	2.145	2.454	2.358	2.206	2.573	2.761	2.411	2.544	2.489	2.509	2.490

flattened. The complex habitat created by the interstitial spaces of the finger coral framework, was partially maintained in the aftermath of the storm event. Juveniles belonged mostly to the family Acanthuridae (surgeon fishes), with representatives from the families Labridae (wrasses), Mullidae (goat fishes) and Chaetodontidae (butterfly fishes). Planktivorous damselfishes, principally of the genus Chromis were extremely abundant in all areas surveyed. Members of this genus often comprised more than a third of the total number of individuals encountered along a transect. The species C. agilis and C. hanui predominated at the outer edge of the shelf and in deeper water, whereas C. vanderbilti was the primary shallow water species.

Herbivores, primarily the acanthurids Zebrasoma flavescens and Ctenochaetus strigosus were also abundant. At the shallower sites, adult Acanthurus olivaceus and scarids (parrot fishes) were also common. In areas where coral rubble were abundant, common fishes included the angelfish Centropyge potteri, and several species of wrasse, notably Psuedochilinus tetrataenia and P. octotaenia. Large numbers of the fantail filefish Pervagor spilosoma were observed swarming in the water column. Many of these individuals looked unhealthy in having faded colors and a gaunt appearance. Such aggregations of filefish appears to be a cyclic phenomenon that occurs with at irregular frequencies.

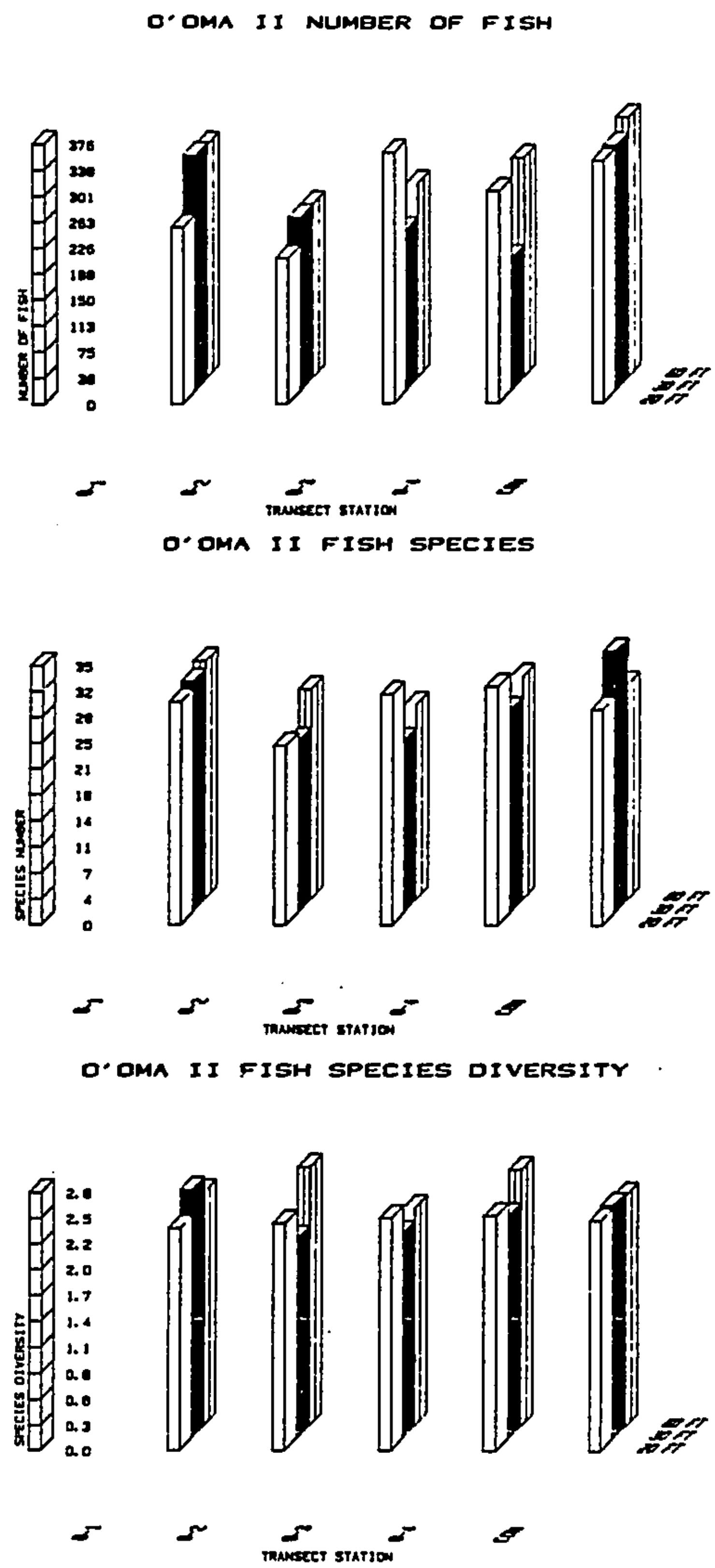


FIGURE 4. Bar graphs showing reef fish abundance, species number and diversity at O'oma II transects.

Surge zone fishes were not quantitatively assessed because of the difficulty in working on the wave-swept basalt terraces that these fish inhabit. Visual observations, however, revealed that this biotope supported a large number of fishes, principally herbivores of the genera Kyphosus, Acanthurus, and Naso. The wrasses Thallassoma trilobatum and T. purpureum were also abundant in the surge zone. Few juvenile fishes were seen inhabiting the boulder zone environment, although inshore tidepools are generally inhabited by young individuals.

Several species of "food fishes" were observed during the survey. These included parrotfishes (Scarus spp.), goatfishes (Parupaneus spp.), introduced snappers (Lutjanus kasmira), jacks (Caranx melamphygus), grand-eyed porgys (Monotaxis grandoculis), and groupers (Cephalalopholus argus). None of these fishes were particularly abundant, and all tended to avoid divers. Squirrelfishes (Myripristes berndti) and orange-eye surgeonfishes (Ctenochaetus strigosus) were abundant, but tended to be small in size.

One important characteristic of the reef fish community off O'oma II is the relative scarcity of butterfly fishes. With the exception of Chaetodon multicinctus, most individuals encountered were very small juveniles that appeared to have only recently ended their planktonic larval phase, and joined the reef community. One explanation for the scarcity of butterfly fishes is that this family is the principle group harvested by aquarium fish collectors.

Overall, the fish community at the O'oma II site is fairly typical of the assemblages found in Hawaiian reef environments. The reduced size of some food fishes, their tendency to avoid divers, and their general scarcity indicated that this area is subjected to a substantial, but not overwhelming, degree of fishing pressure. The scarcity of commercially valuable reef fishes also suggests that the community is somewhat affected by aquarium fish collectors.

As discussed above, the control site differed from the O'oma II sites by having a greater percentage of living coral cover. The fish communities at the control site, however, did not follow the same trend, and all three fish community parameters (number of individuals, number of species, and species diversity) showed only slight differences (Figure 4). The 30 and 60 foot deep transects at the control site showed somewhat higher numbers of individuals than the comparable O'oma II sites, primarily owing to the presence of large schools of *Mulloidicthys flavolineatus* and *Acanthurus thompsoni*. Overall, however, it is apparent that fish community structure is not nearly as influenced by the storm-related damage to reef corals off the O'oma II property as might be expected. This is in contrast to changes in reef fish community structure off Oahu following Hurricane Iwa in 1982. Wave forces from Iwa caused total decimation of many reef areas, reducing the coral habitat to a flattened rubble pavement without interstitial spaces suitable for shelter. As a result, reef fish populations were drastically reduced, and recolonization was slow (Pfeffer and Tribble 1985). In contrast, the storm damage at O'oma II decreased living coral cover, but did not result in total destruction of the physical habitat necessary for normal fish population.

Threatened or Endangered Species

Two species of marine animals that occur in Hawaiian waters have been declared threatened or endangered by Federal jurisdiction. The threatened green sea turtle (Chelonia mydas) occurs commonly along the Kona Coast, and is known to feed on selected species of macroalgae. No turtles were observed along the O'oma II property during the course of the present survey, but several individuals were sighted to the south of the property near the entrance to Honokahau boat harbor.

Populations of endangered humpback whale (Megaptera novaeangliae) are known to winter in the Hawaiian Islands, and have been sighted in the offshore waters in the vicinity of the development property from December to April. In general, however, it is not common for whales to occupy the shallow reef areas that are the focus of this survey.

CONCLUSIONS

The ultimate purpose of the data collected during the baseline survey is to provide estimates on the degree of environmental impact that might occur as a result of construction of the O'oma II development.

Implementation of the proposed action would involve grading, vegetation removal, new construction and other changes to the existing environment on several hundred acres of land. There are currently no plans, however, for alteration of the shoreline for such purposes as marina construction or beach improvement.

Based on the descriptive and quantitative data characterizing these environments contained in the baseline survey it is possible to predict what impacts, if any, might occur as a result of proposed development. With regard to the aquatic resources, the major potential impact parameters would be: 1) increased sedimentation from wind or runoff as a consequence of grading; 2) changes in groundwater discharge, especially with respect to nutrient loads from sewage-laden irrigation and golf course fertilization; 3) shoreline modification including changing coastline access; and 4) changes in runoff.

Below, each of these factors is treated in turn followed by a summary section which addresses the potential for impacts to the O'oma II environment as a whole.

Increased Sedimentation

In most cases in Hawaii the greatest potential cause for impact to the marine environment as a result of nearshore development practices is increased sediment loading. The offshore environment at O'oma II does not appear to be subjected to any substantial level of natural sedimentation from land runoff. Sediment could be transported as wind-borne dust or runoff during the period when ground cover is removed during grading. With regard to the offshore communities, increased sedimentation is generally regarded as one of the most important water quality characteristics, especially in connection with the ecology of corals. Increased sedimentation does not appear, however, to be a likely source of environmental alteration for the development scenario at O'oma II. The main reason for this is that the ground cover of a majority of the land to be graded is raw lava that has not been weathered to any appreciable extent and has little or no soil cover. When moved and crushed by bulldozers a smooth surface of cobbles 1 to 4 inches in size generally results. In addition, only a fraction of the wind-blown material would be carried in a westerly direction toward the ocean. As the size distribution of the wind-blown fraction would probably be in the silt-clay range, it would be expected that this material would remain in suspension for some time if it entered the water column, and therefore it is unlikely that any measurable settlement would occur anywhere in the nearshore marine environment.

Likewise, for several reasons it is not expected that runoff during construction would increase oceanic sediment loads. The climate of the O'oma II region is one of the driest in the Hawaiian Islands; therefore substantial rainfall during construction is rather unlikely. However, in the event of heavy rainfall, the porous nature of the lava fields is such that sheet flow carrying suspended sediment toward the ocean is highly unlikely. Rather, most rainwater that enters the ocean as runoff appears to do so following percolation through the surface rock layers to the water table and subsequent groundwater extrusion at the shoreline. Such groundwater flow would not have the effect of transporting sediment to the ocean since the basal rock acts as a filter. Therefore, it appears that a major effect of rain during the period of grading might be to significantly decrease the amount and distribution of airborne dust--a circumstance that would have to be considered a beneficial side effect.

Several other scenarios around the Hawaiian Islands can also be drawn upon to estimate the potential for impact from sedimentation at O'oma II. In particular, a study conducted at Princeville, Kauai (Grigg and Dollar, 1980) compared the reef environments off the completed phase of the resort with the environments off an area of pristine coastline. The hypothesis tested during this comparison was that increased runoff during construction caused some modification of the coral reef environments offshore. Results of the survey showed that, if anything, the coral environments were better developed off of the existing Princeville development that was subjected to increased runoff than off the unperturbed parcel. Even though the resort construction might have temporarily increased suspended sediment loads, this increase would have been insignificant in comparison to the natural sediment loads to which the reef communities are already pre-adapted. Therefore, the hypothesis was rejected that developmental alteration of land for Princeville construction, and hence similar developments such as O'oma II could result in offshore impacts to the marine environment.

In addition, while it is generally accepted that sedimentation is a major source of impact on coral reefs throughout the world, several studies show that Hawaiian reefs may be significantly more resistant to heavy sediment loads than other reef areas. Results of surveys conducted at French Frigate Shoals (Dollar and Grigg, 1981) following the inadvertent grounding of a freighter and subsequent dumping of 2000 tons of a fine-grained mineral clay indicated that there was no damage to the reef corals and associated communities except where the organisms were actually buried by clay deposits for greater than a two week period. Another study, conducted in Hilo Bay where natural sediment loads are very high, resulting in extremely turbid conditions, reported that the dominant bottom cover consisted of nearly solid living coral - a condition rarely found under even the most "optimal" conditions (Dollar 1985).

Increased Nutrient Loading From Irrigation and Fertilization

Because operation of the O'oma II resort calls for irrigation and fertilization of the golf course with treated sewage effluent, the potential for impacts to the aquatic ecosystem exists owing to high rates of nutrient loading. When subjected to substantial increases in nutrients, the response of marine and freshwater systems is termed "eutrophication", and consists of increased growth of a portion of the community, generally at the expense of normal community intergrity. The overall result of this process is usually a degradation of environmental quality. In the past, coral reefs in some areas of Hawaii, primarily Kaneohe Bay and off Sand Island on Oahu, have been severely damaged in this manner by sewage impacts.

At O'oma II, it is not anticipated that such impacts will occur for several reasons. Most importantly, the unrestricted circulation of the offshore zone by tides, current, wind, and wave action promotes rapid dilution and water exchange. Residence time of a parcel of water at any one location over the reef is probably on the order of hours, so buildup of any nutrient materials is unlikely.

Another reason that the marine environment will probably show no effects as a result of golf course irrigation is that much of the nutrient load is taken up by the vegetation on the golf course. Other chemical processes including cation exchange, fixation and adsorption on the soil, and leaching will also lessen the nutrient load that could potentially reach the marine environment through groundwater runoff.

Another factor that accounts for the lack of potential for impact is the secondary level of sewage treatment planned for the development effluent. Studies done at several of the ocean discharges on Oahu that intentionally discharge much greater volumes of secondary sewage into marine environments indicate there is no detrimental effects whatsoever due to the discharge. In fact, the impacts that have been reported all can be considered beneficial since they result in increased fish populations, apparently in response to increased particulate food and shelter due to the outfall structure.

The negative effects of sewage impact on open ocean reefs that have been reported in Hawaii all have been due to point source discharge of raw sewage over a time span of years. Since there appears to be no provisions which would allow raw sewage to enter the marine environment under any of the O'oma II development plans for even the shortest length of time, it can be concluded that there does not appear to be any potential for impact to the marine environment.

Potential for negative alteration to marine ecosystems owing to pesticides and herbicides also seems to be nil. It has not been found necessary to utilize substantial quantities of pesticides on golf courses in Hawaii, and only very small applications of herbicides are periodically made to the greens. Such small quantities do not appear to be of a magnitude great enough to leach through the soil and lava, be carried to the ocean via groundwater extrusions, and then bioaccumulate to the point of producing a noticeable effect.

Storm Runoff

Changes in storm runoff patterns have the potential to affect the quality of coastal waters and the marine biota that live within them. At this time no estimates exist of how drainage patterns might be changed as a result of the development plans. There appear to be no areas offshore of the O'oma II boundaries where marine systems have been adversely affected by runoff to date. It is expected that this would remain the case. However, if analyses indicate that the proposed changes in land use and drainage patterns might result in substantial changes in water quality, additional field surveys will be conducted to determine the best location for the discharge of drainage and to assess the significance of expected water quality with respect to marine community structure.

Shoreline Modification

There are currently no plans for direct alterations of the shoreline area. As such, any environmental changes resulting from development would come about via the indirect mechanisms discussed in the previous sections. Future plans may, however, call for structural changes to the shoreline, probably in the form of beach modification. As described above, the majority of the existing shoreline along the property is composed of rugged basaltic structures, that do not present a suitable environment for access to the water for swimmers. Modification of one of the small existing beaches to improve access would probably entail removal of a section of the basaltic substratum, followed by deposition of sand to create an "artificial" beach. Observation of this type of constructional process at a site to the north of the O'oma II site (Mauna Lani Resort) revealed that the initial grading and rock removal, accomplished by heavy equipment, resulted in temporary high turbidity plumes near the beach site. These plumes dissipated in less than 24 hours, and surveys of reef biota indicated that the increased sediment loading had no adverse effects on community structure.

Effects to NELH

Of special concern to the planning scenarios of the O'oma II resort is the possibility of effects to water quality parameters in the vicinity of Keahole Pt, the site of the Natural Energy Laboratory of Hawaii (NELH). The high-precision surface water nutrient monitoring program being conducted at NELH could potentially be influenced by material input at the O'oma II site. This concern is amplified by the occurrence of periodic strong northerly currents, which could transport water from the development site past Keahole Pt.

The perspective origin of any nutrients which could constitute a spurious signal to the NELH data is most likely runoff from the golf course (i.e. sewage effluent). As discussed above, it appears that such runoff is unlikely owing to the structural qualities of the basal lava rock, and the lack of sheet flow reaching the ocean. There has not been to date, however, a hydrologic study to determine the actual magnitudes of nutrient materials that reach the ocean via golf course irrigation/fertilization. Therefore, it is recommended that in the event of golf course construction, a comprehensive time-course monitoring program should be instituted in the vicinity of O'oma II to identify any potential alterations to natural water quality parameters.

The principal facility of the NELH program is a cold-water intake pipe located at a water depth of about 600 meters (1900 ft.) off Keahole Pt. It does not appear that any modification to the marine environment brought about by the implementation of the O'oma II development could alter the chemical characteristics of the intake water.

Summary

With regard to the O'oma II resort, the potential for direct impact as a result of development to the offshore communities appears to be very small. None of the developmental activities appear to have the potential to induce large changes in physio-chemical water quality parameters. In addition, as described in the RESULTS section, the offshore reef areas adjacent to the development property are constantly exposed to natural stresses, especially in the form of storm waves, that are the primary factor determining the make-up of the reef communities. The most relevant point of illustrating the effects of such natural phenomena is to show that marine environments are routinely subjected to stresses of massive proportions that are much more influential (or destructive) than the incremental changes that could result from any development activity. If some unexpected event related to development activities does occur, the resulting alterations to marine community structure would probably be negligible, and recovery rapid once the stress factor is mitigated. Tolerance to such changes appears to already be part of the physiological range of the community. Observations of the response of marine ecosystems to such shoreline development as Princeville, on Kauai, Kaanapali on Maui, Kailua-Kona on Hawaii and even Waikiki on Oahu substantiate the overall conclusion that the marine environment is capable of withstanding shoreline development activities without suffering any loss in quality.

It can be concluded that as long as the normal reasonable steps are taken in construction practices, and operational procedures for the golf course and sewage treatment systems are carefully maintained, there should be no adverse impacts to the marine environments. However, the baseline marine biological studies were implemented in such a way that replicate surveys conducted in subsequent years can show actual changes in marine community structure. Regardless of how unlikely, there is always the potential for an unexpected event. If any development practices cause changes in physical-chemical parameters which lead to changes in environmental integrity, these effects could be quantified through time-series surveys. Therefore, it is recommended that the planners of O'oma II utilize the bench-mark stations to the fullest by incorporating into their long-range plans subsequent marine surveys. If, and when, development construction near the shoreline commences, it would appear to be a prudent action to initiate a monitoring program at that site during the activity. With such an ongoing program, it would be possible to quickly pinpoint any detrimental processes as they happen and remedy the situation before significant or irreversible environmental damage occurs.

REFERENCES CITED

Dollar, S. J. 1975. Zonation of reef corals off the Kona Coast of Hawaii. M.S. Thesis in Oceanography, University of Hawaii. 183 p.

Dollar, S. J. 1982. Wave stress and coral community structure in Hawaii. Coral Reefs 1:71-81.

Dollar, S. J. 1985. Environmental assessment of Hilo Bay: Marine biological community structure in the vicinity of the proposed Hilo sewage outfall extension. Prepared for M & E Pacific, Inc.

Dollar, S. J. and R. W. Grigg. 1981. Impact of a kaolin clay spill on a coral reef in Hawaii. Marine Biology 65:269-76.

Grigg, R. W. and S. J. Dollar. 1980. Environmental impact assessment of nearshore marine life at Princeville, Kauai, Hawaii. Prepared for Princeville Development Corp.

Pfeffer, R. A. and G. W. Tribble. 1985. Hurricane effects on an aquarium fish fishery in the Hawaiian Islands. Proc. 5th Int. Coral Reef Symp. Tahiti. pp 331-336.

APPENDIX C

NEARSHORE WATER CHEMISTRY ASSESSMENT

Marine Research Consultants

ASSESSMENT OF CHEMISTRY OF NEARSHORE WATERS IN THE VICINITY OF THE O'OMA II DEVELOPMENT, NORTH KONA, HAWAII

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INTRODUCTION AND PURPOSE

Kahala Capital Corporation is currently in a second stage of planning for the O'oma II Development on the West Coast of the Island of Hawaii. The 300-acre development, which extends from the ocean landward to Queen Kaahumanu Highway, lies between the Hawaii Ocean Science and Technology (HOST) Park, to the north, and the planned Kohana'iki Resort to the south. The property is one mile south of the Keahole Airport, and seven miles north of Kailua-Kona. The current O'oma II plan includes a variety of land uses including: a golf course, hotel, shopping village, marine park and ocean science center, water recreation park, office business park, condominiums, single family residences, and an 18-acre waterfront lagoon and beach park.

A concern of the local community, as well as various regulatory agencies, is likely to center on the potential for environmental degradation of the nearshore ocean resulting from the project. This concern is especially critical for the O'oma Project owing to the close proximity of the Natural Energy Laboratory of Hawaii (NELH) and HOST Park facilities, which rely on pristine ocean waters. Significant questions include the potential impacts from runoff of soil, fertilizers, and other chemicals which could cause alterations to water quality and marine life. In addition, as the project plans call for excavation of lagoons behind the shoreline, it is important to assess if, and to what extent, this action will affect groundwater discharge into the nearshore ocean.

In the interest of addressing these concerns and assuring maintenance of environmental quality, it has been deemed appropriate to conduct a marine environmental survey and potential impact analysis of the nearshore areas off the O'oma II property. In 1986, a "Baseline Assessment of the Marine Environment in the Vicinity of the O'oma II Development" was prepared. This study presented a detailed description of the physical and biological setting at four representative areas fronting the property. It did not include, however, analyses of water chemistry constituents that contribute to water quality in the nearshore regions that are most likely to be affected by the proposed project. The present report describes the results of a survey designed to characterize the present water quality in the vicinity of O'oma II.

The specific objectives of the survey are to establish a quantitative baseline set of water chemistry parameters that delineate the present environmental conditions of the nearshore ocean offshore of the site planned for development. Particular attention is given to evaluating the influence of groundwater entering the marine environment. Consideration is also given to comparing water chemistry off the existing NELH-HOST Park facility in order to compare effects from potential land uses at O'oma.

METHODS

Three survey stations were established in the vicinity of the O'oma property: Station 1 was located off the public bathhouse located to the north of the northern property boundary (this site was selected so as to be able to differentiate inputs from the O'oma area and neighboring facilities); Station 2 was located off the approximate center of the property; and Station 3 was located near the southern boundary (see Figure 1).

Water quality was evaluated at each station on transects that were oriented perpendicular to the shoreline and depth contours. Water samples were collected at 6 locations on each transect from just seaward of the shoreline to approximately 200 meters (m) offshore. Such a sampling scheme was designed to span the greatest range of salinity with respect to potential freshwater efflux at the shoreline. Sampling was more concentrated in the nearshore zone because this area is most likely to show the effects of shoreline modification. With the exception of the two locations nearest to shore, samples were collected at two depths; a surface sample was collected within approximately 10 centimeters (cm) of the sea surface, and a bottom sample was collected within 1 m of the sea floor. In addition, samples were collected from a potable well located upslope from the O'oma property, and from an open ocean station located approximately 2 kilometers from shore.

Water quality parameters evaluated included the ten specific criteria designated for open coastal waters in Chapter 11-54, Section 06 (Open Coastal waters) of the State of Hawaii Department of Health (DOH) Water Quality Standards. These criteria include: total nitrogen (TN), nitrate + nitrite nitrogen (NO_3^- + NO_2^-, hereafter referred to as NO_3^-), ammonium nitrogen (NH_4^+), total phosphorus (TP), chlorophyll a (Chl a), turbidity, dissolved oxygen, temperature, pH and salinity. In addition, orthophosphate phosphorus (PO_4^{-3}) and silica (Si) were also reported because these parameters are sensitive indicators of biological activity and the degree of groundwater mixing.

All fieldwork was conducted on September 13-14, 1990 using a 19-foot boat. Water samples were collected by opening 1-liter polyethylene bottles at the desired depth. Subsamples for nutrient analyses were immediately placed in 125-milliliter (ml) acid-washed, triple rinsed, polyethylene bottles and stored on ice. Analyses for NH_4^+, PO_4^{3-}, and NO_3^- were performed using manual spectrophotometric techniques on a Brinkman fiber-optic colorimeter. TN and TP were analyzed in a similar fashion following digestion. Dissolved organic nitrogen (DON) and dissolved organic phosphorus (DOP) were calculated as the difference between TN and dissolved inorganic N, and TP and dissolved inorganic P, respectively. The chemistry procedures were performed according to standard methods for seawater analysis (Strickland and Parsons 1968, Grasshoff 1983).

Water for other analyses was subsampled from 1-liter polyethylene bottles and kept chilled until analysis. Turbidity was determined on 60-ml subsamples fixed with HgCl to terminate biological activity. Fixed samples were kept refrigerated until turbidity was measured on a Monitek Model 21 nephelometer, and reported in nephelometric turbidity units (NTU). Chl a was measured by filtering

300 ml of water through glass-fiber filters; pigments on filters were extracted in 90% acetone in the dark at -5^{o} C for 12-24 hours. Fluorescence before and after acidification of the extract was measured with a Turner Designs fluorometer. Salinity was determined using an AGE Model 2100 laboratory salinometer with a readability of 0.0001 ^{o}/oo.

In-situ field measurements included water temperature (measured with a hand-held mercury thermometer readable to 0.1^{o} C), and pH (measured with portable meter with a readability of 0.01 pH units).

RESULTS OF WATER CHEMISTRY ANALYSES

Horizontal and Vertical Stratification

Table 1 shows results of all water chemistry analyses for samples collected off the O'oma site. Concentrations of eight dissolved nutrient constituents in surface and deep samples are plotted as functions of distance from the shoreline in Figure 2. Values of salinity, turbidity, Chl a and temperature are shown in Figure 3.

Several patterns of distribution are evident in Figures 2 and 3. It can be seen in Figure 2 that the dissolved nutrients Si, NO_3^-, PO_4^{3-}, TP and TN, display a marked elevation in concentration in the samples collected 1 and 5 m from the shoreline at Station 1. Salinity displays the opposite trend, with sharply lower concentrations within 5 m of the shoreline at Station 1. These substantially different nearshore values are not evident at Stations 2 and 3.

These patterns appear to be a result of concentrated input of groundwater through a lava tube at the shoreline at the origin of the sampling transect at Station 1. Low salinity groundwater, which contains high concentrations of Si, NO_3^-, and PO_4^{3-} (see values for potable well water in Table 1), percolates to the ocean at the shoreline, resulting in a nearshore zone of mixing. In many areas of the Hawaiian Islands, such groundwater percolation results in horizontal gradients of increasing salinity and decreasing nutrients moving seaward. It can be seen in Figures 2 and 3, however, that at Station 1 groundwater is mixed to oceanic levels within 10 m of the shoreline. At Stations 2 and 3, there is only a very slight indication of increased concentration of the nutrients found in groundwater in the nearshore samples.

In addition, groundwater efflux often results in a surface lens with lower salinity and higher nutrient content relative to subsurface water. At the O'oma sites, there is a slight indication of vertical statification of salinity, and the nutrient constituents found in groundwater.

Water chemistry parameters that are not associated with groundwater input do not show the same pattern of decreasing concentration with respect to distance from the shoreline. NH_4^+ displays higher values at the nearshore samples at Station 3, as well as higher values in the most seaward samples. DOP and DON appear to be lower in concentration in the samples collected 1 m from the shoreline. Beyond this distance, these constituents do not appear to display any recognizable pattern with respect to horizontal or vertical stratification, and are essentially invariant with distance from the shoreline (Figure 2).

Turbidity and Chl a exhibit highest concentrations at nearshore samples at Station 3. The remainder of the sampling sites show no apparent pattern with respect to distance from shore or location in the water column. Temperature is lowest at the nearshore sampling sites at Station 1 owing to the input of cool groundwater. At Station 3, nearshore samples displayed higher temperatures than offshore samples, probably as a result of solar warming of the surface layer. Beyond the nearshore zone (10 m from the shoreline) the water column was slightly stratified with the surface layer slightly warmer than the deeper layer.

Compliance with DOH Criteria

Also shown in Table 1 are samples that exceed DOH water quality standards for open coastal waters under "dry" conditions. The criteria for dry conditions are applied to the O'oma site as this area probably receives less than 3 million gallons of groundwater input per mile per day (T. Nance, personal communication).

The sample set for the initial phase of monitoring was collected during what appeared to be "normal" summer weather, and is likely to represent the typical conditions that characterize the area. Comparing water chemistry results from the O'oma samples to DOH standards reveals that 2 measurements of NO_3^-, 5 measurements of NH_4^+, 1 measurement of TP, and 2 measurements of TN exceeded the "not to exceed more than 2% of the time" standards. TN values are essentially reflections of NO_3^-, and TP values are indicative of PO_4^{3-} concentrations.

As discussed above, NO_3^- and PO_4^{3-} are normal constituents of groundwater. The concentrations found in waters off the survey sites appear to be the result of groundwater discharge at the shoreline. All of the values that exceed DOH standards for these two constituents occur at Station 1, where substantial freshwater is entering the ocean. Along the two transects fronting the O'oma property, there are no concentrations of NO_3^- and PO_4^{3-} that exceed DOH standards.

Examination of NH_4^+ as a function of salinity indicate that there is little relationship between concentrations in nearshore ocean samples and inputs from land. Thus, it appears that the measurements of NH_4^+ that exceed DOH criteria are a result of normal marine processes in the area.

Thus, by comparison of the water chemistry constituents with DOH criteria, it is apparent that under the present conditions (prior to any construction activities), natural processes can cause measurements of water quality that exceed specified DOH limits.

No measured values of turbidity or Chl a at any of the sites exceeded DOH specific limits.

Comparison with NELH Monitoring Program

As part of the ongoing "Keahole Point Comprehensive Environmental Monitoring Program", coastal seawater samples have been collected from a series of stations that extends along the shoreline southward from the approximate location of Station 1 in the present survey. In order to determine if water quality off the O'oma site differs significantly from nearshore waters to the north, data from the present survey and the Keahole Point Program were compared.

Figure 4 shows plots of dissolved Si and NO_3^- as functions of salinity from the present survey (labelled MRC), and three sites from the Keahole Program (NELH 1-3). NELH 1 corresponds to sites C-25, 26,and 27; NELH 2 corresponds to sites C-22, 23, and 24, while NELH 3 corresponds to C-19, 20 and 21 (see Figure 5). Thus, NELH 1 lies closest to O'oma, while site NELH 3 is farthest away.

Considering dissolved Si, it can be seen in Figure 4 that for both salinity ranges (5-35^{o}/oo and 34-35^{o}/oo), data from the present survey falls in a fairly straight line. Data from the NELH program does not prescribe as clear a line with respect to Si concentration as a function of salinity. There is no indication, however, of a pattern of influence with respect to position along the coastline for the NELH data. The essentially random distribution of data points, especially in the 34-35^{o}/oo plot, suggests that no conclusions can be drawn relating to differential input of freshwater along the coastline.

With respect to input of NO_3^-, similar conclusions can be drawn. Owing to the scatter of data, there does not appear to be any substantial differences between input along the O'oma property compared to the NELH sites.

SUMMARY

1. Evaluation of nearshore water chemistry off the proposed O'oma II site was carrried out in September 1990. Thirty-two water samples were collected from three stations located in the vicinity of the project. Water samples were collected on transects perpendicular to shore, extending from the shoreline to a distance of approximately 200 m offshore. Analysis of 13 water chemistry constituents included all parameters specified in DOH water quality standards.

2. Several dissolved nutrients (NO_3^-, TN, and Si) displayed horizontal gradients with highest values closest to shore and lowest values at the most seaward sampling sites. Correspondingly, salinity was lowest closest to the shoreline. These patterns indicate that groundwater is entering the marine

environment near the shoreline and mixing with oceanic water. This pattern was especially evident at Station 1, in the proximity of a major seep of groundwater.

3. Along with horizontal gradients in some water chemistry constituents, there is a slight indication of vertical stratification within the water column. Such stratification is the result of incomplete mixing of a low density surface layer originating from groundwater input at the shoreline.

4. Other water chemistry constituents that are not related to groundwater efflux do not display discernible gradients with respect to distance from the shoreline. Turbidity and temperature appear to be slightly elevated at Station 3.

5. Several water samples exceeded State DOH standards for NO_3^-, TN, NH_4^+, TP and TN. These samples appear to contain dissolved materials in excess of standards solely as a result of natural processes of groundwater efflux and biological activity. Off the O'oma site (Stations 2 and 3), the only constituent to exceed DOH criteria was NH_4^+. No measured values of turbidity or Chl a were in excess of DOH standards.

6. Comparison of the data collected for this survey with data from the Keahole Comprehensive Environmental Monitoring Program indicates that there are presently no major discernible differences between inputs at the O'oma site and at more northerly locations toward Keahole Point.

7. Results of the water chemistry analysis indicate that presently there does not appear to be any unusual inputs or processes occurring off the O'oma site. Water chemistry in the area is indicative of typical nearshore oceanic conditions, without significant influences from land.

REFERENCES CITED

Grasshoff, K. 1983. Methods of seawater analysis. Verlag Chemie, Weinheim, 419 pp.

Strickland J. D. H. and T. R. Parsons. 1968. A practical handbook of sea-water analysis. Fisheries Research Bd. of Canada, Bull. 167. 311 p.

TABLE 1. Water chemistry constituents measured on three transects off the O'oma property.
D.F.S. = distance from shore; O.O. = open ocean; "S" = surface sample; "D" = deep sample.
B.D.L. = below detectable limits. Values in boxes exceed D.O.H. water quality standards for open ocean waters under "dry" conditions.
For station locations, see Figure 1.

STATION		D.F.S. (m)	PO4 (µM)	NO3 (µM)	NH4 (µM)	Si (µM)	DOP (µM)	DON (µM)	TDP (µM)	TDN (µM)	TURB (ntu)	SALINITY (o/oo)	CHL a (µg/l)	TEMP (deg C)	pH
1-1	S	1	1.87	61.76	0.05	449.63	0.07	2.78	1.94	64.59	0.10	16.966	0.07	26.2	8.06
1-2	S	5	0.37	7.74	0.25	67.82	0.15	5.58	0.52	13.57	0.16	32.385	0.09	27.5	8.14
1-3	S	10	0.11	0.48	0.05	6.37	0.20	6.47	0.31	7.00	0.09	34.642	0.10	27.7	8.16
1-3	D	10	0.10	0.53	0.05	6.37	0.20	6.15	0.30	6.73	0.09	34.643	0.10	27.6	8.16
1-4	S	50	0.24	0.86	0.14	11.51	0.14	6.52	0.38	7.52	0.20	34.517	0.13	27.8	8.16
1-4	D	50	0.10	0.28	0.20	5.75	0.18	6.25	0.28	6.73	0.12	34.697	0.08	27.8	8.16
1-5	S	100	0.11	BDL	0.09	3.29	0.19	5.99	0.30	6.08	0.06	34.791	0.11	27.5	8.16
1-5	D	100	0.07	BDL	BDL	1.85	0.23	5.68	0.30	5.68	0.08	34.786	0.11	27.5	8.16
1-6	S	200	0.07	BDL	0.31	1.44	0.20	6.16	0.27	6.47	0.08	34.805	0.11	27.7	8.17
1-6	D	200	0.08	BDL	BDL	1.44	0.20	5.94	0.28	5.94	0.10	34.795	0.09	27.7	8.17
2-1	S	1	0.08	0.66	0.09	10.89	0.17	4.35	0.25	5.10	0.15	34.484	0.09	27.6	8.16
2-2	S	5	0.07	0.43	0.50	6.99	0.18	7.81	0.25	8.84	0.22	34.627	0.13	27.7	8.16
2-3	S	10	0.08	0.13	0.05	4.93	0.15	4.32	0.23	4.50	0.12	34.687	0.09	27.8	8.16
2-3	D	10	0.08	0.05	0.09	3.49	0.16	4.23	0.24	4.37	0.10	34.734	0.11	27.7	8.17
2-4	S	50	0.11	0.25	0.09	6.37	0.14	4.03	0.25	4.37	0.19	34.662	0.10	27.8	8.17
2-4	D	50	0.08	0.08	0.09	4.32	0.17	4.20	0.25	4.37	0.11	34.728	0.11	27.8	8.17
2-5	S	100	0.11	0.23	0.23	5.34	0.23	8.51	0.34	8.97	0.09	34.701	0.11	27.7	8.17
2-5	D	100	0.08	0.05	0.05	3.29	0.22	6.37	0.30	6.47	0.09	34.748	0.11	27.5	8.17
2-6	S	200	0.07	BDL	0.09	4.32	0.20	5.93	0.27	6.02	0.08	34.795	0.09	27.6	8.17
2-6	D	200	0.04	BDL	0.27	2.67	0.30	8.25	0.34	8.52	0.25	34.800	0.09	27.6	8.17
3-1	S	1	0.10	0.25	0.07	8.84	0.15	5.36	0.25	5.68	0.33	34.574	0.19	28.5	8.16
3-2	S	5	0.08	0.40	1.45	10.48	0.16	9.49	0.24	11.34	0.27	34.476	0.22	28.3	8.16
3-3	S	10	0.04	0.28	0.88	6.78	0.21	7.15	0.25	8.31	0.22	34.634	0.11	28.2	8.16
3-3	D	10	0.04	0.13	0.09	6.37	0.19	5.41	0.23	5.63	0.17	34.651	0.09	28.3	8.16
3-4	S	50	0.10	0.20	0.11	5.75	0.15	5.11	0.25	5.42	0.15	34.671	0.11	28.0	8.16
3-4	D	50	0.08	BDL	0.09	3.29	0.16	4.54	0.24	4.63	0.26	34.754	0.10	27.8	8.17
3-5	S	100	0.08	BDL	0.05	1.85	0.17	4.71	0.25	4.76	0.15	34.799	0.10	27.9	8.17
3-5	D	100	0.08	BDL	0.05	1.23	0.19	5.10	0.27	5.15	0.12	34.794	0.07	27.5	8.17
3-6	S	200	0.03	BDL	0.65	1.64	0.20	5.56	0.23	6.21	0.28	34.789	0.10	27.7	8.17
3-6	D	200	0.04	BDL	0.44	1.44	0.19	6.03	0.23	7.47	0.12	34.792	0.07	27.5	8.17
O.O.	S	2000	0.07	BDL	0.09	1.23	0.21	5.72	0.28	5.81	0.08	34.833	0.04	28.1	8.18
O.O.	D	2000	0.07	BDL	0.79	1.44	0.18	6.99	0.25	7.78	0.06	34.818	0.08	27.9	8.18
DOH															
N.T.E. 10%				0.71	0.33				0.97	12.86	0.50		0.50		
N.T.E. 2%				1.43	0.64				1.45	17.86	1.00		1.00		

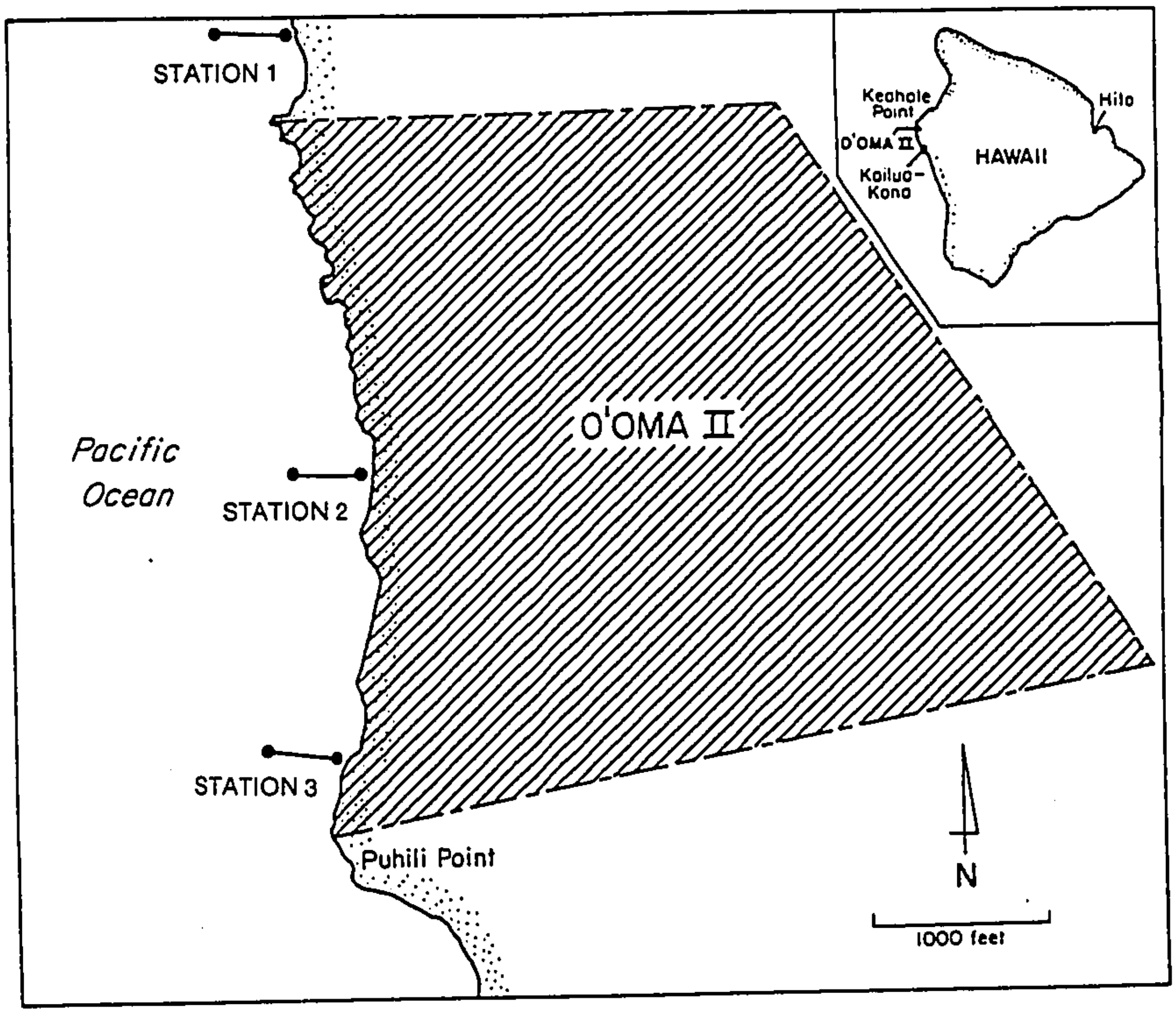

FIGURE 1. Map showing location of water sampling transects in the vicinity of the planned O'oma development.

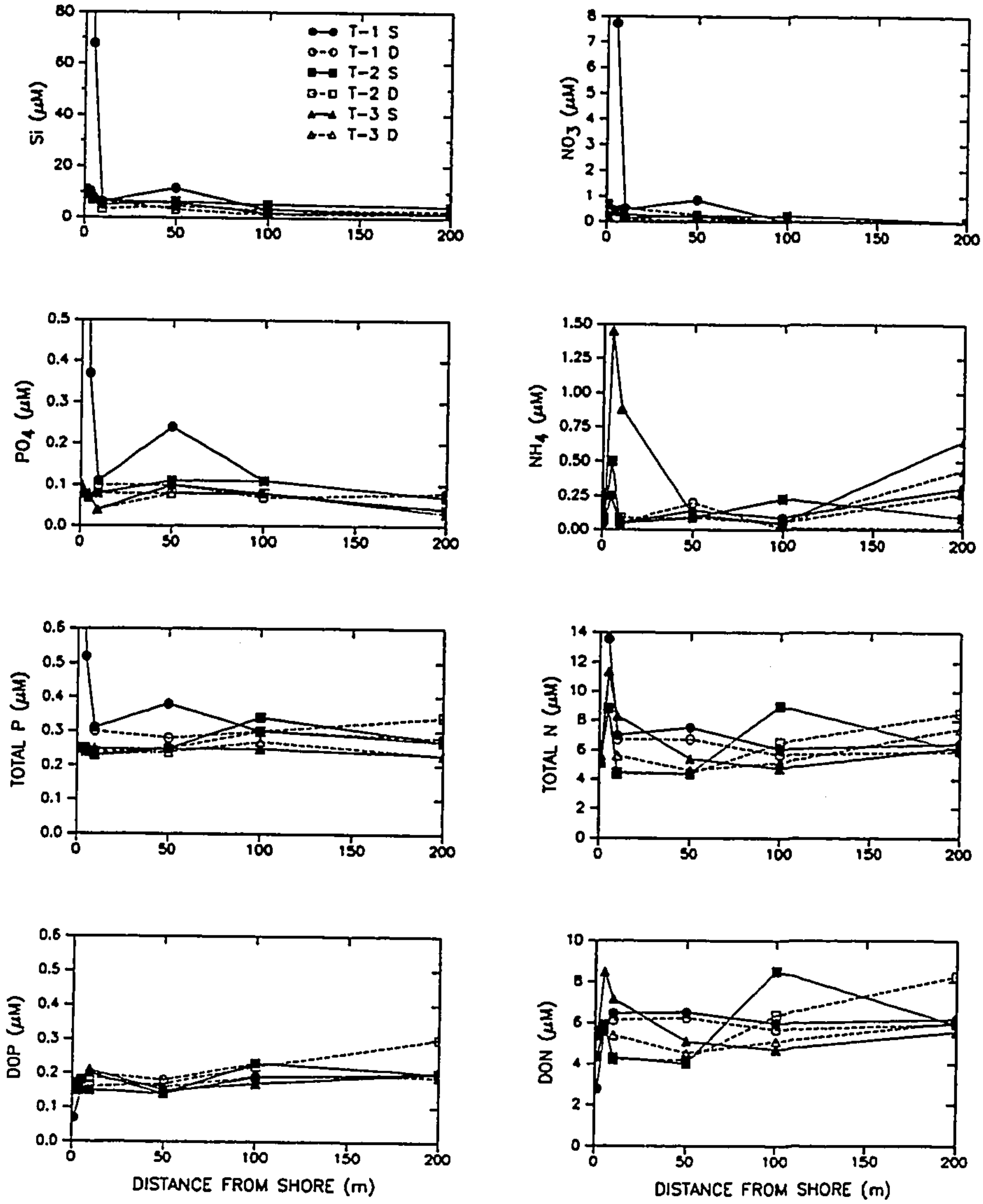

FIGURE 2. Plots of dissolved nutrients as functions of distance from shore in surface (S) and deep (D) water samples collected on three transects (T-1, 2, 3) off the planned O'oma development. For transect station locations, see Figure 1.

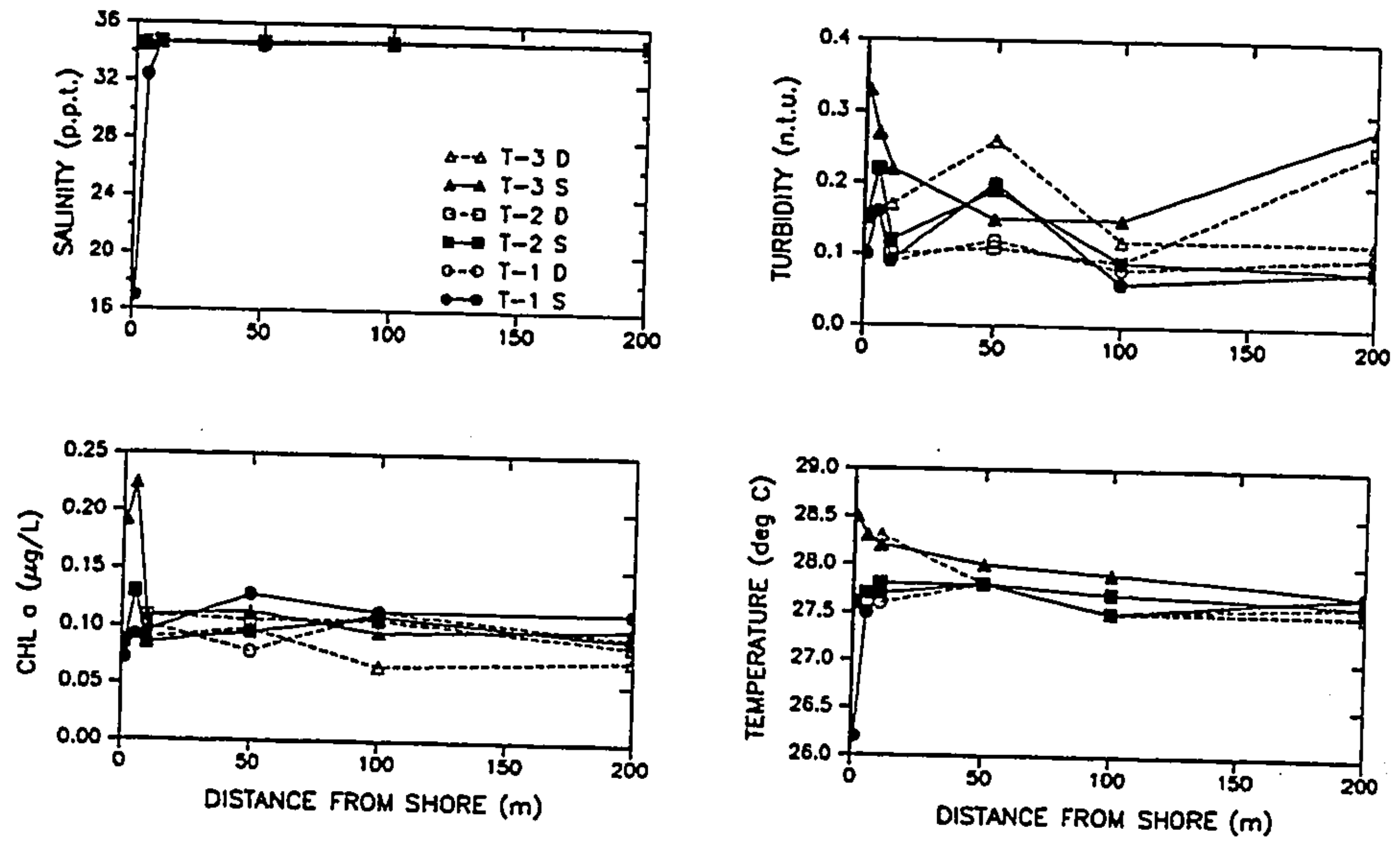

FIGURE 3. Plots of four water chemistry constituents as functions of distance from shore in surface (S) and deep (D) water samples collected on three transects (T-1, 2, 3) off the planned O'oma development. For transect station locations, see Figure 1.

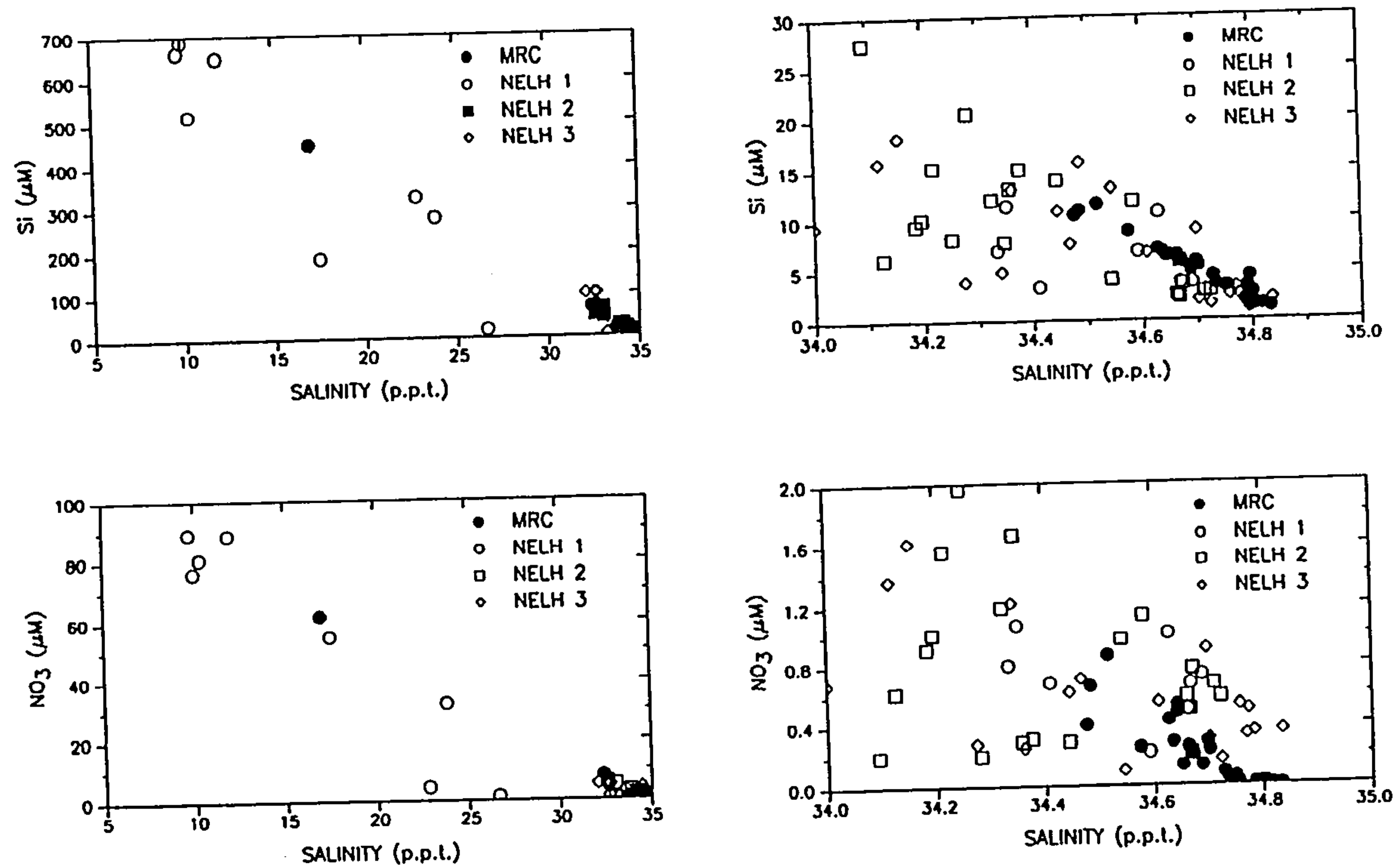

FIGURE 4. Plots of dissolved Si and NO_3^- as functions of salinity for data collected in the present survey (MRC), and collected as part of the NELH comprehensive environmental monitoring program. NELH 1, 2 and 3 samples are composed of three sampling sites each, moving progressively farther away from the O'oma property. For locations of NELH sites, see Figure 5.

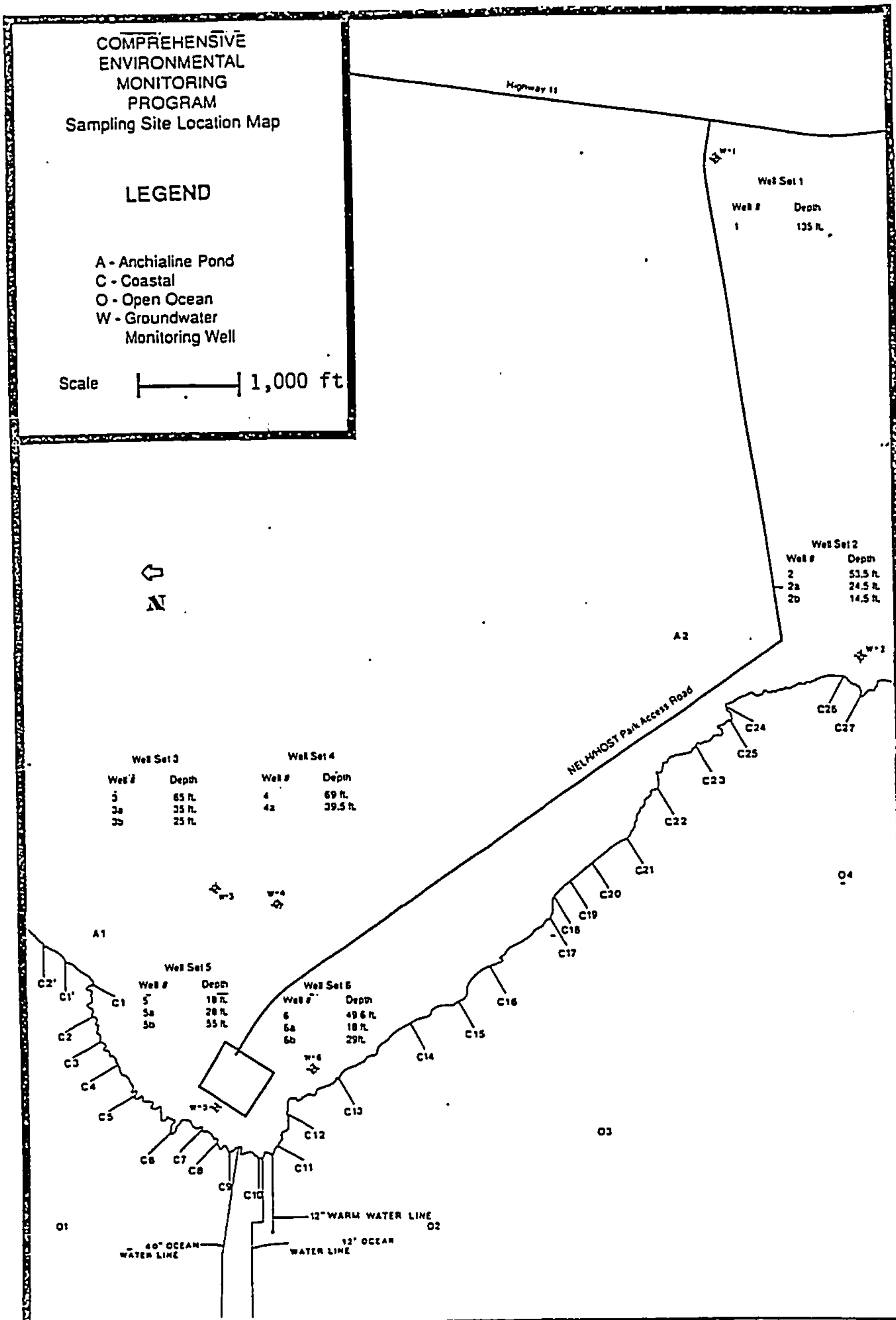

FIGURE 5. Sites of coastal ocean sampling for the NELH comprehensive environmental monitoring program. NELH 1 consists of sites C-25, 26, 27; NELH 2 consists of sites C-22, 23 and 24; NELH 3 consists of sites C-19, 20 and 21

APPENDIX D

NEARSHORE MARINE COMMUNITY STRUCTURE ASSESSMENT

Marine Research Consultants

AN ASSESSMENT OF NEARSHORE MARINE COMMUNITY STRUCTURE AT O'OMA, NORTH KONA, HAWAII

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INTRODUCTION

Kahala Capital Corporation is currently in the second stage of planning for the O'oma II Development on the West Coast of the Island of Hawaii. The 300-acre development, which extends from the ocean landward to Queen Kaahumanu Highway, lies between the Hawaii Ocean Science and Technology (HOST) Park, to the north, and the planned Kohana'iki Resort to the south. The property is one mile south of the Keahole Airport, and seven miles north of Kailua-Kona. The current O'oma II plan includes a variety of land uses including: a golf course, hotel, shopping village, marine park and ocean science center, water recreation park, office business park, condominiums, single family residences, and an 18-acre waterfront lagoon and beach park.

A concern regarding implementation of the project is the potential for impacts to the marine environment owing to changes in land uses. This concern is especially critical for the O'oma Project owing to the close proximity of the Natural Energy Laboratory of Hawaii (NELH) and HOST Park facilities, which rely on pristine ocean waters. Significant questions include the potential impacts from runoff of soil, fertilizers, and other chemicals which could cause alterations to water quality and marine life. In addition, as the project plans call for excavation of lagoons behind the shoreline, it is important to assess if, and to what extent, this action will affect groundwater discharge into the nearshore ocean.

In the interest of addressing these concerns and assuring maintenance of environmental quality, it has been deemed appropriate to conduct a marine environmental survey of the nearshore areas off the O'oma II property. The survey is composed of two components, an assessment of marine water chemistry, and a survey of nearshore biological community structure.

This report describes the results of the baseline survey of the nearshore marine communities. The survey is a continuation of previous work performed in the vicinity of the O'oma II property. In 1986, a "Baseline Assessment of the Marine Environment in the Vicinity of the O'oma II Resort Development" provided a detailed description of the physical and biological setting fronting the property. The strategy of the present report was to replicate the 1986 survey. Repeating the survey, using the same techniques in the same locations, provides a descriptive and quantitative baseline of biotic communities off the proposed development that addresses change over time as well as space. Such a characterization of biotic assemblages will provide a basis for estimating alteration of community structure as a result of modifying the shoreline. This baseline will also serve to identify any specific biotic communities that may be especially susceptible (or resistant), to the potential alterations that may result from the planned development. As this aspect of the survey will be repeating the investigations conducted in 1986, it will provide information on the degree of natural variability in community structure.

An important part of this investigation is to provide an evaluation of the degree of natural stresses (sedimentation, wave scour, freshwater input, etc.) that influence the nearshore marine environment in the area that could be potentially influenced by the proposed project. Typically, water quality and the composition of nearshore marine communities are intimately associated with the magnitude and frequency of these stresses, and any impacts caused by the proposed project may either be mitigated in large part, or amplified, by natural environmental factors. Therefore, evaluating the range of natural stress is a prerequisite for assessing the potential for additional change to the marine environment owing to shoreline modification.

Marine community structure can be defined as the abundance, diversity, and distribution of stony and soft corals, motile benthos such as echinoderms, and pelagic species such as reef fish. In the context of time-series surveys, the most useful biological assemblages for direct evaluation of environmental impacts to the offshore marine environment are benthic (bottom-dwelling) communities. Because benthos are generally long-lived, immobile, and can be significantly affected by exogenous input of sediments and other potential pollutants, these organisms must either tolerate the surrounding conditions within the limits of adaptability or die. As members of the benthos, stony corals are of particular importance in nearshore Hawaiian environments. Corals compose a large portion of the reef biomass and their skeletal structures are vital in providing a complex of habitat space, shelter, and food for other species. Since corals serve in such a keystone function, coral community structure is considered the most "relevant" group in the use of reef community structure as a means of evaluating past and potential impacts associated with land development. For this reason, and because alterations in coral *communities are easy to identify, observable* change in coral population parameters is a practical and direct method for obtaining the information for determining the effects of stress in the marine environment. In addition, because they comprise a very visible component of the nearshore environment, detailed investigations of reef fish assemblages are presented.

METHODS

All fieldwork was carried out on September 22-23, 1990, and was conducted from a 26-foot boat. Biotic structure of benthic (bottom dwelling) communities inhabiting the reef environment was evaluated by establishing a descriptive and quantitative baseline between the shoreline and the 20 meter (m) (~60 foot) depth contour. Initial qualitative reconnaissance surveys were conducted that covered the area off the O'oma property from the shoreline out to the limits of coral reef formation. These reconnaissance surveys were useful in making relative comparisons between areas, identifying any unique or unusual biotic resources, and providing a general picture of the physiographic structure and benthic assemblages occurring throughout the region of study.

Following the preliminary survey, four quantitative transect sites were selected offshore of the development area at the same sites as in the 1986 survey (see Figure 1). Station 1 was located at the northern property boundary, Stations II and III were located in the central area, and Station IV was located off Puhili Point, at the southern boundary of the property. At each station, three transect sites were selected, one in each of the dominant reef zones. Each transect was oriented parallel to depth contours so as to bisect a single reef zone. Care was taken to place transects in random locations that were not biased toward either peak or low coral cover. In total, twelve quantitative transects were conducted.

Quantitative benthic surveys were conducted by stretching a 50-m long surveying tape in a straight line over the reef surface. An aluminum quadrat frame, with dimensions of 1 m by 0.66 m, was sequentially placed over 10 random marks on the transect tape so that the tape bisected the long axis of the frame. At each quadrat location a color photograph recorded the segment of reef area enclosed by the quadrat frame. In addition, a diver knowledgeable in the taxonomy of resident species visually estimated the percent cover and occurrence of organisms and substratum type within the quadrat frame. No attempt was made to disturb substrata to observe organisms, and no attempt was made to identify and enumerate cryptic species dwelling within the reef framework. Only macrofaunal species greater than approximately 2 centimeters were noted.

Following the period of fieldwork, quadrat photographs were projected onto a grid and units of bottom cover for each benthic faunal species and bottom type were recorded. Results of the photo-quadrats were combined with the in-situ cover estimates and community structure parameters (percent cover, species diversity) were calculated. The photo-quadrat transect method is a modification of the technique described in Kinzie and Snider (1978), and has been employed in numerous field studies of Hawaiian reef communities (e.g. Dollar 1979, Grigg and Maragos l974), and has proven to be particularly useful for quantifying coverage of attached benthos such as corals and large epifauna (e.g., sea urchins, sea cucumbers). While this methodology is quantitative for the larger exposed fauna, many coral reef invertebrates are cryptic or nocturnal. Coupled with the generally small size of cryptic invertebrates, quantitative assessment of these groups requires methodologies that are beyond the scope of the present monitoring program.

Quantitative assessment of reef fish community structure was conducted in conjunction with the benthic surveys. As the transect tape was being laid along the bottom, all fish observed within a band approximately 2 meters wide along the transect path were identified by species name and enumerated. Care was taken to conduct the fish surveys so that the minimum disturbance was created by divers, ensuring the least possible dispersal of fish. Only readily visible individuals were included in the census. No attempt was made to seek out cryptic species or individuals sheltered within coral. This transect method is an adaptation of techniques described in Hobson (1974).

RESULTS AND DISCUSSION

Physical Structure

The main structural feature of the approximately one mile of shoreline of the O'oma II development is a basaltic ledge of pahoehoe lava with interspersed pockets of white calcareous sand. The intertidal platform, which is constantly subjected to the wash of waves, is flooded in places to form tidepools. None of these pools, however, appeared to be separated from the ocean on a permanent basis so they are not classified as "anchialine". Rimming many of the pools formed in the basalt bench are dense bands of the intertidal seaweeds Anhfeltia concinna and Ulva fasciata. The submerged portions of the intertidal pools are lined with various forms of encrusting red algae, and contain numerous urchins of the species Echinometra matheai, Echinostrephus aciculatus, and Colobocentrotus atratus, as well as numerous juvenile reef fish. The seaward edge of the lava shoreline is composed of either basaltic boulder fields, or vertical sea cliffs 2 to 5 feet in height. The one exception is a small area at the northern border of the property where a small sandy beach reaches the shoreline.

Beyond the shoreline, the structure of the offshore environment at O'oma generally conforms to the pattern that has been documented as characterizing much of the west coast of the Island of Hawaii (Dollar 1982). The zonation scheme consists of three predominant regions. Beginning at the shoreline and moving seaward, the shallowest zone beyond the shoreline is comprised of a seaward extension of the basaltic shoreline bench, along with scattered basaltic boulders that have entered the ocean after breaking off from the shoreline. Pocillopora meandrina, a sturdy hemispherical coral is the dominant colonizer of the nearshore area. This species is able to flourish in areas that are physically too harsh for most other species, particularly due to wave stress. The shallow transects conducted off O'oma all traversed the Pocillopora meandrina-boulder zone.

Seaward of the nearshore boulder zone, bottom structure is composed predominantly of a gently sloping reef bench composed of basalt, interspersed with lava extrusions and sand channels. In some areas, the bench is characterized by high relief in the form of undercut ledges and basaltic pinnacles. Fine-grained calcareous sediment also comprises a component of bottom cover. Water depth in this mid-reef zone ranges from about 20 to 50 feet. As wave stress in this region is substantially less than in the shallower areas, and suitable hard substrata abound, the area provides an ideal locale for colonization by attached benthos, particularly reef corals, and generally the widest assortment of species and growth forms are encountered in this region. The intermediate depth transects at each survey station were located on the reef bench.

The seaward edge of the reef platform (at a depth of about 50 feet) is marked by an increase in slope to an angle of approximately 20-30 degrees. In the deep slope zone, substratum changes from the solid continuation of the island mass to an aggregate of generally unconsolidated sand and rubble. The predominant coral cover in the slope zone is typically interconnected mats of "finger coral", which grow laterally over unconsolidated substrata. In some areas, notably Station III, the deep reef slope is covered primarily with rubble fragments generated by breakage of P. compressa from wave forces. Moving down the reef slope, coral settlement and growth cease at a depth of approximately 80 feet; beyond this depth the bottom consists mostly of sand, with occasional basaltic outcrops. The deep transects at each survey station were located on the upper portions of the reef slope.

Biotic Community Structure

Coral Communities

Table 1 shows abundance estimates of invertebrates observed throughout the region of study. The predominant taxon of macrobenthos (bottom-dwellers) throughout the reef zones off the O'oma property are Scleractinian (reef-building) corals. Results of quantitative line transects conducted within the three dominant reef zones provide a data base characterizing coral community structure. Table 2 shows the quantitative summary of coral community structure from the 1990 transects, while Appendix A is comprised of individual transect results. Table 3 shows similar transect data collected in the 1986 survey.

In total, fourteen species of "stony" corals, and two "soft corals" were encountered on transects, while the number of coral species on a single transect ranged from three to seven. Only one species of coral (Pocillopora eydouxi) was observed in the study area that did not occur on any transects (see Table 1). The dominant species on all of the O'oma transects was Porites lobata, which accounted for about 60% of total coral cover. The second and third most abundant species, Pocillopora meandrina and Porites compressa, accounted for about 33% of coral cover. Thus, these three species comprised about 93% of living coral cover. In 1986, the distribution of coral cover was remarkably similar (see Table 3); P. lobata comprised 60% of coral cover, and the three dominant species totaled 94% of living coral cover. In total, coral cover accounted for 44.8% of bottom cover.

With respect to zonation of coral cover, the most abundant species on the shallow 15-20 foot transects were P. lobata and P. meandrina. Other species that were common in the shallow boulder covered areas were Montipora verrucosa and Leptastrea purpurea. The mid-depth reef platform zone had the highest number of coral species at each of the survey stations. The dominant species, however, was P. lobata. This species occurs in various growth forms including flat encrustations and large dome-shaped colonies, which are responsible for much of the true "reef" accumulation in the mid-depth zones.

At the seaward edge of the reef bench, the slope of the bottom increases, and the substratum consists primarily of unconsolidated rubble and sand. In areas that are protected from damage from storm surf, this region is generally covered by P. compressa, which assumes a spreading growth form that extends laterally over areas of unconsolidated substratum in a manner that is not possible by other species. Owing to a fragile skeletal growth form, however, this species is especially susceptible to breakage by storm waves. On the deep reef transects off O'oma, P. compressa accounted for large percentages of bottom cover at Stations 1 and 2. Observations of the deep reef zones at Stations III and IV, however, revealed P. compressa cover of only about 2%, while substantial bottom cover consisted of rubble fragments composed of broken P. compressa branches. Such levels of rubble cover suggest a relatively recent storm event that resulted in substantial damage to the P. compressa mats.

Figure 2 depicts coral community structure in histograms that are useful in showing relationships with respect to depth zone and station location. It can be seen in the histograms that there appear to be no substantial patterns with respect to distribution of any of the community parameters. Coral cover varies with respect to depth between all of the stations. At Station 1, cover is highest on the deep reef slope, owing to a relatively intact P. compressa framework, and lowest in the shallow boulder zone. At Stations 2-4, cover was lowest in the deep slope zones owing to apparent recent storm damage.

At each station, the number of coral species is similar at the shallow and mid-depth transects, and decreases on the deep transects. The number of species appears to be lower on all transects at Station II, relative to corresponding sites at other stations.

Coral species diversity also did not exhibit any repeatable pattern within stations. This result is somewhat unusual in that the "typical" zonation pattern for West Hawaii is usually reflected in highest diversity in the mid-reef zones, and lowest diversity on the deep reef slope (Dollar 1982).

In 1986, coral cover at all of the O'oma survey sites appeared noticeably reduced compared to other nearby areas. The decrease was attributed to the physical destruction of coral colonies brought on by a severe winter storm that occurred in February of 1986. The direction of wave propagation (from the northwest) was such that breaking waves estimated at 15-20 feet in height directly impacted the O'oma site. It was apparent the greatest effects of the storm waves occurred at the deep reef zones, which normally are not subjected to severe water motion.

Table 4 shows coral community parameters from both the 1986 and 1990 surveys, as well as the differences between the two surveys. Differences in community structure parameters is in part an inevitable result of imprecision of relocation of transect locations. It is also apparent, however, that differences between years also is indicative of major processes that have influenced community structure. With respect to coral cover, on only one of the twelve transects (I-15') was cover higher in 1986 compared to 1990. The greatest increases occurred in the mid-reef zones, where total cover increased from between 14% to 43% during the years between surveys. The number of species remained unchanged on four transects, and increased in 1990 on seven transects. Species cover diversity increased on six transects. A documented result of storm stress on Hawaiian reefs is an increase in diversity owing to reduction in dominance by a single preferred species (Dollar 1982). It appears that since the 1986 storm, which was responsible for decimation of much of the living coral cover off O'oma, the community is returning to prestorm conditions.

Other Benthic Macroinvertebrates

The other dominant group of macroinvertebrates are the sea urchins (Class Echinoidea). Table 5 summarizes the occurrence of sea urchins at all of the survey stations. The most common urchin is

Echinometra matheai, which occurred in all reef zones. E. matheai are small urchins that are generally found within interstitial spaces bored into basaltic and limestone substrata. E. matheai were most abundant at the mid-reef transects where the number of individuals ranged from 7 to 137. This species was least abundant on the reef slope transects where solid substrata was not common.

Tripneustes gratilla, and Heterocentrotus mammillatus are other species of urchins that occurred commonly on many transects. Both of these urchins occur as larger individuals (compared with E. matheai) that are generally found on the reef surface, rather than within interstitial spaces.

Sea cucumbers (Holothurians) observed during the survey consisted of three species, Holothuria atra, H. nobilis, and Actinopyga obesa. Individuals of these species were distributed sporadically across the mid-reef and deep reef zones (Table 1). The most common starfish (Asteroidea) observed on the reef surface were Linckia spp.. Several crown-of-thorns starfish (Acanthaster planci) were observed feeding on colonies of Pocillopora meandrina. Numerous sponges were also observed on the reef surface, often under ledges and in interstitial spaces. The green conical-shaped sponge Iotrocha protea was observed throughout the mid-depth reef zones.

Frondose benthic algae are conspicuously rare on the reefs of West Hawaii. Several plants were observed, however, off Kohana'iki. Most common were the encrusting red calcareous algae (Porolithon spp., Peysonellia rubra, Hydrolithon spp.). These algae were abundant on bared limestone surfaces, and on the nonliving parts of coral colonies. Frondose algae observed on the reef included Valonia sp., Lyngbya majuscula, Halimeda spp., and Galauxura spp.

The design of the reef survey was such that no cryptic organisms or species living within interstitial spaces of the reef surface were enumerated. Since this is the habitat of the majority of mollusks and crustacea, detailed species counts were not included in the transecting scheme. No dominant communities of these classes of biota were observed during the reef surveys at any of the study stations.

Reef Fish Community Structure

Reef fish community structure was largely determined by the topography and composition of the benthos. Transect results are presented in Table 6 and Figure 3. On individual transects, the ranges for species diversity, numbers of species, and numbers of individuals were 1.74-2.86, 20-46, and 239-616 respectively. A total of 4895 individuals representing 89 species was recorded during transect surveys. It can be seen in Figure 3 that no significant pattern is evident with respect to distribution of fish species, number and diversity with respect to depth, or station location.

The reef fish community off O'oma is typical of that found along most of the Kona Coast, as described by Hobson (I974), and Walsh (I984). Fish community structure can be divided into six general categories: juveniles, planktivorous damselfishes, herbivores, rubble-dwelling fish, swarming tetrodonts, and surge-zone fish.

Juvenile fish belonged mostly to the family Acanthuridae (surgeon fish), with representatives from the families Labridae (wrasses), Mullidae (goat fish) and Chaetodontidae (butterfly fish). Juveniles were most abundant on the deepest transects of the reef slope zone (60 feet) in areas dominated by finger coral (P. compressa), or basalt boulders. The complex habitat created by the spreading growth form of P. compressa provides shelter for small fish. Apparent storm damage to the mats of finger coral in the deep slope zone in many areas appeared to lower substantially the percentage of living finger coral. Because the coral framework was not completely flattened, habitat complexity was partially maintained in the aftermath of the storm event(s). It is apparent that fish abundance is not related directly to composition of intact living coral, but rather to the degree of shelter afforded by coralline structures, whether alive or dead.

Planktivorous damselfish, principally of the genus Chromis were abundant in all areas surveyed, and often comprised more than a quarter of the total number of individuals encountered along a transect. Agile chromis (Chromis agilis) were very abundant along the outer edge of the shelf and in deeper water, whereas blackfin chromis (C. vanderbilti) was the primary shallow water species.

Herbivores, primarily the yellow tang (lau'i-pala, Zebrasoma flavescens) and goldring surgeonfish (kole, Ctenochaetus strigosus) were also abundant. On the shallower reef terrace, adult whitebar surgeonfish (maikoiko, Acanthurus leucopareius), orangeband surgeonfish (na'ena'e, A. olivaceus), brown surgeonfish (ma'i'i'i, A. nigrofuscus) and parrotfish (uhu, Scarus spp.) were also common. In areas where coral rubble was abundant, common fish included potters angelfish (Centropyge potteri), and several species of wrasses, notably fourline wrasse (Psuedochilinus tetrataenia), eightline wrasse (P. octotaenia), and yellowtail wrasse (aki-lolo, Coris gaimard).

Surge zone fish were not quantitatively assessed because of the difficulty in working on the wave-swept basalt terraces that these fish inhabit. Visual observations, however, revealed that this biotope supported a large number of fish, principally herbivores such as rudderfish (nenue, Kyphosus bigibbus), surgeonfish (Acanthurus spp.), and unicornfish (mostly umaumalei, Naso lituratus). Saddle wrasse (hinalea lau-wili, Thallassoma trilobatum) and surge wrasse (hou, T. purpureum) were also abundant in the surge zone. Few juvenile fish were seen inhabiting the boulder zone environment. Black durgon (humuhumu-ele'ele, Melanichthys niger) and pinktail durgon (humuhumu-hi'u-kole, M. vidula) were also observed congregating in the water column over the reef platform.

Several species of "food fish" (taken by subsistence and/or recreational fishermen) were observed during the survey. Schools of several hundred individuals of goatfish (weke, Mulloidichthys flavolineatus), Hawaiian mackeral (opelu, Decapterus macarellus), and blue-lined snapper (taape, Lutjanus kasmira) were observed while diving. Numerous grand-eyed porgeys (mu, Monotaxis grandoculis) were observed. Rocky ledges and large coral heads sheltered fair numbers of squirrelfish (u'u, Myripristes berndti). Other food fishes included parrotfish (uhu, Scarus spp.), goatfish (moana kea and malu, Parupaneus cyclostomus and P. bifasciatus), jacks (papio, Caranx melamphygus), and grouper (roi, Cephalopholus argus). None of these species were particularly abundant. Orange-eyed surgeonfish (kole, Ctenochaetus strigosus), while abundant, were generally not large enough to be considered suitable as "food fish".

Overall, fish community structure at O'oma is fairly typical of the assemblages found in undisturbed Hawaiian reef environments. The presence of large schools of some food fish indicates that the area has been subjected to moderate amounts of fishing pressure, by aquarium fish collectors and fishermen.

Endangered and Protected Species

Three species of marine animals that occur in Hawaiian waters have been declared threatened or endangered by Federal jurisdiction. The threatened green sea turtle (Chelonia mydas) occurs commonly along the Kona Coast, and is known to feed on selected species of macroalgae. The endangered hawksbill turtle (Eretmochelys imbricata) is known infrequently from waters off the Kona Coast. While turtles undoubtedly occur in the nearshore areas off O'oma, no individuals were observed during the course of the present survey.

Populations of the endangered humpback whale (Megaptera novaeangliae) are known to winter in the Hawaiian Islands from December to April. The present survey was conducted in September, when whales are not present in Hawaiian waters.

CONCLUSIONS

Implementation of the proposed O'oma project would involve grading, vegetation removal, new construction, and other land use changes. There are no plans, however, for alteration of the shoreline, or offshore environments in any manner. The 1986 report describing the marine environment off of O'oma presents a detailed discussion of potential effects from activities on land, including sedimentation and changes in groundwater discharge with respect to fertilizer input. This discussion will not be repeated in the present report. In summary, the proposed project does not appear to present the potential for alteration of the offshore environments. None of the proposed development activities appears to have the potential to induce large changes in physico-chemical properties that could affect biotic community structure.

As described above, the reefs off O'oma are constantly exposed to natural stresses, primarily from storm waves, that are the major forcing function determining the make-up of reef communities. If some unexpected event related to shoreline development did occur, the resulting impact would likely be negligible in comparison to impacts caused by natural factors. Unexpected changes associated with a temporary situation of increased sedimentation during the construction phase at O'oma are not likely to result in noticeable change to the nearshore community. Observations of the response of marine ecosystems to shoreline development at Princeville on Kauai (Grigg and Dollar 1980), Keauhou Kona (Marine Research Consultants 1990a), and even Waikiki on Oahu (Marine Research Consultants 1990b) indicate that marine environments are not necessarily impacted by shoreline development.

It can be concluded that as long as reasonable steps are taken in construction practices, and operational procedures for the shoreline projects do not involve substantial changes in material delivery to the nearshore ocean, there should be no adverse impacts to the marine environment. An ongoing monitoring program is in place to assess if shoreline activities at O'oma are resulting in changes to nearshore water quality. Such changes in water quality would be indicative of potential changes to marine community structure. Thus, any changes in water quality owing to shoreline development would trigger mitigative action, hopefully at a level below that capable of inducing change in biotic structure.

SUMMARY

1. Assessment of the benthic and reef fish community structure off the proposed O'oma II Development was conducted on September 22-23, 1990. Twelve transects were evaluated at four stations located offshore of the property. Transect surveys were repeated at the same locations as a previous survey of the same region conducted in 1986.

2. Physical structure of the nearshore region consists predominantly of sandy beaches that abut rocky basaltic shorelines that form the land-sea interface. The reef area is divided into three major zones; a shallow nearshore zone characterized by basaltic boulders and substantial water motion from breaking waves, a mid-reef zone which comprises the major "reef-building area", and a deep reef slope. Substrata on the shallow and mid-reef consist predominantly of solid limestone and basalt, while substrata on the deep reef slope are predominantly sand and coral rubble.

3. In general, the coral communities off O'oma are typical of the type that occurs throughout much of the west Hawaii coastline. Sixteen coral species were encountered on transects, and total coral cover was approximately 45% of bottom cover. The dominant coral species at all sites was Porites lobata, which comprised 60% of total coral cover in both the 1986 and 1990 surveys. The three dominant coral species accounted for 93% of coral cover in 1990, and 94% in 1986.

4. Quantitative estimates indicate that coral cover ranges from about 15% to 72% on individual transects. There were, however, no consistent patterns between coral cover and reef zones at the four survey stations. It appeared that coral cover is relatively high in the shallow zones owing to the steep

shoreline cliff which absorbs wave energy. Coral cover was also relatively low at several of the deep reef slope transects owing to recent storm-induced breakage of finger coral mats.

5. Comparison of coral cover between 1986 and 1990 indicates higher cover on eleven of the twelve transects in the more recent survey. The consistent increase appears to be a result of regrowth across the entire reef following a particularly intense winter storm in 1986, which preceded the survey.

6. The other dominant benthic macrofauna are sea urchins. The most abundant urchin is Echinometra mathaei, which occurs predominantly in the shallow and mid-reef zones.

7. Reef fish community structure at O'oma is fairly typical of the assemblages found in undisturbed Hawaiian reef environments, and is characterized by six general categories: juveniles, plantivorous damselfishes, herbivores, rubble-dwellers, swarming tetrodonts, and surge-zone fishes. The presence of large schools of some food fishes indicates that the area has been subjected to low to moderate amounts of fishing pressure, both by aquarium fish collectors and fishermen.

8. It does not appear that the planned development at O'oma has the potential to cause adverse impacts to the marine environment. Stresses from natural forces that are presently the dominant factors in influencing community structure appear to be substantially greater than those that could result from shoreline development. The absence of plans to modify the shoreline or nearshore environment eliminates the potential for direct alteration of ecosystems. Secondary impacts associated with runoff of materials associated with the development do not appear to present the potential for changes based on similar, existing projects, and proper management scenarios.

REFERENCES CITED

Dollar, S. J. 1979. Ecological response to relaxation of sewage stress off Sand Island, Oahu, Hawaii. Water Resources Research Center Tech. Rpt. No. 124. Water Resources Research Center, University of Hawaii.

Dollar, S. J. 1982. Wave stress and coral community structure in Hawaii. Coral Reefs 1:71-81.

Grigg, R. W. and S. J. Dollar. 1980. Environmental impact assessment of nearshore marine life at Princeville, Kauai, Hawaii. Prepared for Princeville Development Corporation.

Grigg, R. W. and J. E. Maragos. 1974. Recolonization of hermatypic corals on submerged lava flows in Hawaii. Ecology 55:387-395.

Hobson, E. S. 1974. Feeding relationships of teleostean *fishes on coral reefs in* Kona, Hawaii. Fishery Bull. 72:915-1031.

Marine Research Consultants. 1990a. Effects of golf course irrigation and fertilization on nearshore marine waters off the West Coast of the Island of Hawaii. Prepared for Helber, Hastert and Kimura Planners.

Marine Research Consultants. 1990b. Assessment of marine community structure off Waikiki. In prep. for O. I. Consultants, Inc.

Kinzie, R. A. III and R. H. Snider. 1978. A simulation study of coral reef survey methods. In:Coral reefs: research methods. UNESCO, eds: D. R. Stoddart and R. E. Johannes.

Walsh, W. J. 1984. Aspects of nocturnal shelter, habitat space, and juvenile recruitment in the Hawaiian coral reef fishes. PhD. Dissertation, University of Hawaii, 475 pp.

TABLE 1. Marine Invertebrate occurrence at Survey stations in the vicinity of O'oma.
For station locations, see Figure 1.
Abundance code: "R" = rare (0 – 5 individuals or colonies sited on station)
"O" = occasional (5 – 20 individuals or colonies sited on station)
"C" = common (more than 20 individuals or colonies sited on station)

	TRANSECT											
	I 15'	I 30'	I 60'	II 15'	II 30'	II 60'	III 15'	III 30'	III 60'	IV 20'	IV 30'	IV 60'
SCLERACTINIA												
(Reef-Building Corals)												
Porites lobata	C	C	C	C	C	C	C	C	C	C	C	C
Porites compressa		O	C		O	C		O	C			
Porites brighami		R			R						R	R
Porites evermanni		R	R		R	R		R	R		R	R
Porites canvexa	R											
Pocillopora meandrina	C	C	C	C	C	C	C	C	C	C	C	C
Pocillopora eydouxi		R			O			R			R	
Montipora verrucosa	C	C	R	C	C	R	C	C	R	C	C	O
Montipora patula	C	O	O	O	O	O	O	O	O	O	O	O
Montipora flabellata										R		
Leptastrea purpurea	O	O		O	O		O	O		O	O	
Cyphastra ocellina	O	O	R	O	O	R	O	O	R	O	O	R
Pavona varians	R	R		R	R		R	R		R	R	
Pavona duerdeni		R			R			R			R	
Fungia scutaria												
ZOANTHINIARIA												
(Colonial "soft" corals)												
Palythoa tuberculosa	O	O	R	R	R	R	R	O	R	R	O	R
ALCYONACEA												
(Colonial "soft" corals)												
Anthelia edmondsoni	O	O	C	O	O	C	O	O	C	O	O	C
HOLOTHUROIDEA												
(Sea Cucumbers)												
Actinopyga obesa		O			O	R		O			O	
Holothuria atra	R	O	R		O	O	O	O	R	R	O	R
Holothuria nobilis		O	O		O	O	O	O	R	R	O	R
ECHINOIDEA												
(Sea Urchins)												
Diadema paucispinum		O	O		O		O	O		O	O	
Echinothrix diadema	R	C	R	R	C	R	O	C	R	O	C	R
Echinothrix calamaris		R	R	R	R			R		R	R	
Tripneustes gratilla	C	C	O	C	C	C	C	C	C	C	C	C
Echinometra mathaei	C	C	C	C	C	C	C	C	C	C	C	C
Echinometra oblonga	C	O		C			C	C		C	C	
Echinostrephus aciculatus	C	R	R	C	R		C	R		C	R	
Heterocentrotus mammillatus	C	C	C	C	C	C	C	C	C	C	C	C
ASTEROIDEA												
(Starfish)												
Linckia multifora		R			R							
Linckia diplax		R				R				R		
Acanthaster planci	R	R			R			R			R	
MOLLUSCS												
Spondylus tenebrosus		R		R			R			R	R	
PORIFERA												
Iotrocha protea		C			C			C			C	
misc. sponges	C	C	C	C	C	C	C	C	C	C	C	C

TABLE 2. Coral species percent cover, non-coral substrata cover, and coral community statistics for transects off O'oma in 1990. For transect station locations, see Figure 1.

	TRANSECT											
CORAL SPECIES	I 15'	I 30'	I 60'	II 15'	II 30'	II 60'	III 15'	III 40'	III 60'	IV 20'	IV 30'	IV 60'
Porites lobata	7.5	27.1	24.8	35.3	45.6	21.1	3.5	18.8	18.7	22.9	23.8	21.6
Porites compressa		0.5	37.9			19.6			2.3			2.6
Porites brighami											0.3	0.6
Porites evermanni												0.1
Pocillopora meandrina	3.2	0.4	1.5	2.8	0.1		18.4	26.8	1.7	15.1	14.6	0.1
Montipora patula	1.9	0.4	0.1					1.0		0.4	0.4	
Montipora verrucosa	1.6	1.0		2.3	0.4		0.2	0.7	0.1	0.3	0.3	0.6
Montipora flabellata										0.3		
Pavona varians								0.6	0.2			
Leptastrea purpurea	1.1	0.2		0.1	0.2	0.1		0.4		0.1	0.3	
Pavona duerdeni										1.1		
Palythoa tuberculosa	0.1			1.2			0.2	0.2				
Porites canvexa	0.1											
Anthelia edmondsoni		0.2	7.7				1.5					
Cyphastrea ocellina					0.4		0.1				0.2	
Fungia scutaria									0.1			
TOTAL CORAL COVER	15.5	29.8	72.0	41.7	46.7	40.8	23.9	48.5	23.1	40.2	39.9	25.6
NUMBER OF SPECIES	7	7	5	5	5	3	6	7	6	7	7	6
CORAL COVER DIVERSITY	1.42	0.45	1.03	0.59	0.21	0.71	0.79	0.95	0.68	0.92	0.86	0.59
NON-CORAL SUBSTRATA												
Limestone	2.5	6.4	2.5	1.2	4.5	2.5	2.4	4.8	1.4	14.3	24.3	14.0
Sand		1.3	6.5		11.6	24.5		3.4	9.3		3.1	13.0
Basalt	80.4	59.8		57.1	35.8	1.5	72.3	41.0	17.5	45.5	31.4	
Rubble	1.6	2.7	19.0		1.4	30.7	1.4	2.3	48.7		1.3	47.4

TABLE 3. Coral species percent cover, non-coral substrata cover, and coral community statistics for transects off O'oma in 1986. For transect station locations, see Figure 1.

	TRANSECT											
CORAL SPECIES	I 15'	I 30'	I 60'	II 15'	II 30'	II 60'	III 15'	III 40'	III 60'	IV 20'	IV 30'	IV 60'
Porites lobata	19.3	11.2	4.4	20.2	13.7	24.8	14.9	3.0	14.5	9.7	8.7	4.2
Porites compressa			31.2	0.6	1.6	10.0		1.5	4.3			1.1
Pocillopora meandrina	0.1	0.4	0.6	0.6	1.5	1.8	7.6	1.2	0.7	1.7	15.3	1.4
Montipora patula	0.2				0.2							
Montipora verrucosa	0.2			0.1	0.1		0.2			0.6	0.1	0.1
Pavona varians				0.1						0.1		
Leptastrea purpurea		2.1	0.2				0.1			0.7		0.1
Anthelia edmondsoni		2.1	4.1			1.6			1.1			0.1
TOTAL CORAL COVER	19.8	15.8	40.5	21.6	17.1	38.2	22.8	5.7	20.6	12.8	24.1	7.0
NUMBER OF SPECIES	4	4	5	5	5	4	4	3	4	5	3	6
CORAL COVER DIVERSITY	0.14	0.84	0.76	0.31	0.69	0.90	0.78	1.02	0.85	0.77	0.63	1.10
NON-CORAL SUBSTRATA												
Limestone	21.0	2.4	0.0	24.9	10.0	8.3	10.8	5.7	11.2	4.3	2.3	0.0
Sand				30.0		6.5			9.7			
Basalt	52.3	35.4	59.5	23.5	28.7		77.2	13.3	1.1	63.4	64.2	38.6
Rubble	6.9	50.9	59.5		27.5	47.5	10.0	70.2	57.4	23.9	10.8	54.5

TABLE 4. Differences in coral community parameters between 1986 and 1990 reef transects at O'oma.

	TRANSECT											
	I 15'	I 30'	I 60'	II 15'	II 30'	II 60'	III 15'	III 40'	III 60'	IV 20'	IV 30'	IV 60'
TOTAL CORAL COVER												
1990	15.5	29.8	72.0	41.7	46.7	40.8	23.9	48.5	23.1	40.2	39.9	25.6
1886	19.8	15.8	40.5	21.6	17.1	38.2	22.8	5.7	20.6	12.8	24.1	7.0
DIFFERENCE	−4.3	14	31.5	20.1	29.6	2.6	1.1	42.8	2.5	27.4	15.8	18.6
NUMBER OF SPECIES												
1990	7	7	5	5	5	3	6	7	6	7	7	6
1886	4	4	5	5	5	4	4	3	4	5	3	6
DIFFERENCE	3	3	0	0	0	−1	2	4	2	2	4	0
CORAL COVER DIVERSITY												
1990	1.42	0.45	1.03	0.59	0.21	0.71	0.79	0.95	0.68	0.92	0.86	0.59
1886	0.14	0.84	0.76	0.31	0.69	0.90	0.78	1.02	0.85	0.77	0.63	1.10
DIFFERENCE	1.27	−0.3	0.26	0.27	−0.4	−0.1	0.01	−0.0	−0.1	0.14	0.22	−0.5

TABLE 5. Sea urchin abundance on benthic transects off O'oma. For transect station locations, see Figure 1.

SEA URCHIN SPECIES	TRANSECT I 15'	I 30'	I 60'	II 15'	II 30'	II 60'	III 15'	III 40'	III 60'	IV 20'	IV 30'	IV 60'
Echinometra matheai	34	71	7	65	102	5	36	6	14	4	135	17
Echinostrephus aciculatus	12	32		3			6	1				14
Heterocentrotus mammillatus		1	1	1	1	2	1		1	1	1	
Tripneustes gratilla	3	6		5	4		1		1	6	1	4
Echinothrix diadema												
Echinothrix calamaris					1			1				3
TOTAL URCHIN COUNT	49	110	8	74	107	7	44	7	16	11	137	35

TABLE 6. Reef fish abundance on transects off O'oma.

FAMILY Species	TRANSECT I 15'	 I 30'	 I 60'	 II 15'	 II 30'	 II 60'	 III 15'	 III 40'	 III 60'	 IV 20'	 IV 30'	 IV 60'
MYLIOBATIDAE												
Aetobatus narinari						1						
MURAENIDAE												
Gymnothorax meleagris	1											
AULOSTOMIDAE												
Aulostomus chinensis		2				1						
KYPHOSIDAE												
Kyphosus bigibbus	10						18					
CIRRHITIDAE												
Cirrhitops fasciatus	2						2			2		
Cirrhitus pinnulatus										1		
Paracirrhites arcatus		1	4	2		2		2	2	3	2	
MULLIDAE												
Mulloides flavolineatus			40									8
Parupeneus multifasciatus	6	3	7	9	8	5	6	9	2	7	6	3
P. pleurostigma					1	2						
P. bifasciatus	2						15		1	12		
P. porphyreus							2					
P. cyclostomus											10	
SERRANIDAE												
Cephalopholis argus								1	1	3	1	
CARANGIDAE												
Caranx melamphygus	1							1			1	
LUTJANIDAE												
Lutjanus kasmira						20	2	6		8		
Aprion virescens									1			
Aphareus furcatus									2			

TABLE 6. continued

FAMILY Species	I 15'	I 30'	I 60'	II 15'	II 30'	II 60'	III 15'	III 40'	III 60'	IV 20'	IV 30'	IV 60'
						TRANSECT						
LETHRINIDAE												
Monotaxis grandoculis						7			6	8		
CHAETODONTIDAE												
Chaetodon lunula		2	2				2			2		
C. quadrimaculatus	2	1		2	4		2	4	2			
C. miliaris					2				3			
C. ornatissimus	2					2			2			2
C. multicinctus	4	5		2	4	8		6	6	6	8	6
C. fremblii				1								
C. kleinii									3			
C. auriga				2								
C. lineolatus	2									2		
Forcipiger flavissimus	4		3	2	1	8	7	3	4		2	6
Heniochus diphreutes						2			15			
Hemtaurichthys polylepis									30			
POMACANTHIDAE												
Centropyge potteri			2			1			4			
C. fisheri									2			
POMACENTRIDAE												
Abudefduf abdominalis							15			25	15	
A. sordidus							3					
Plectro. johnstonianus					1						1	
P. imparipennis	3	1		2	1					3		
Stegastes fasciolatus					2		2					
Dascyllus albisella			3			35			12			20
Chromis agilis			400		12	112			60		30	210
C. hanui			30			5			10		11	30
C. vanderbilti	60	150		80	120			150	120	90	70	
C. ovalis			100									

TABLE 6. continued

FAMILY Species	I 15'	I 30'	I 60'	II 15'	II 30'	II 60'	III 15'	III 40'	III 60'	IV 20'	IV 30'	IV 60'
						TRANSECT						
LABRIDAE												
Novaculichthys taeniourus						1			2			
Cheilinus unifasciatus												1
Cheilinus bimaculatus			3			1			2			
Pseudocheilinus octotaenia			2			1			2			
Coris gaimard		3		1		2		2	2	2		
C. venusta					1							
C. flavovittata										4		
Thalassoma duperrey	12	12	6	10	7	7	10	16	7	21	13	21
T. trilobatum									1			
Gomphosus varius	2							3	3		4	
Labroides phthirophagus			1	1								
Macropharyngodon geoffroy			1									
Pseudojuloides cerasinus									2		1	2
Stethojulis balteata					1			3			1	
Halichoeres ornatissimus		1	1	3	1				1		1	1
SCARIDAE												
Scarus sordidus			2			4			2	2		2
S. perspicillatus			2	2				2		4		
S. rubroviolaceus									3			
juvenile Scarus				12		3			8	16		
ACANTHURIDAE												
Zebrasoma flavescens	45	13	44	14	9	28	40	24	17	95	33	32
Acanthurus achilles				1	2		35		2	25		
A. triostegus				4								
A. guttatus	30						15					
A. leucopareius	55			8			140			90		
A. thompsoni									40			78
A. olivaceus	22	7	3	14	6	6		7	3		1	
A. dussumieri	10						7					
A. blochii		5		8					2			
A. nigrofuscus	70	35		30	25	11	40	20		80	50	12
Ctenochaetus strigosus	15	8	48		15	70		25	20	65	54	43
C. hawaiiensis						2	2	4				

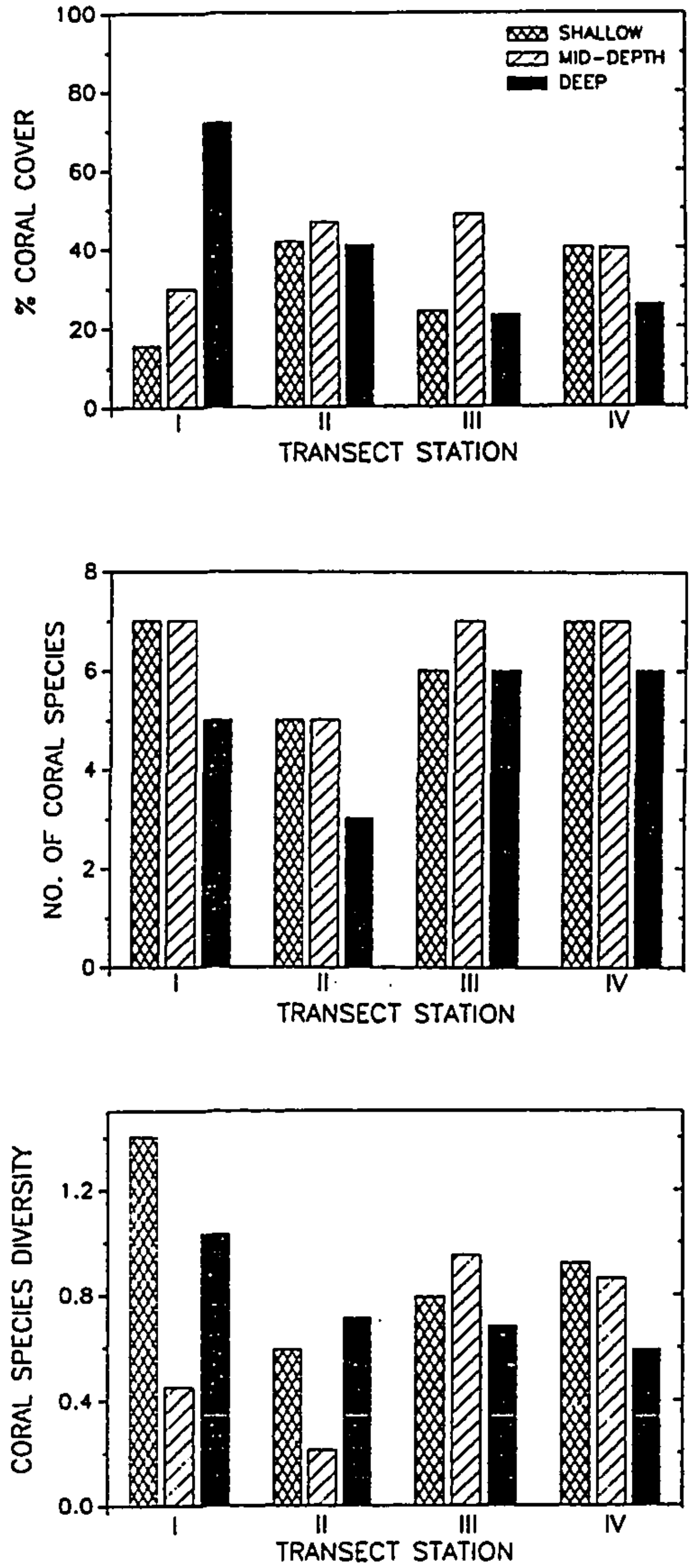

FIGURE 2. Histograms showing percent coral cover, number of coral species, and coral species diversity on transects off the O'oma site.

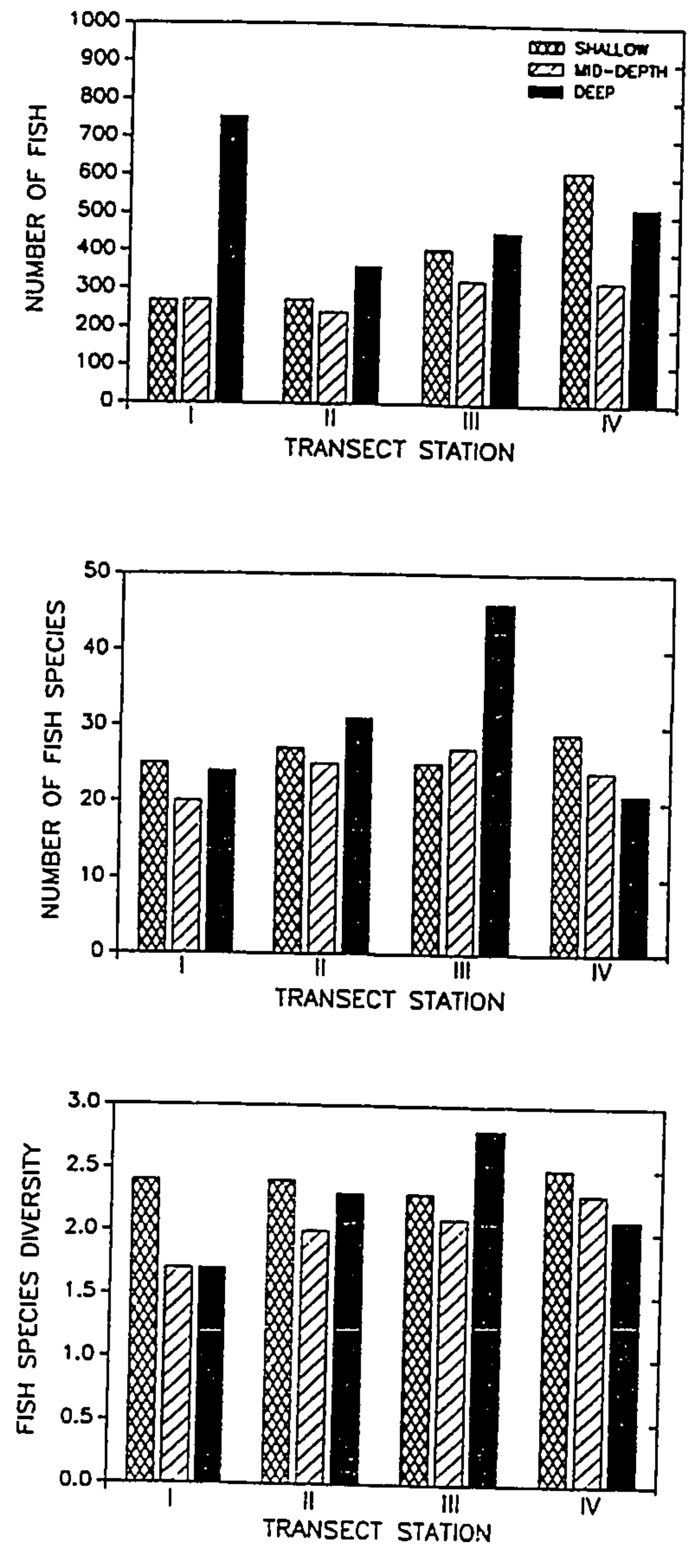

FIGURE 3. Histograms showing number of fish, number of fish species, and fish species diversity on transects off the O'oma site.

APPENDIX A. Coral transect data.

REEF CORAL TRANSECT DATA SHEET
(PERCENT COVER)

TRANSECT SITE:	OOMA	MEAN CORAL COVER	15.5 %
TRANSECT ID #:	1-15'	STD. DEV.	9.7
DATE:	08/26/90	SPECIES COUNT	7
		SPECIES DIVERSITY	1.421

SPECIES	QUADRAT										SPECIES TOTAL
	1	2	3	4	5	6	7	8	9	10	
Porites lobata	12.0	10.0	24.0	5.0		13.0	3.0	5.0		3.0	75.0
Pocillopora meandrina		1.0					3.0	6.0	16.0	6.0	32.0
Montipora verrucosa			12.0	4.0							16.0
Montipora patula		5.0		8.0	2.0				3.0	1.0	19.0
Leptastra purpurea		3.0							8.0		11.0
Palythoa tuberculosa	1.0										1.0
Porites canvexa			1.0								1.0
QUADRAT TOTAL	13.0	19.0	37.0	17.0	2.0	13.0	6.0	11.0	27.0	10.0	155.0

REEF CORAL TRANSECT DATA SHEET
(PERCENT COVER)

TRANSECT SITE:	OOMA	MEAN CORAL COVER	29.8 %
TRANSECT ID #:	1-30'	STD. DEV.	7.6
DATE:	08/26/90	SPECIES COUNT	7
		SPECIES DIVERSITY	0.451

SPECIES	QUADRAT										SPECIES TOTAL
	1	2	3	4	5	6	7	8	9	10	
Porites lobata	26.0	30.0	23.0	29.0	43.0	27.0	18.0	19.0	27.0	29.0	271.0
Porites compressa					5.0						5.0
Pocillopora meandrina		1.0		2.0					1.0		4.0
Montipora verrucosa	1.0	2.0		3.0		2.0	2.0				10.0
Montipora patula			2.0	1.0						1.0	4.0
Leptastra purpurea							2.0				2.0
Anthelia edmondsoni						2.0					2.0
QUADRAT TOTAL	27.0	33.0	25.0	35.0	48.0	31.0	22.0	19.0	28.0	30.0	298.0

APPENDIX A. Coral transect data.

REEF CORAL TRANSECT DATA SHEET
(PERCENT COVER)

TRANSECT SITE:	OOMA	MEAN CORAL COVER	72 %
TRANSECT ID #:	I-60'	STD. DEV.	24.9
DATE:	08/26/90	SPECIES COUNT	5
		SPECIES DIVERSITY	1.033

SPECIES	QUADRAT										SPECIES
	1	2	3	4	5	6	7	8	9	10	TOTAL
Porites lobata	12.0	6.0	6.0	2.0	6.0	63.0	61.0	15.0	4.0	73.0	248.0
Porites compressa	26.0	85.0	5.0	56.0	73.0		26.0	35.0	62.0	11.0	379.0
Pocillopora meandrina		3.0			1.0		3.0			8.0	15.0
Montipora patula									1.0		1.0
Anthelia edmondsoni	21.0			30.0		26.0					77.0
QUADRAT TOTAL	59.0	94.0	11.0	88.0	80.0	89.0	90.0	50.0	67.0	92.0	720.0

APPENDIX A. Coral transect data.

REEF CORAL TRANSECT DATA SHEET
(PERCENT COVER)

TRANSECT SITE:	OOMA	MEAN CORAL COVER	41.7 %
TRANSECT ID #:	II-15'	STD. DEV.	16.0
DATE:	08/26/90	SPECIES COUNT	5
		SPECIES DIVERSITY	0.598

SPECIES	QUADRAT										SPECIES
	1	2	3	4	5	6	7	8	9	10	TOTAL
Porites lobata	36.0	25.0	21.0	42.0	32.0	36.0	43.0	54.0	52.0	12.0	353.0
Pocillopora meandrina						6.0			19.0	3.0	28.0
Montipora verrucosa		18.0				3.0	2.0				23.0
Leptastra purpurea								1.0			1.0
Palythoa tuberculosa						12.0					12.0
QUADRAT TOTAL	36.0	43.0	21.0	42.0	32.0	57.0	45.0	55.0	71.0	15.0	417.0

REEF CORAL TRANSECT DATA SHEET
(PERCENT COVER)

TRANSECT SITE:	OOMA	MEAN CORAL COVER	46.7 %
TRANSECT ID #:	II-30'	STD. DEV.	21.7
DATE:	08/26/90	SPECIES COUNT	6
		SPECIES DIVERSITY	0.209

SPECIES	QUADRAT										SPECIES
	1	2	3	4	5	6	7	8	9	10	TOTAL
Porites lobata	43.0	24.0	61.0	46.0	51.0	81.0	6.0	52.0	55.0	31.0	450.0
Porites evermanni						6.0					6.0
Pocillopora meandrina						1.0					1.0
Montipora verrucosa			1.0		1.0	2.0					4.0
Leptastra purpurea		1.0				1.0					2.0
Cyphastrea ocellina		1.0	1.0	1.0	1.0						4.0
QUADRAT TOTAL	43.0	26.0	63.0	47.0	53.0	91.0	6.0	52.0	55.0	31.0	467.0

APPENDIX A. Coral transect data.

REEF CORAL TRANSECT DATA SHEET
(PERCENT COVER)

TRANSECT SITE:	OOMA	MEAN CORAL COVER	45.5 %
TRANSECT ID #:	II-60	STD. DEV.	25.2
DATE:	08/26/90	SPECIES COUNT	3
		SPECIES DIVERSITY	0.707

SPECIES	QUADRAT										SPECIES TOTAL
	1	2	3	4	5	6	7	8	9	10	
Porites lobata	60.0	6.0	46.0	12.0	3.0	36.0	6.0	21.0	21.0	29	211.0
Porites compressa	21.0		12.0	14.0	24.0	14.0	31.0	72.0	8.0	18	196.0
Leptastra purpurea										1.0	1.0
QUADRAT TOTAL	81.0	6.0	58.0	26.0	27.0	50.0	37.0	93.0	29.0	48.0	408.0

APPENDIX A. Coral transect data.

REEF CORAL TRANSECT DATA SHEET
(PERCENT COVER)

TRANSECT SITE:	OOMA	MEAN CORAL COVER	23.9 %
TRANSECT ID #:	III-15'	STD. DEV.	7.5
DATE:	08/26/90	SPECIES COUNT	7
		SPECIES DIVERSITY	0.791

SPECIES	QUADRAT										SPECIES TOTAL
	1	2	3	4	5	6	7	8	9	10	
Porites lobata	2.0	4.0	1.0	3.0		14.0	2.0	5.0	1.0	1.0	33.0
Porites evermanni	1.0						1.0				2.0
Pocillopora meandrina	21.0	26.0	16.0	26.0	24.0		18.0	19.0	14.0	20.0	184.0
Montipora verrucosa	1.0						1.0				2.0
Cyphastrea ocellina					1.0						1.0
Palythoa tuberculosa	1.0						1.0				2.0
Anthelia edmondsoni					15.0						15.0
QUADRAT TOTAL	26.0	30.0	17.0	29.0	40.0	14.0	23.0	24.0	15.0	21.0	239.0

REEF CORAL TRANSECT DATA SHEET
(PERCENT COVER)

TRANSECT SITE:	OOMA	MEAN CORAL COVER	48.5 %
TRANSECT ID #:	III-40'	STD. DEV.	24.0
DATE:	08/26/90	SPECIES COUNT	7
		SPECIES DIVERSITY	0.952

SPECIES	QUADRAT										SPECIES TOTAL
	1	2	3	4	5	6	7	8	9	10	
Porites lobata	16.0	26.0	8.0	4.0	8.0	27.0	18.0	4.0	46.0	31.0	188.0
Pocillopora meandrina	42.0	53.0	15.0	6.0	6.0	38.0	21.0	46.0	12.0	29.0	268.0
Montipora verrucosa		5.0		1.0			1.0				7.0
Montipora patula					2.0				7.0	1.0	10.0
Pavona varians									6.0		6.0
Leptastra purpurea									4.0		4.0
Palythoa tuberculosa									2.0		2.0
QUADRAT TOTAL	58.0	84.0	23.0	11.0	16.0	65.0	40.0	50.0	77.0	61.0	485.0

APPENDIX A. Coral transect data.

REEF CORAL TRANSECT DATA SHEET
(PERCENT COVER)

TRANSECT SITE:	OOMA	MEAN CORAL COVER	23.1 %
TRANSECT ID #:	III-60'	STD. DEV.	10.5
DATE:	08/26/90	SPECIES COUNT	6
		SPECIES DIVERSITY	0.681

SPECIES	QUADRAT										SPECIES
	1	2	3	4	5	6	7	8	9	10	TOTAL
Porites lobata	31.0	2.0	5.0	31.0	17.0	12.0	12.0	27.0	24.0	26.0	187.0
Porites compressa		2.0					14.0		2.0	5.0	23.0
Pocillopora meandrina	1.0	2.0	2.0						10.0	2.0	17.0
Montipora verrucosa								1.0			1.0
Pavona varians			1.0	1.0							2.0
Fungia scutaria		1.0									1.0
QUADRAT TOTAL	32.0	7.0	8.0	32.0	17.0	12.0	26.0	28.0	36.0	33.0	231.0

APPENDIX A. Coral transect data.

REEF CORAL TRANSECT DATA SHEET
(PERCENT COVER)

TRANSECT SITE:	OOMA	MEAN CORAL COVER	40.2 %
TRANSECT ID #:	IV-20'	STD. DEV.	15.1
DATE:	08/26/90	SPECIES COUNT	7
		SPECIES DIVERSITY	0.920

SPECIES	QUADRAT										SPECIES TOTAL
	1	2	3	4	5	6	7	8	9	10	
Porites lobata	32.0	12.0	16.0	46.0	10.0	24.0	26.0	6.0	13.0	44.0	229.0
Pocillopora meandrina	26.0	17.0		21.0	31.0		14.0	24.0	14.0	4.0	151.0
Montipora verrucosa						3.0					3.0
Montipora patula							4.0				4.0
Montipora flabellata								3.0			3.0
Pavona duerdeni									3.0	8.0	11.0
Leptastra purpurea			1.0								1.0
QUADRAT TOTAL	58.0	29.0	17.0	67.0	41.0	27.0	44.0	33.0	30.0	56.0	402.0

REEF CORAL TRANSECT DATA SHEET
(PERCENT COVER)

TRANSECT SITE:	OOMA	MEAN CORAL COVER	39.9 %
TRANSECT ID #:	IV-30	STD. DEV.	24.6
DATE:	08/26/90	SPECIES COUNT	7
		SPECIES DIVERSITY	0.859

SPECIES	QUADRAT										SPECIES TOTAL
	1	2	3	4	5	6	7	8	9	10	
Porites lobata	17.0	8.0	16.0	19.0	8.0	21.0	51.0	38.0	18.0	42.0	238.0
Porites brighami				3.0							3.0
Pocillopora meandrina	5.0		6.0		16.0	24.0	19.0	52.0	14.0	10.0	146.0
Montipora verrucosa	1.0		2.0								3.0
Montipora patula					2.0				2.0		4.0
Leptastra purpurea								2.0		1.0	3.0
Cyphastrea ocellina								1.0		1.0	2.0
QUADRAT TOTAL	23.0	8.0	24.0	22.0	26.0	45.0	70.0	93.0	34.0	54.0	399.0

APPENDIX A. Coral transect data.

REEF CORAL TRANSECT DATA SHEET
(PERCENT COVER)

TRANSECT SITE: OOMA
TRANSECT ID #: IV-60
DATE: 08/26/90

MEAN CORAL COVER 25.6 %
STD. DEV. 6.4
SPECIES COUNT 6
SPECIES DIVERSITY 0.594

SPECIES	QUADRAT										SPECIES TOTAL
	1	2	3	4	5	6	7	8	9	10	
Porites lobata	21.0	12.0	21.0	26.0	28.0	32.0	22.0	18.0	19.0	17.0	216.0
Porites compressa	2.0	1.0	3.0	4.0	7.0			3.0	3.0	3.0	26.0
Porites brighami							6.0				6.0
Porites evermanni						1.0					1.0
Pocillopora meandrina	1.0										1.0
Montipora verrucosa	2.0			2.0					2.0		6.0
QUADRAT TOTAL	26.0	13.0	24.0	32.0	35.0	33.0	28.0	21.0	24.0	20.0	256.0

APPENDIX E

EFFECTS OF GOLF COURSE IRRIGATION AND FERTILIZATION

Marine Research Consultants

EFFECTS OF GOLF COURSE IRRIGATION AND FERTILIZATION ON NEARSHORE MARINE WATERS OFF THE WEST COAST OF THE ISLAND OF HAWAII

Prepared for

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November 14, 1990

INTRODUCTION

Purpose

With the recent increase in planning for shoreline developments in West Hawaii, the potential for detrimental impacts to nearshore marine is currently a subject of substantial controversy. Integral to many of the planned developments is the construction of golf courses. All of the planned courses will require application of fertilizers to sustain optimal turf growth. In some cases, such fertilization will utilize treated sewage effluent, generated from on-site facilities. Such effluent, owing to the lack of industrial wastes, consists essentially of organic carbon, nitrogen and phosphorus. In situations where treated sewage effluent is not used, agricultural fertilizers will be applied to promote optimal grass conditions.

The possibility exists that fertilizers applied in excess of the uptake capacity of the plant-soil complex will leach to groundwaters, and subsequently cause changes in the chemical properties of nearshore marine and anchialine pond waters, and cause changes to associated biotic communities. Particular concern is focused on planned developments in the vicinity of Keahole Point, the site of the Natural Energy Laboratory of Hawaii (NELH), and the Hawaii Ocean Science and Technology (HOST) Park. These facilities require pristine warm and cold ocean waters, and any factors with the potential to influence oceanic water quality should be carefully considered.

The O'oma II Development is a proposed project on a 300-acre site located on the West Hawaii shoreline between Kailua-Kona and the Keahole Airport. The proposed plan includes various land uses including a golf course and marine education and recreational complex. Maintenance of the existing pristine nature of the marine environments fronting O'oma is a requisite of the project. Thus, it is important to address all questions regarding the potential for negative effects to water quality and biological community structure from construction and operation of the project, and especially the golf course. Because O'oma is located adjacent to NELH and the HOST Park, attention is also focused on the potential for negative effects to water quality that may impinge on the Keahole Point area.

In February of 1988, a report entitled "The Effects of Golf Course Irrigation and Fertilization on Nearshore Marine Waters off West Hawaii" was prepared by Marine Research Consultants. The purpose of this study was to address the effects of golf course operation on nonpoint source discharge of groundwater and subsequent effects to the marine environment. The major objective of this study was to answer two questions: 1) what proportion of the "upstream" (landward) concentration of sewage-fertilizer material was added to groundwater by the time the flow reached the shoreline, and 2) if there was augmentation to groundwater, what happened to the terrigenous (derived from land) input in the nearshore environment (between the shoreline and "true" oceanic conditions)? With respect to the first objective, the role of the land margin was defined as a "source" or "sink" for materials applied to golf courses. With respect to the second question, were nutrients released from land taken up within the nearshore zone (potentially altering biotic structure and function), or were these nutrients passively diffused offshore?

The investigative strategy for the study was based on assessing the effects from four existing golf courses in West Hawaii (Mauna Kea, Mauna Lani, Waikoloa, and Keauhou). Several of the existing courses also had been using treated sewage effluent for fertilization/irrigation for several years. Thus, evaluating the magnitude of impacts from actual situations provided the basis of a "long-term experiment" that was used to make valid estimates of the potential effects of the future developments.

In July of 1989, a second study was prepared to repeat a portion of the 1988 sampling program. Assessment of inputs to the marine environment from two of the golf courses (Keauhou and Waikoloa) that are fetilized with treated sewage effluent was conducted to augment the data base of the earlier survey.

The present study constitutes the third investigation of the West Hawaii golf courses. The four courses that were the subject of the initial investigation were reexamined in September of 1990. The purpose of the 1990 study is to establish if the results obtained in the previous surveys remain unchanged, or if there have been measurable changes in the intervening years. The results of the 1988, 1989, and 1990 surveys provide a basis for evaluating the potential impacts to nearshore marine waters from the planned O'oma golf course.

Sampling Sites

The four investigative sites are in the vicinity of existing golf courses in the North Kona-South Kohala region. Moving south to north, the golf course at Keauhou utilizes secondary treated sewage from a County-owned wastewater treatment plant to irrigate the entire acreage. Treated effluent is pumped uphill to several holding reservoirs prior to irrigation. This procedure has been employed at Keauhou for approximately 20 years. An additional 9 holes were added in 1985 to the original I8-hole course. Keauhou Bay, which is surrounded by the golf course, extends about 500 meters (m) inland from the open ocean.

The Waikoloa Beach Golf Course is approximately 10 years old and presently is irrigated with effluent from a treatment plant on site. Owing to a thin soil layer that promotes rapid percolation of water, rates of sewage effluent irrigant have been higher than normal at Waikoloa (T. Nance, personal communication). The Waikoloa Kings Course, which opened in 1989, is located adjacent to the older course. Directly downslope from the Waikoloa Golf courses is a series of "anchialine" ponds. These ponds do not have any surface connection with the ocean, and contain brackish water that is a mixture of seaward flowing groundwater and shoreward diffusing seawater. As these ponds receive input of materials percolating to groundwater, it was deemed necessary to sample water from the ponds as well as the open ocean directly fronting the golf courses.

The Mauna Lani golf course has been operational for approximately 10 years, and is presently employing commercial fertilizer mixes only. The golf course surrounds Pauoa Bay, a small crescent-shaped indentation in the basaltic coastline. Recently, the Ritz-Carlton Hotel was constructed on the shoreline of Pauoa Bay. Water samples from Pauoa Bay, extending from the shoreline to the open ocean constituted the sampling scheme for this area. It should be noted that Pauoa Bay was not sampled in the previous surveys.

The golf course at the Mauna Kea Beach Hotel has been operational for about 25 years. Presently, sewage effluent from a secondary treatment plant on the resort property is not being applied to the course acreage. Effluent is passed through ponds filled with vegetation as a natural filter, and is subsequently used to irrigate plants at a nursery on the treatment plant site. The Mauna Kea course lies directly upslope from Kaunaoa Bay, which can be described as a crescent-shaped indentation in the shoreline bounded by basaltic projections at either end. Sampling to determine the inputs from the Mauna Kea course was conducted at the borders of Kaunaoa Bay where groundwater input was most evident.

MATERIALS AND METHODS

Hydrographic Model

The approach used in this analysis employed a standard hydrographic model that relates the concentration of any material in question to conservative mixing. Based on these relationships, it is possible to quantify the degree of material removal, or subsidy, within the system under study. Such an approach is commonly used to evaluate the chemical behavior of estuaries or other bodies of water that typically exhibit a strong gradient in salinity.

The present investigation employs a modification of the one-dimensional hydrographic model as presented by Kaul and Froelich (1984), Officer (1979), and Smith, et al. (1987). Hypothetical graphical representations of the model are shown in Figure 2. Quantitatively, the essence of the model is based on simple mixing. If waters of two different compositions are mixed, relative admixtures should produce straight lines on 2-dimensional plots. It follows that plots of any material Y versus salinity should yield straight lines if only mixing is involved. On a salinity versus Y plot, deviation of Y from the straight line between end members implies some additional source or sink of material.

Derivation of the mixing model is presented in the 1988 and 1989 reports and will not be repeated. Based on the mixing model, the equation to calculate flux (Ry) of material (Y) to the ocean is:

$$R_y = F * [Y_o - Y_f - (S_o * dY/dS)]$$

where F is flux of water from land to the ocean. In the case of West Hawaii, rainfall, evaporation, and stream flow are small relative to groundwater (F). Salinity is represented as S, and the subscripts "o" and "f" denote the composition of the ocean and groundwater flow, respectively.

Water Sampling

Water samples were collected at each of the four sites over the widest possible salinity range during September of 1990. The sampling strategy was to get both a wide salinity range, to "spread" the salinity-Y plots, and to infill the plots with intermediate salinity points. Groundwater endpoint samples were collected from existing wells located from "above" the golf courses. At Waikoloa, where anchialine ponds were present, water samples were collected over a spatial range with respect to distance from the shoreline.

Ocean water samples were collected from the shoreline in areas where groundwater seepage was evident, and seaward to distances of approximately 100 m from the shoreline. Ocean endpoint samples were collected a distance offshore deemed to be beyond major influence of groundwater. All ocean sampling was conducted in embayments, as these areas are often sites of increased groundwater discharge. Thus, sampling was conducting in Keauhou Bay, Anaehoomalu Bay (Waikoloa), Pauoa Bay (Mauna Lani), and Kaunaoa Bay (Mauna Kea). In all, 159 water samples were collected and utilized in the analysis.

Water samples were collected in 1-liter polyethylene containers; subsamples for dissolved nutrient analyses were immediately filtered through glass-fiber filters into triple-rinsed, acid-cleaned, 125-milliliter polyethylene bottles. Subsamples for dissolved nitrogen and phosphorus were immediately frozen on dry ice, while subsamples for dissolved silica were chilled, but not frozen. Salinity of each sample was determined in the field using a hand-held refractometer with readability of 0.5 ^{o}/oo. In the laboratory, salinity was determined to 0.0001 using an AGE salinometer.

Dissolved inorganic analyses for NO_3^- + NO_3^-, NH_4^+, PO_4^{3-} and Si were performed using manual spectrophotometric techniques on a fiber-optic colorimeter. All chemistry procedures followed standard methods for seawater analysis (Strickland and Parsons 1968).

RESULTS AND DISCUSSION

Summary of 1988 and 1989 Results

The overall strategy employed in the original 1988 study was based on the supposition that existing golf courses, located in similar hydrogeological settings and irrigated in a similar fashion as planned courses, present valid representations of the expected behavior of the planned courses. Thus, assessment of the effects to nearshore water quality from existing courses was assumed to be indicative of the effects to be expected in the future.

Four existing golf courses were sampled and assessments were made using the hydrographic mixing model described above. It was found that in all cases, Si exhibited essentially conservative mixing properties along the range of salinity from groundwater to open ocean water. Such conservative mixing indicated that this material was not added, or removed, from the system except by physical dispersive mixing. PO_4^{3-} showed similar behavior at all sites without anchialine ponds. There was no addition of PO_4^{3-} from golf course irrigants to the nearshore ocean at any of the sites.

Golf courses that were shoreward of open coastal areas, and were using either no sewage effluent for irrigation, or only effluent generated by the resort, did not provide an external source of nitrogen to the nearshore waters, even when the courses were over-irrigated, as occurred at Waikoloa.

The situation at Keauhou was considerably different. Dissolved N concentrations were greater than would be expected with conservative mixing. Such deviation from the groundwater-to-ocean mixing line indicated an external source term for dissolved nitrogen. It also appeared that there was no indications of altered biological processes as a result of the additional input. The replicability of the data between 1989 and 1990 appears to indicate that the observed nonconservative behavior was not a result of sampling error, or an "unusual" event.

In 1988, in order to determine if the nonconservative behavior of DIN was restricted to Keauhou Bay, or if the pattern was characteristic of the entire shoreline fronting the Keauhou golf course, a set of samples was collected in the ocean directly offshore of the Keauhou sewage treatment plant. There was no indication of nonconservative behavior of DIN near the open ocean shoreline. This result indicated that non-conservative behavior within Keauhou Bay was a function of groundwater focusing and reduced circulatory exchange. It is also important to note that it does not appear that the sewage treatment plant located on the shoreline at Keauhou was contributing any nutrient subsidy to nearshore waters.

Results of 1990 Analyses

Figures 2-5 show concentrations of dissolved Si, NO_3^- and PO_4^{3-} as functions of salinity from samples collected offshore of the four existing golf courses in West Hawaii. NO_3^- is shown, as this is the form of dissolved nitrogen that has the most potential to leach to groundwater owing to a low binding affinity in soils (Murdoch and Green 1989). Also shown on each plot are conservative mixing lines constructed by connecting endpoint concentrations from well water samples located upslope of each golf course, and from the open ocean fronting each course.

It can be seen in each of the figures that the data points on plots of Si as functions of salinity produce virtually straight lines in all cases. In addition, the data lines fall very close to the conservative mixing lines. Such agreement indicates that the groundwater entering the ocean off the golf courses is essentially the same groundwater that is sampled from the upland wells. In addition, the match of the data line and the conservative mixing line indicates that Si is behaving conservatively; there is no substantial uptake or removal of this material between the site of well samplings and the open ocean. Thus, this material can be considered a conservative tracer in the systems under study.

Examination of the plots of PO_4^{3-} as functions of salinity reveals some variation between sampling sites. At Mauna Kea (Figure 2) and Mauna Lani (Figure 3), PO_4^{3-} concentrations fall on or near the conservative mixing line, indicating that at these sites there is no subsidy from land to the ocean. At Waikoloa (Figure 4), the situation is different. At salinities below about $15^o/oo$, PO_4^{3-} concentrations lie substantially above the conservative mixing line; at salinities above $15^o/oo$, PO_4^{3-} concentrations fall on the conservative mixing line.

This clearcut shift in distribution is a result of the differences in the environments from which samples were collected. The lower salinity suite of samples was collected in the anchialine ponds that lie between the Waikoloa Golf Courses and the ocean, while the higher salinity samples were collected in the nearshore regions of Anaehoomalu Bay. It is apparent from the distribution of data that PO_4^{3-} concentrations in the ponds are substantially elevated as a result of the leaching of golf course fertilizers to groundwater. While it is evident that nutrient enrichment has occurred in the ponds, it is not apparent from the data if the subsidies are resulting in adverse changes to the pond environments.

Observations of the ponds do not suggest that the subsidies are resulting in any alteration in water quality or biotic composition. As the ponds are not nutrient limited, it does not appear that the subsidies are responsible for changing the trophic status of the environments. Similar conclusions have been reached by R. Brock (personal communication) as a result of an ongoing monitoring program conducted on the Waikoloa Anchialine Ponds.

While the ponds are clearly experiencing input from land, such input is not evident in the ocean. Water from the ponds flows to the ocean on falling tides. It appears, however, that the residence time of water in the nearshore zone is sufficiently short so that the excess nutrients are rapidly mixed to "conservative" levels. Thus, with consideration only of the nearshore ocean, there is no indication of any measurable input of land-derived PO_4^{3-} to the nearshore ocean.

At Keauhou Bay (Figure 5), the distribution of PO_4^{3-} data points lies above the conservative mixing line. Such a pattern indicates a slight input of PO_4^{3-} to the coastal waters, likely as a result of percolation of fertilizer materials from the golf course to groundwater.

Examination of the plots of NO_3^- reveals different patterns for each of the golf courses. At Mauna Kea (Figure 2), all data points fall near the conservative mixing line, suggesting that there is no measurable subsidy of NO_3^- reaching the ocean. At Waikoloa (Figure 4), the situation for NO_3^- is virtually identical as described above for PO_4^{3-}. Substantial subsidies from golf course leachates are apparent in the anchialine ponds. There is no indication, however, of enrichment in the nearshore ocean.

The situations regarding NO_3^- subsidies at Mauna Lani (Figure 3) and Keauhou (Figure 5) appear to be similar. At both locales the distributions of data points lie substantially above the conservative mixing line, and prescribe straight lines. Both of these sampling sites are embayments which are observed to concentrate groundwater input. At the Mauna Lani site, sampling was conducted through Pauoa Bay soon after completion of excavation of a swimming lagoon behind the shoreline. Creation of the lagoon also appeared to enhance, or at least concentrate, groundwater discharge at the shoreline of Pauoa Bay. It is clear that in these situations there is a substantial enhancement of NO_3^- to nearshore waters of the receiving environments.

Application of the mixing model to the NO_3^- concentrations at Keauhou and Mauna Lani allow an estimate to be made of the percentage increase of delivery to the nearshore ocean. A best estimate of groundwater flux in these areas ranges from 4 to 8 million gallons per mile per day (9.4 to 18.7 x 10^3 m^3 km^{-1} day^{-1}). At Keauhou Bay, which encompasses approximately 1 km of coastline, and has a cross-sectional distance across the mouth of about 250 m, groundwater flux is concentrated by approximately a factor of 4. At Keauhou, the intercept of the regression line of NO_3^- data indicates that the external subsidy is about 127% of natural inputs from groundwater. In terms of material flux to Keauhou Bay, the external subsidy ranges from about 27 to 54 pounds of nitrogen per day. Average fertilizer use rates for golf courses developed on lava flows in Hawaii is about 165 pounds of nitrogen per day for the 27 holes at Keauhou (Murdoch and Green 1989). Thus, it appears that from about 25% to 50% of the nitrogen applied to the course is entering Keauhou Bay.

Downslope from the Mauna Lani course, Pauoa Bay encompases approximately 0.5 km of coastline. The regression line of data points suggests that external sources supply approximately 270% of NO_3^- to the Bay compared to natural inputs from groundwater. The external flux ranges from about 30 to 60 pounds of nitrogen added to Pauoa Bay per day, an estimate that is very close to the extenal flux at Keauhou. As the 1990 investigation is the first increment of sampling in Pauoa Bay, it is not possible to establish if the external flux is a result of recent completion of construction in the area, or is the result of long-term percolation from the surrounding golf course.

A study by Brown et al. (1982) on highly porous sand golf greens in Texas compared the amount of nitrogen lost by leaching from various nitrogen sources. Irrigation was applied at relatively high rates to provide leaching opportunity. Results of their study showed that over a five-month period, approximately 23% of the nitrogen applied as a soluble N source (ammonium nitrate) was leached. Tavares (1983) showed that high application rates of soluble nitrogen sources at high irrigation rates in Hawaii resulted in leaching of about 10% of the total N applied in the first 2-4 days after application. These leaching rates are of the same order of magnitude as those calculated for entry into Keauhou and Pauoa Bays.

Examination of the lines prescribed by the data points for Keauhou Bay and Pauoa Bay at Mauna Lani shows that they are essentially straight, with no indication of curvature. The lack of curvature suggests that either the nutrient subsidy is mixed seaward by purely physical processes, or that the nutrient subsidy is of such a magnitude that the maximal uptake by biological communities is not sufficient to produce a measurable degree of uptake from the water column.

Examination of the chemical makeup of the water columns of both Keauhou Bay and Pauoa Bay reveals distinct vertical stratification, with a surface layer of low density water formed from groundwater. Formation of the low density surface layer results in a continuous seaward flow that reduces overall residence time of water within the embayments. Such a two-layer flow has also been described for Honokohau Harbor, which receives substantial input of low density groundwater along the landward margins (U.S. Army Corps of Engineers 1983). In Honokohau, the potential for eutrophication in the back basins owing to increased nutrient concentrations appears to be substantially lessened as a result of the rapid flushing rates caused by the persistent seaward outflow.

Because the nutrient subsidies from the golf courses enter the ocean entrained in groundwater flow, the surface layer contains higher nutrient concentrations than underlying waters. It appears that the excess nutrients that are delivered to the nearshore zone are removed from the region via seaward flow of the surface layer. As such, the dissolved materials contained in the surface layer do not have the opportunity to mix with bottom water. The maintenance of the surface layer prevents nearshore benthos from exposure to excess nutrients, minimizing the potential for any changes in ecosystem structure or function.

It is also possible to evaluate the temporal variability of the detected nutrient inputs over the time span of the three surveys. Figures 6 and 7 show plots of all data for the two sites (Keauhou and Waikoloa) that were analyzed in all three sampling years (1988, 1989 and 1990). At Keauhou, it is evident in all of the plots that there are no clear differences with respect to data collected in different years. At Waikoloa, Si data points for the three years all fall along the same line. PO_4^{3-} and NO_3^- measured in 1988 and 1989 do not reflect the increased concentrations in the achialine ponds that is evident in 1990. PO_4^{3-} and NO_3^- in the samples collected in the nearshore ocean do not show distinct differences between years. It appears that nutrient delivery to the ocean over the three years of this investigation appears to essentially be in a steady state, with no indication of decreasing or increasing rates.

CONCLUSIONS

The results of this study are interpreted as follows. It appears that golf courses constructed inland from open coastlines, or embayments that do not cause substantial reduction in water residence time (Waikoloa and Mauna Kea), do not cause detectable nutrient input into the nearshore region. If a proportion of nutrients added to the golf courses situated on open coasts is reaching the shoreline, it appears that "normal" rates of water mixing are sufficient to reduce the increased input function to below detection limits. As the golf courses sampled in this study have been operating for a time period of 10 to 25 years, it appears safe to conclude that any cumulative impacts, should they be occurring, would be discernible at the present time.

Owing to the sandy soil base, the course at Waikoloa is continually over irrigated, yet shows no indication of nutrient subsidy seaward of the shoreline. Anchialine ponds adjacent to the golf courses appear to contain nutrient concentrations elevated above simple mixing lines, owing to leaching from the golf course. Results of a monitoring program of the ponds at Waikoloa, however, show that changes in nutrient parameters in ponds are within the range of natural variability, suggesting that any changes that may be a result of the surrounding development do not have the potential to cause alteration of biological processes (Brock et al. 1987).

As was found previously, fertilizer input is detectable in the ocean from golf courses located upslope from embayments or areas of reduced circulation (Keauhou Bay and Pauoa Bay at Mauna Lani). This effect appears to be primarily a result of focusing of groundwater flow into the embayment, and reduced mixing-circulation relative to the open ocean.

In the instances where nutrient input beyond that from groundwater alone is detectable, there are no cases where environmental changes (water quality or biological community structure) are evident. As a function of the increased groundwater discharge in the embayments, low density surface layers are formed which contain the nutrient subsidies. These surface layers do not mix with underlying bottom water until beyond the outer boundary of the embayment. As a result, the marine communities that inhabit the bottom are never exposed to the nutrient subsidies.

These results can be related to the O'oma project in several ways. First, as the coastal area off the project is an area of unrestricted circulation, any material that should reach the shoreline will likely be rapidly and thorougly mixed to background oceanic levels below the limit of detection (i.e., Waikoloa and Mauna Kea). Wave energy and current flow in the area prevent any periods of stagnated water or restricted circulation (Noda 1988). Even if some material from the project is incorporated into groundwater flow that reached the ocean, such material will remain in a surface layer in the nearshore zone before being thorougly mixed.

This conclusion can be carried one step further to say that there does not appear to be any potential for influencing intake water at NELH and HOST Park by a golf course at O'oma with structural and operational characteristics similar to the existing courses. The shallowest warm water intake pipe at

Keahole Point is situated approximately 100 m offshore, at a depth of 13.7 m. Such a locale is far below the depth of the surface layer (measured to be about 1 m deep), and far enough from shore as to be virtually unaffected by even the worst case situation that exists today for golf courses located near embayments. It is apparent that water quality would not be adversely affected even if the Keauhou golf course and Keauhou Bay were situated adjacent to NELH. At an open ocean site, such as O'oma, it appears that there will be no impacts to offshore water quality from a properly managed golf course.

Based on the results of this study, it appears that a golf course and associated development at the O'oma site would not cause any negative effects to the marine environment. As long as nutrient loading rates from irrigation do not overwhelm the carrying capacity of the golf course (i.e. extreme over irrigation) there does not appear to be any indication that the quality of nearshore waters would be affected. Thus, with prudent management practices that preclude intense over-irrigation and fertilization, there does not appear to be potential for negative alteration of nearshore water quality.

These conclusions, however, are relevant only for the relatively low loading associated with the type of land use typical of golf courses and associated development. It is entirely possible that higher loading, such as may occur with discharge of nutrient-laden waste waters directly into the nearshore zone, might invoke uptake and biotic response. Even though over irrigating and rapid percolation appear to be characteristics of some golf courses, *and do not appear to result in measurable* throughput to the ocean, the potential exists for impacts with inputs of larger magnitudes.

Finally, it should be noted that measuring nutrient parameters, in the absence of some scaling, is not likely to be particularly informative about the potential, or realized, impacts of nutrients on the marine or anchialine pond environments. In the present case, it can be seen that the range of nutrient concentrations is large over the entire salinity range. Attempting to interpret trends from concentrations alone would prove difficult owing to the high natural variability through the system. Scaling against a conservative property such as salinity can be a simple, yet powerful, tool for "warning" of potential impacts before detrimental changes occur in marine environments.

REFERENCES CITED

Brock, R. E., J. E. Norris, D. A. Zieman and M. T. Lee. 1987. Characteristics of water quality in anchialine ponds of the Kona, Hawaii, Coast. Pac. Sci. 41:200-208.

Brown, K. W., J. C. Thomas and R. L. Duble. 1982. Nitrogen source effect on nitrate and ammonium leaching and runoff losses from greens. Agronomy Journal. 74:947-950.

Kaul, L. W. and P. N. Froelich, Jr. 1984. Modeling estuarine nutrient geochemistry in a simple system. Geochim. Cosmochim. Acta, 48:1417-1433.

Marine Research Consultants. 1988. The effects of golf course irrigation and fertilization on nearshore marine waters off West Hawaii.

Marine Research Consultants. 1989. Potential effects off golf course irrigation and fertilization on nearshore marine waters off Kohana'iki, North Kona, Hawaii. Prepared for Helber, Hastert and Kimura, Planners.

Noda, Edward K. and Associates. 1988. Kohana-iki resort development assessment of impacts: littoral processes, surf sites, dredge turbidity, & storm water discharge. Prepared for Engineering Concepts, Inc.

Officer, C. B. l979. Discussion of the behavior of nonconservative dissolved constituents in estuaries. Est. Coastal Mar. Sci. 9:91-94.

Smith, S. V., S. J. Dollar and 6 others. 1987. Stoichiometry of C, N, P, and Si fluxes in a temperate-climate embayment. J. Mar. Res. 45:427-460.

Strickland, J. D. H. and T. R. Parsons. 1968. A practical handbook of sea-water analysis. Fisheries Research Board of Canada, Bull. 167, 311 p.

Tavares, W. J. 1983. The effect of N source, N rate and a vesicular-arbuscular mycorrhizal fungus on nitrogen leaching and elemental composition in bermudagrass turf. M. S. Thesis, Horticulture Dept. University of Hawaii. 106 p.

U. S. Army Corps of Engineers. 1983. A decade of ecological studies following construction of Honokohau small boat harbor, Kona, Hawaii.

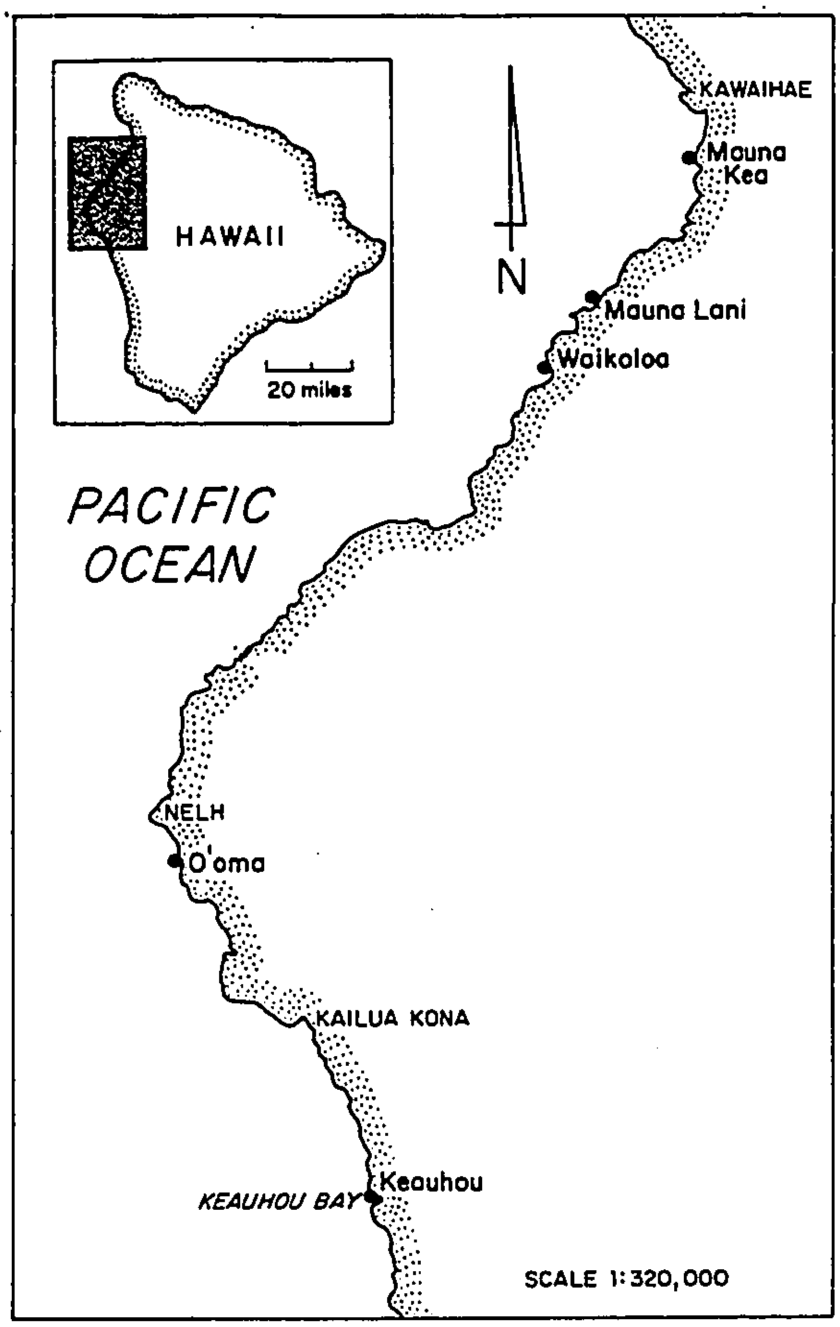

FIGURE 1. Map showing locations of five existing golf courses where water samples were collected. Also shown are locations of O'oma site and the Natural Energy Laboratory of Hawaii (NELH).

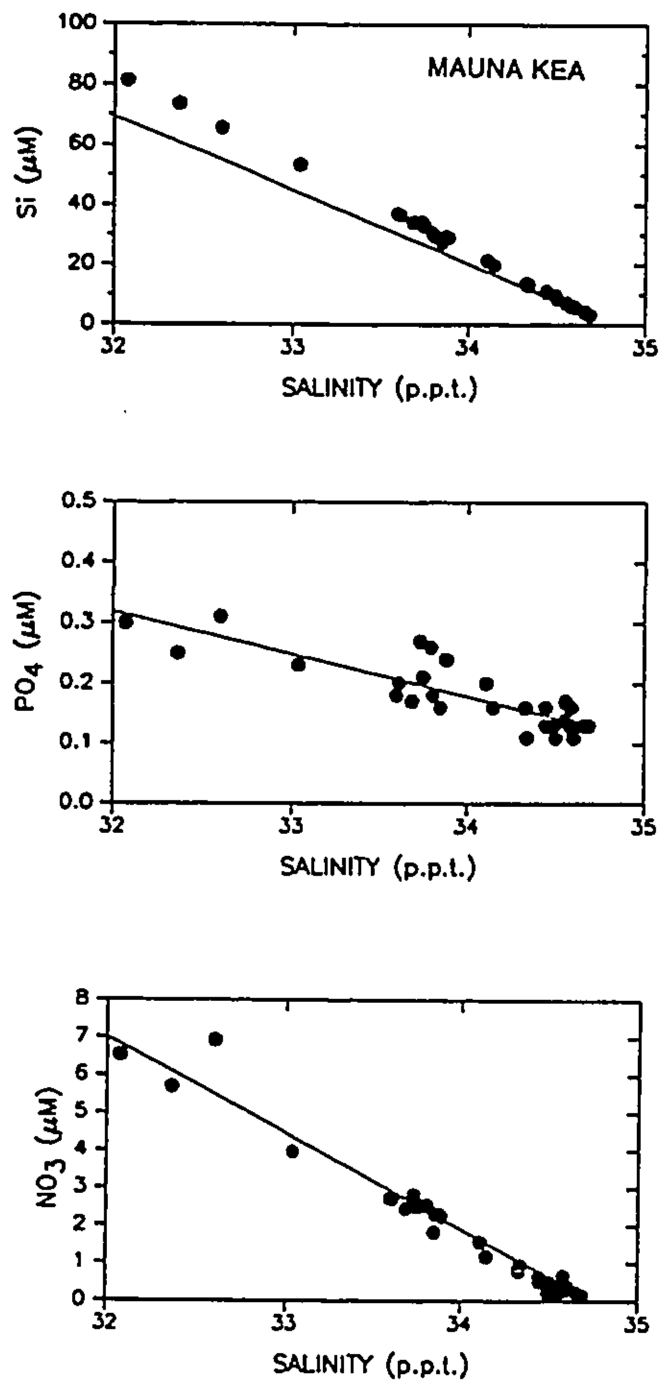

FIGURE 2. Plots of dissolved Si, PO_4^-, and NO_3^- as functions of salinity collected off the Mauna Kea golf course in Kaunaoa Bay.

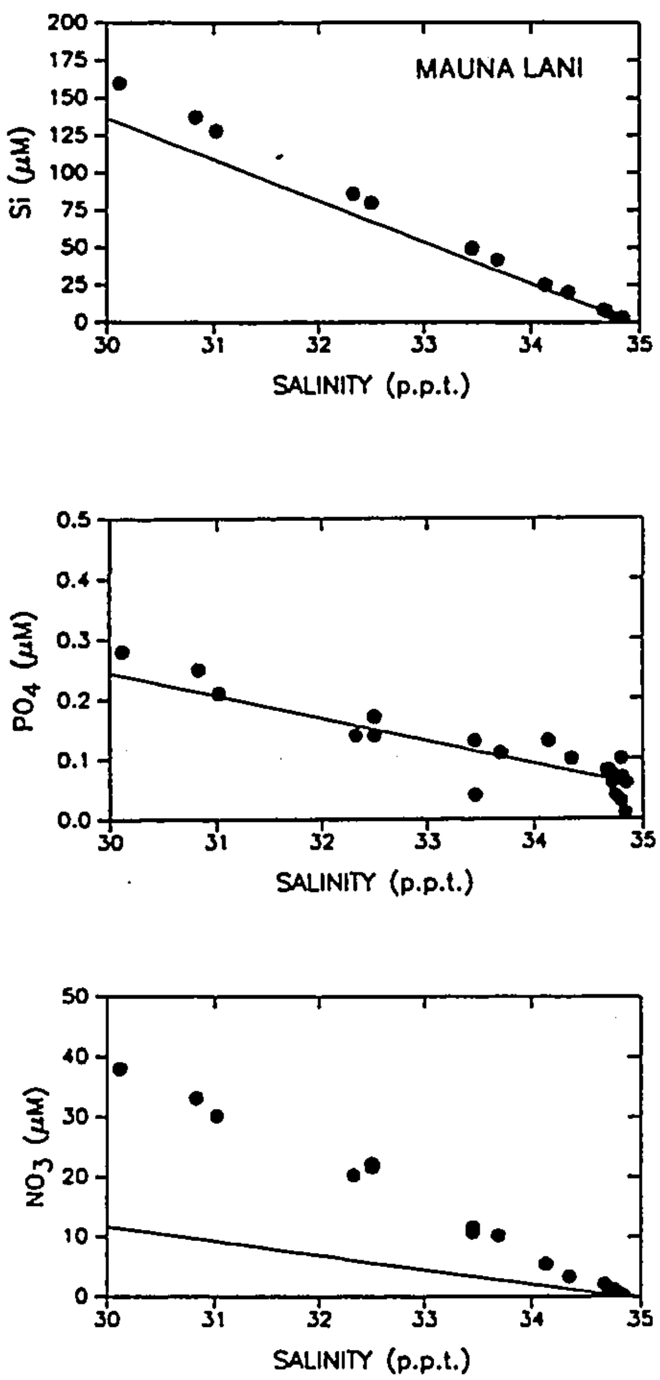

FIGURE 3. Plots of dissolved Si, PO_4^-, and NO_3^- as functions of salinity collected off the Mauna Lani golf course in Pauoa Bay.

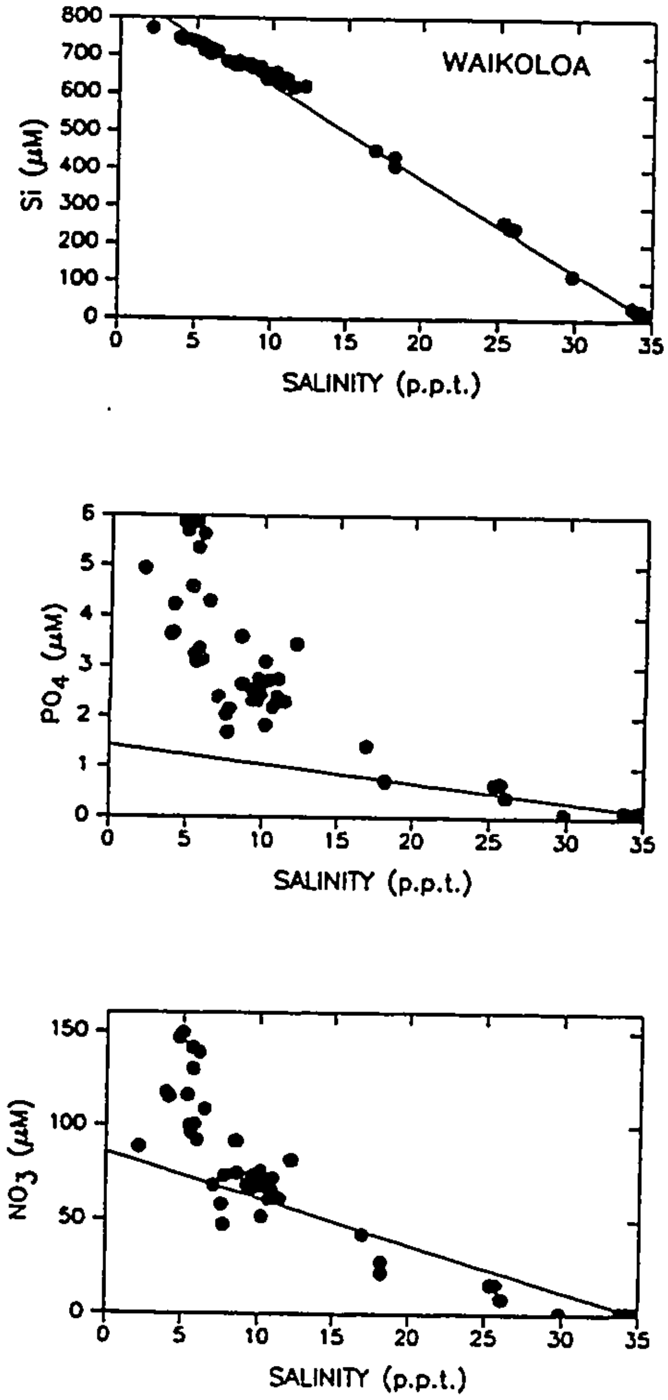

FIGURE 4. Plots of dissolved Si, PO_4^-, and NO_3^- as functions of salinity collected off the Waikoloa golf courses.

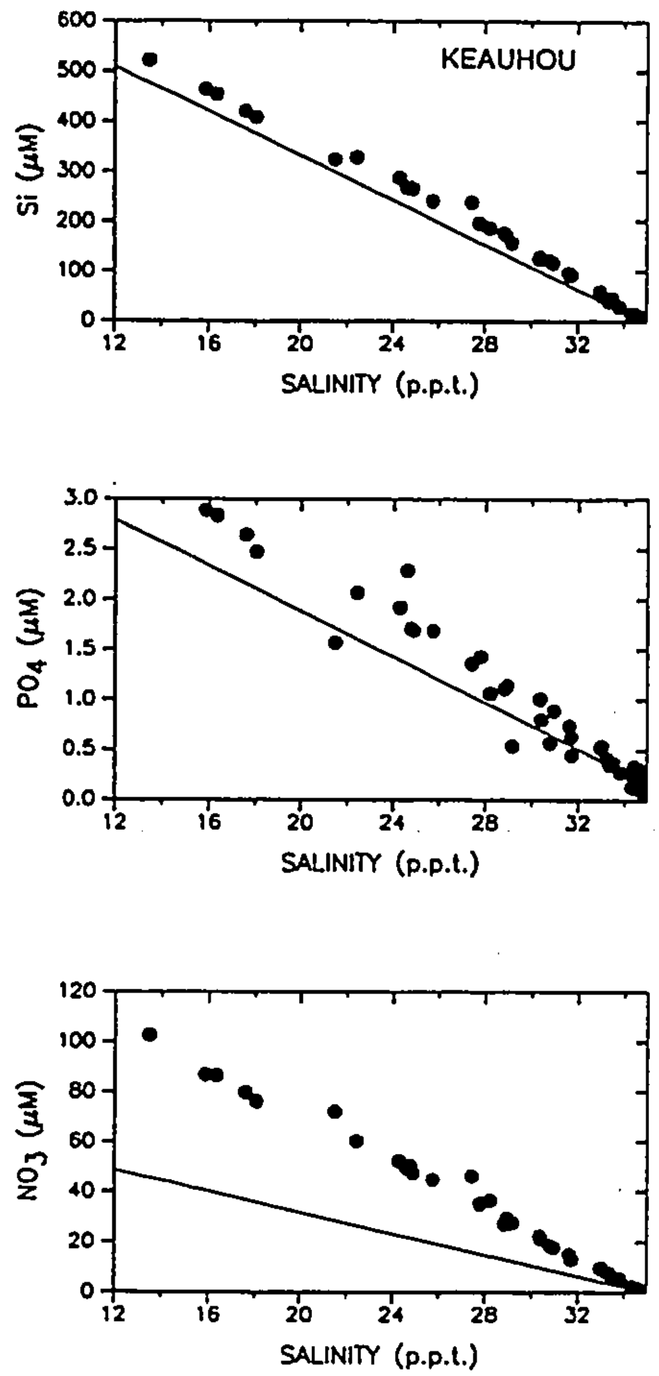

FIGURE 5. Plots of dissolved Si, PO_4^-, and NO_3^- as functions of salinity collected off the Keauhou golf course in Keauhou Bay.

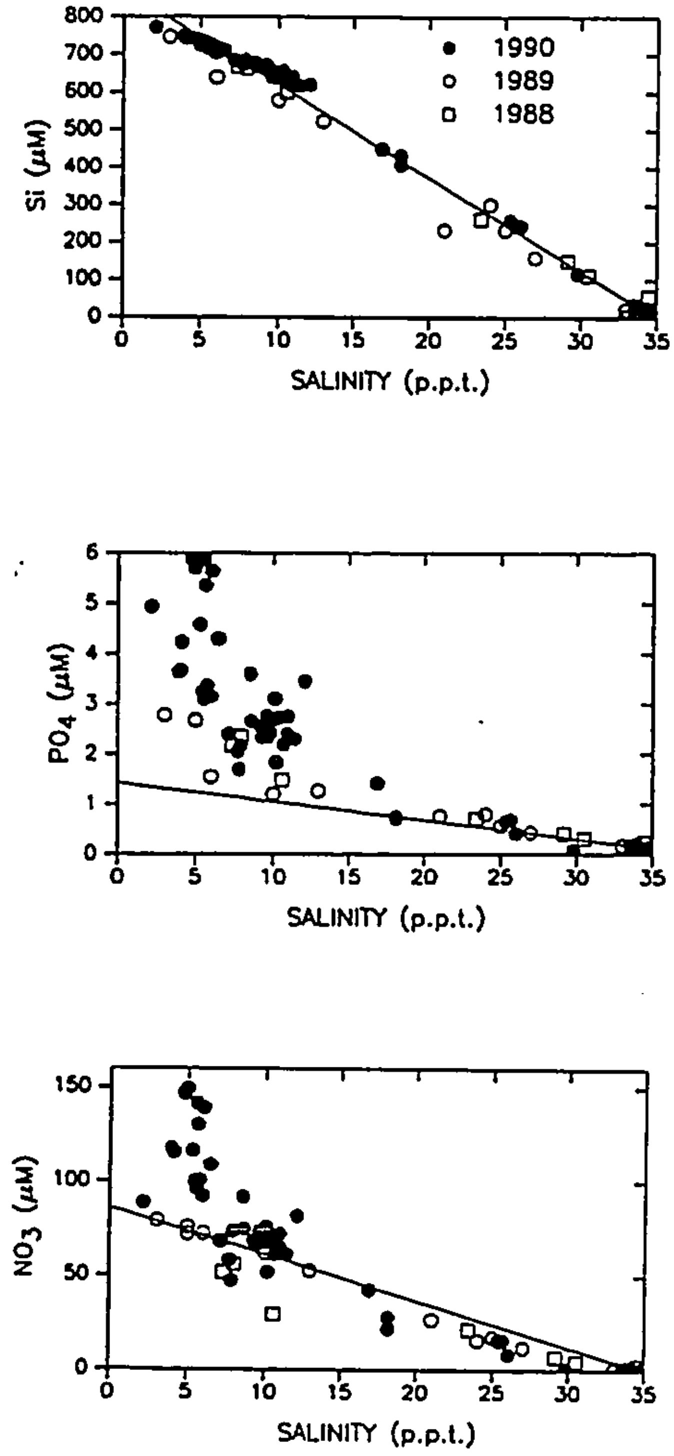

FIGURE 6. Plots of dissolved Si, PO_4^-, and NO_3^- as functions of salinity collected off the Waikoloa golf course during three surveys in 1988, 1989, and 1990.

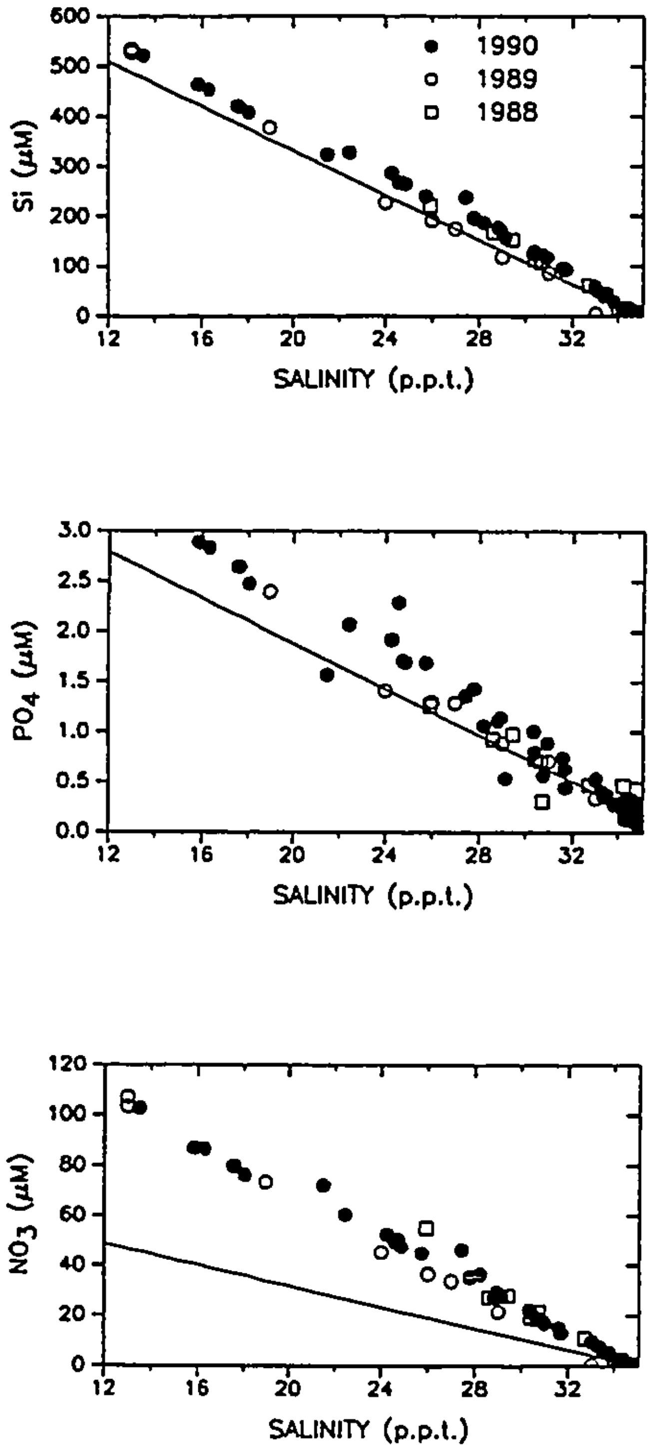

FIGURE 7. Plots of dissolved Si, PO_4^-, and NO_3^- as functions of salinity collected off the Keauhou golf course during three surveys in 1988, 1989, and 1990.

APPENDIX F

ANALYSIS OF SALT WATER PONDS

Tom Nance

Saltwater Ponds of the O'oma II Project: Recommended Circulation System and Analysis of Environmental Effects

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September 1991

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INTRODUCTION

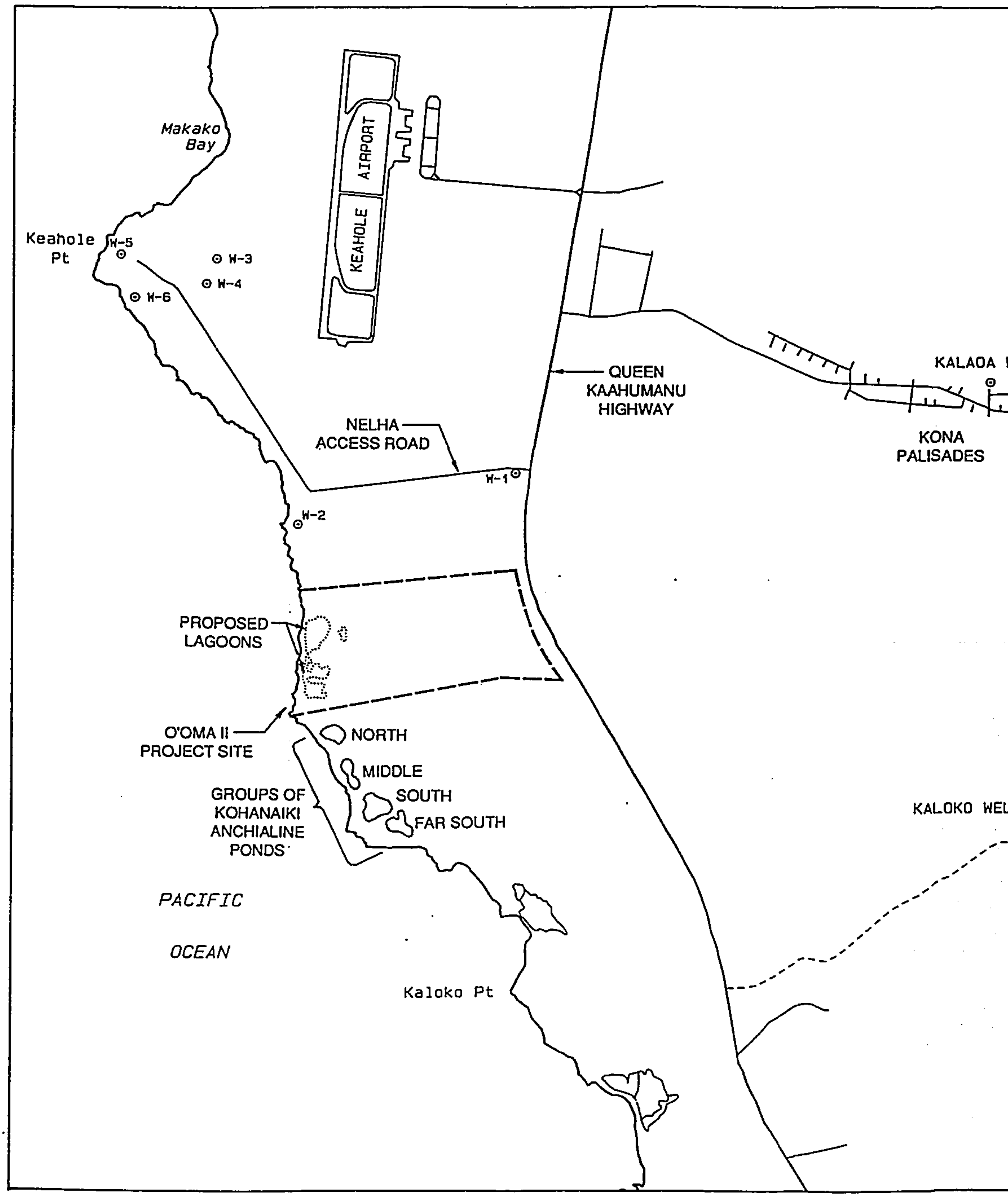
Kahala Capital Corporation proposes to develop a recreational and residential community on a 300-acre parcel along the North Kona coastline between the Natural Energy Laboratory of Hawaii Authority (NELHA) and Kohanaiki parcels. The multi-use project would include a hotel, a small Japanese style inn, condominium units, residential lots, a golf course, related commercial development, an ocean science center, and a water recreation park. Figure 1 locates the project on the Kona coast and Figure 2 shows its proposed development plan.

The water recreation park would feature a 7-acre swimming lagoon, water slides and pools, a wave machine, and a beach around some of the lagoon's perimeter. This study has been undertaken to develop the most appropriate water circulation scheme for this park and to evaluate its potential environmental effects. The investigation has been a team effort. Tom Nance Water Resources Engineering directed the study and is responsible for its basic concepts and conclusions. Rich Heaton of Hardscapes Hawaii and Eric Guinther of AECOS provided information and recommendations regarding circulation turnover rates for the lagoon system and its expected water chemistry. Dr. Tony McNulty of Mackie Martin & Associates created a computer-based numerical model of the groundwater aquifer system. This model has been the primary analytical tool used to assess potential environmental effects.

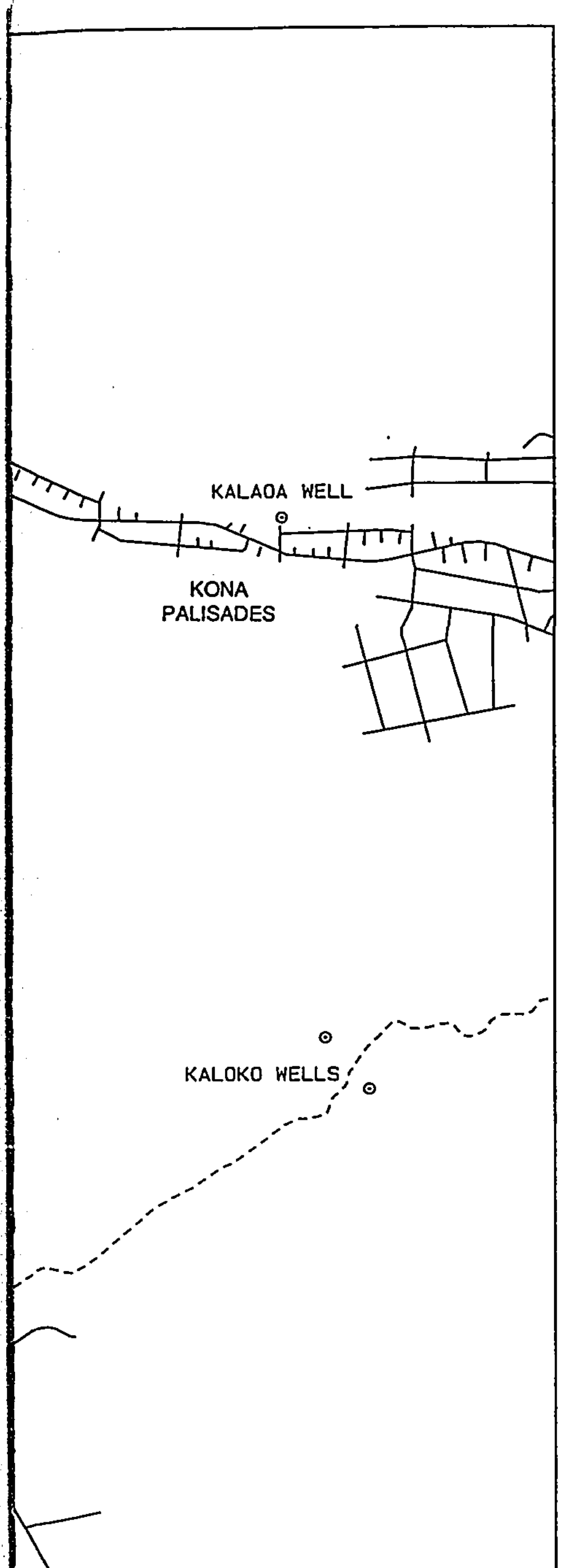
DESCRIPTION OF THE PROPOSED LAGOON SYSTEM AND ITS CIRCULATION SCHEME

Although the water recreation park is the primary focus of this study, Kahala Capital's development plan includes several other nearby water-related features which would be appropriate to include in the circulation system. Two ponds are proposed south of the water park. One would be a golf course amenity and the other would be a feature of the hotel. The ocean science center would be on the north side of the water recreation park. The discussion and analyses which follow includes these three water-related features in the analysis of the circulation system.

Table 1 lists the sizes and volumes of each of the water features which would be included in an integrated circulation system. The largest pond, the 7-acre water recreation park, would have a natural (unlined) bottom. Beaches would be constructed around some of its perimeter and the pond would have an average depth of 4.5 feet at mean tide. Its water level would be elevated slightly above sea level and fluctuate with the ocean tide. A wave machine may also be installed in this lagoon. The water recreation park would also have a smaller, elevated pond directly inland of the larger one. Its water surface would be 30 to 40 feet above sea level and its bottom would have an impervious liner. Water would descend from this higher pond to the lower one through several slides or "rapids".



Makako Bay
Keahole Pt
W-5
W-3
W-4
W-6
KEAHOLE AIRPORT
QUEEN KAAHUMANU HIGHWAY
KALAOA
KONA PALISADES
NELHA ACCESS ROAD
W-1
W-2
PROPOSED LAGOONS
O'OMA II PROJECT SITE
NORTH
MIDDLE
SOUTH
FAR SOUTH
GROUPS OF KOHANAIKI ANCHIALINE PONDS
PACIFIC OCEAN
Kaloko Pt



O'OMA II PROJECT
NUMERICAL MODELING OF THE
GROUNDWATER SYSTEM

On Behalf Of

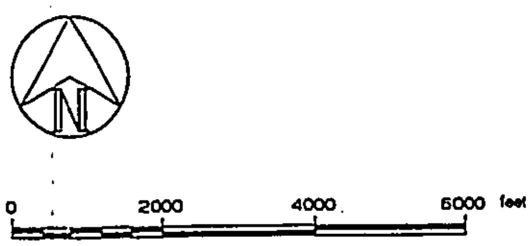
TOM NANCE
WATER RESOURCES ENGINEERING

LEGEND:

- Coast
- Roads
- Tracks
- Ponds
- Monitoring Well
- Project Boundary (NELHA)

NOTE:

Base map from US Department of the Interior, Geological Survey, 7.5 minute series (topographic).



LOCATION OF THE O'OMA II PROJECT SITE ON THE NORTH KONA SHORELINE

FIGURE 1

Mackie Martin & Associates
GROUNDWATER ENGINEERS

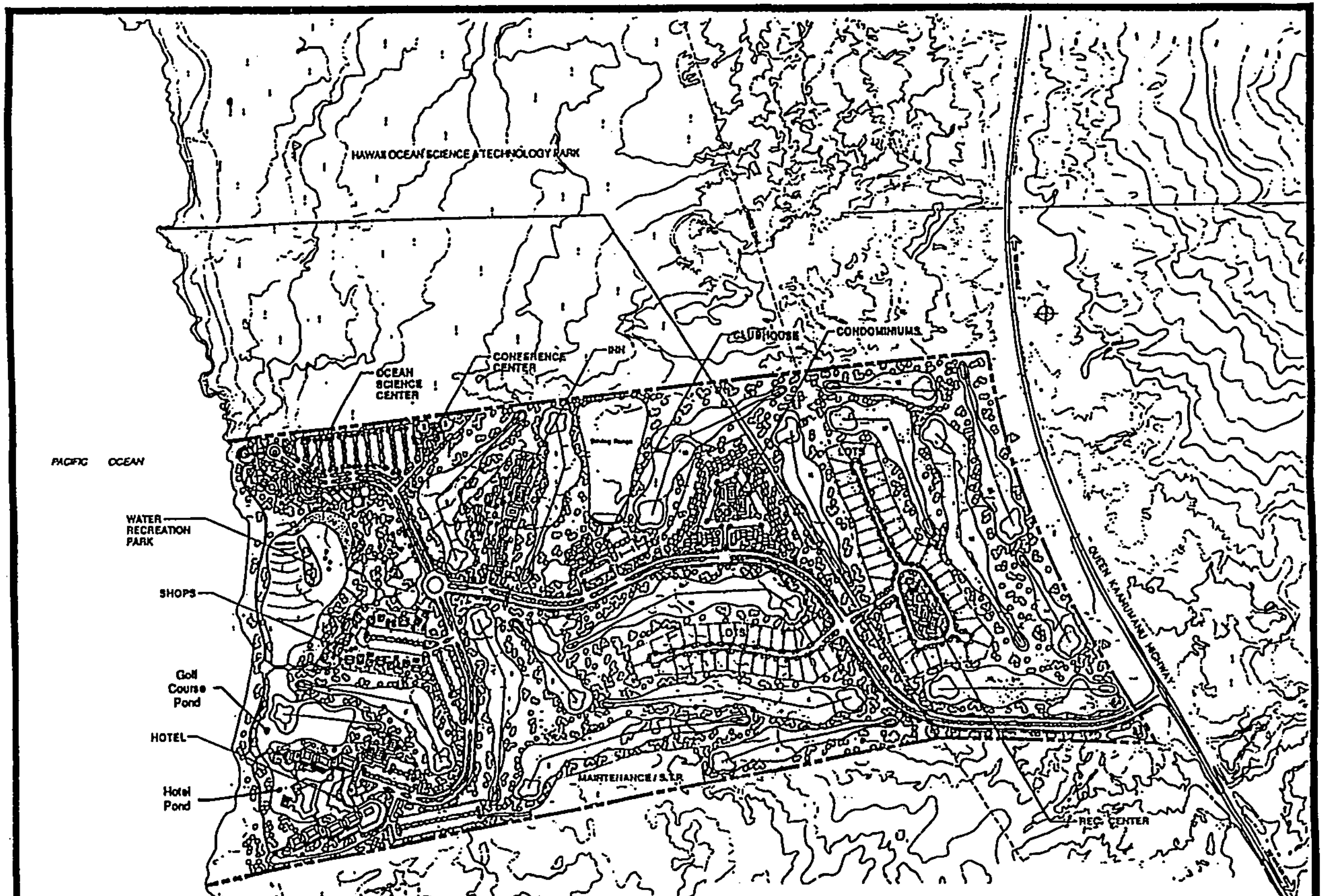


FIGURE 2
PROPOSED O'OMA II DEVELOPMENT PLAN

Table 1
O'oma II Water Features Included in its Circulation System

Water Feature	Water Area (Acres)	Ave. Depth (Feet)	Volume (Million Gallons)	Construction
Water Recreation Park	7.0	4.5*	10.3	Unlined Bottom
Water Recreation Park	1.0	2.5	0.8	Lined Pond
Golf Course Pond	3.0	2.5	2.4	Lined Pond
Hotel Water Feature	3.5	2.5	2.8	Lined Pond
Ocean Science Center	--	Variable	0.2 to 0.3	Aquarium Tanks

* *Water level will fluctuate with ocean tide; depth given above is at mean tide level.*

The golf course water feature would have a lined bottom and a water surface about 10 feet above sea level. The water feature around and within the hotel would include fish and other aquatic animals. It would also be lined and have a water surface about 10 feet above sea level. These two ponds would be hydraulically connected to each other and to the 7-acre pond. The ocean science center located on the north side of the water recreation park would include a number of aquarium tanks, the largest of which would exhibit indigenous Hawaiian marine life.

Circulation System Alternatives

Controlling growth of aquatic plant life, consisting of phytoplankton (microscopic algae suspended in the water column) and benthic algae (micro- and macroscopic algae attached to substrate), is the primary objective of the circulation system. Excessive phytoplankton growth would create turbidity and color in the water column. Such algae "blooms" are followed by death and decay of the plant organisms, producing noxious odors and other undesirable effects. Depending on the type and extent of benthic (attached) algae growth, it could also diminish the aesthetic appeal of the water feature.

There are two basic approaches keeping pond water clear and growth of aquatic plant life at acceptable levels. In small-scale systems requiring swimming pool clarity, water is usually recirculated at very high rates through pressure sand filters and then subjected to an ozonation process. For the volume of water in the O'oma II lagoons, this approach would not be economically practical. Further, it would produce waste products requiring further treatment (the filter backwash, primarily) and it would not control benthic algae growth. Control of temperature and salinity could also pose operational difficulties.

The alternative approach would be to use single pass, flow-through circulation. Supply water would pass through the system only once and then be discharged. Control of phytoplankton growth is maintained by limiting the residence time of water moving through the system and by using a source of supply with low nutrient content. This would not completely control benthic algae growth, however. In fact, some of these plants may actually be encouraged by water motion and would have to be controlled by biological means. Herbivorous fishes, and possibly small invertebrates, could be introduced to feed on benthic algae.

In addition to the fact that the large water volume within this system of lagoons makes recirculation impractical, there are several other aspects which strongly favor the single-pass, flow through circulation approach for O'oma. A low nutrient source of water can be developed through construction of a field of nearshore drilled wells. These would be designed to draw water from well below the overlying brackish basal lens, thereby producing saline groundwater which would be virtually identical to nearby surface seawater in all important chemical respects. This water could be pumped into the higher ponds and flow by gravity to the lowest, 7-acre pond. It would then percolate through the porous bottom and sides of this pond and work its way back to the shoreline.

Proposed Saltwater Supply Wells and Pumping Rates

The turnover rate necessary to achieve acceptable water clarity in a single-pass, flow through system is largely a matter of judgement. Fortunately, operating experience has been gained from similar systems at several resorts located elsewhere along the Kona-Kohala coast. Consistent success has been achieved when the residence time from the well head through the lagoons system to disposal is 10 hours or less. For the proposed O'oma lagoon system, achieving this turnover rate would require pumping at 25,000 gallons per minute (GPM) continuously. This would be equivalent to turning over 36 million gallons per day (MGD).

The exact number of wells needed to achieve this flowrate would be determined through actual drilling and pump testing. Experience has shown, however, that 3,000 to 5,000 GPM per well is a reasonable expectation. At this yield per well, the project would require five to eight wells. These would be arrayed around the pond perimeters for delivery into the respective ponds. Typical well depth is likely to be about 200 feet. The upper 100 to 120 feet would feature 18- or 20-inch solid PVC casing to entirely close off the overlying brackish groundwater lens. The lower 80 to 100 feet would be well screen or simply open hole drilled out through the bottom of the solid casing.

Expected Water Quality From the Supply Wells

The brackish basal lens beneath the O'oma site is thin and too salty for irrigation use. This is the result of relatively limited groundwater recharge by rainfall on the inland slopes of Hualalai. Hydrologic budget calculations suggest this rate is only 1.0 to 3.0 MGD per coastal mile, substantially less than occurs in South Kohala (to the north) and Kailua-Keauhou (to the south). Data from the nearby NELHA monitoring wells support this conclusion drawn from the hydrologic budget estimate. Evidence of limited groundwater flow discharging into nearshore waters is also provided by seawater sampling (in Marine Research Consultants, 1990) and by infrared photography along the shoreline.

Figure 3 illustrates the salinity variation in the brackish lens at several NELHA monitoring wells. Well W-1 is near Queen Kaahumanu Highway and 5,200 feet from the shoreline. At that point, the lens is about 27 feet thick (as defined by the depth where groundwater salinity is 50 percent of seawater). At the top of the lens, salinity is 5 to 7 parts per thousand (ppt). This is 15 to 20 percent seawater, which has a salinity of 34.8 ppt. At Well W-2 located several hundred feet from the shoreline, the lens is 15 to 17 feet thick and it is significantly more saline than at W-1.

Tables 2 and 3 illustrate the variation of selected chemical constituents in groundwater and nearshore surface seawater. The concentration of nutrients (nitrogen and phosphorous compounds) in the groundwater is one to two orders of magnitude greater than seawater. At various locations and depths in the brackish lens, the nutrient concentrations simply reflect a relative amount of dilution with seawater. Figure 4 shows that the concentrations at available sampling points correlate well with such dilution.

NELHA monitoring well data establish that the supply wells need to be located and designed to produce water of virtual seawater salinity in order to avoid drawing even a small amount of nutrient rich brackish groundwater. This can be achieved if each well's solid casing extends far below the brackish lens and is set to take advantage of the anisotropy of flow lavas. Typically, horizontal permeabilities in the direction of the lava lay down sequence are 200 or more times greater than the vertical permeability through a series of lava flow layers. Also, the permeability among lava flows is extremely variable. Operating saltwater wells elsewhere along the Kona-Kohala coast have avoided "contamination" by overlying brackish water with some degree of success. Salinities of about 33.5 ppt have been achieved with wells shallower than proposed for O'oma in areas where the natural groundwater flow is two to four times greater. A salinity of 33.5 ppt suggests dilution of seawater by three to five percent brackish groundwater. Nutrient concentrations in these saline wells confirm this dilution. For the O'oma project, the brackish component in water from the proposed wells, due to their

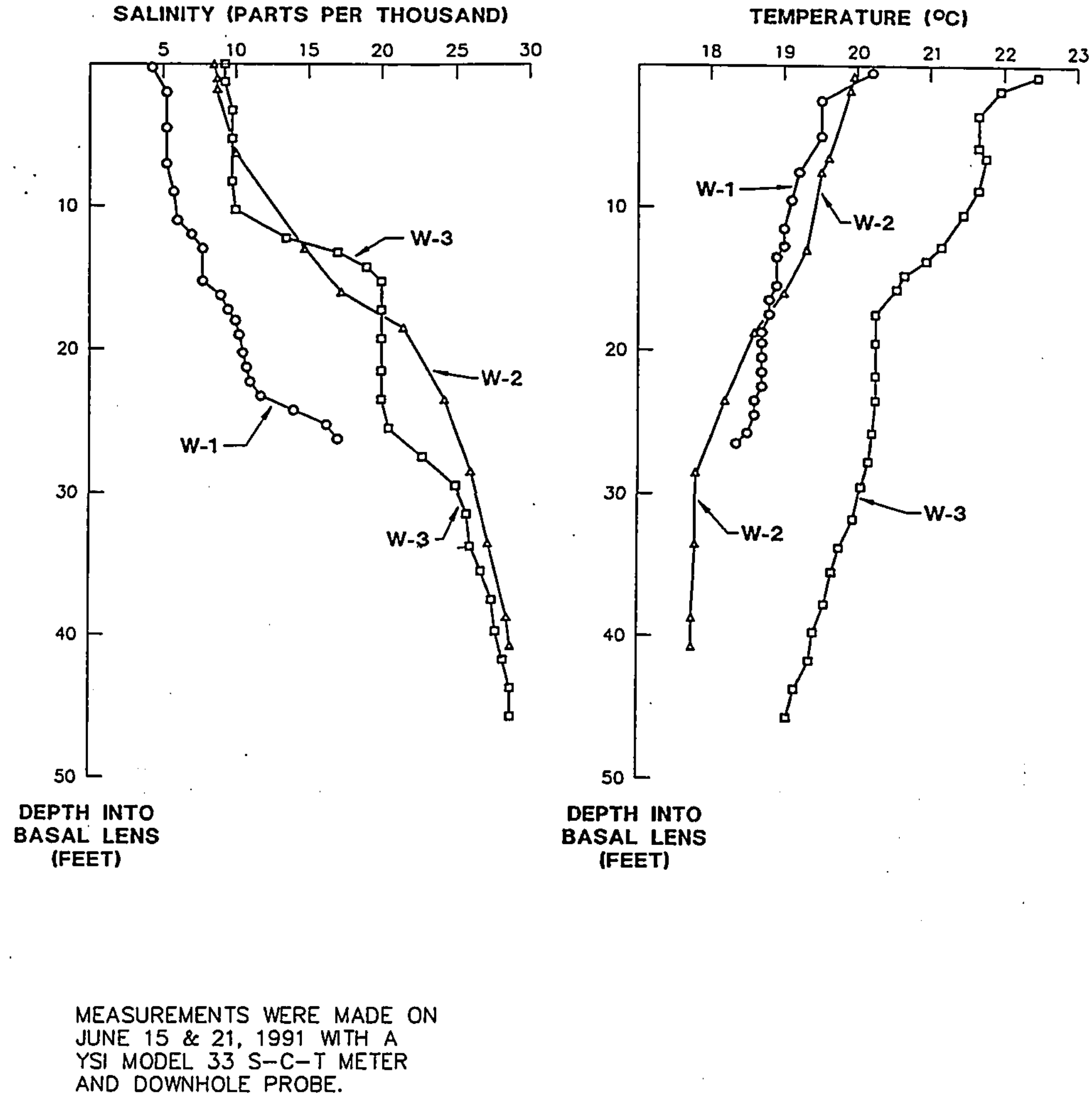


FIGURE 3
SALINITY AND TEMPERATURE PROFILES
IN THE SELECTED NELHA MONITORING WELLS

Table 2

Variations of Selected Chemical Constituents in Seawater and Brackish Groundwater

Chemical Constituent	Units	Seawater	Brackish Groundwater	
			Nearshore	Inland
Salinity	PPT	34.80	7.62	7.03
Nitrate	µM	BDL	81.30	83.90
Ammonia	µM	0.09	0.15	0.11
Total Dissolved Nitrogen	µM	6.02	82.50	84.22
Phosphate	µM	0.07	3.22	3.20
Total Dissolved Phosphorous	µM	0.27	3.62	3.58
Silica	µM	4.32	663	690
Temperature	°C	27.6	20.7	20.4

Notes:

1. The seawater sample is from Marine Research Consultants (1990) offshore station 2-6S sampled in September 1990.
2. The brackish groundwater samples are from NELHA monitoring wells W-2B (nearshore) and W-1 (inland) as sampled on August 7-8, 1990 and reported in NELH (October 1990).

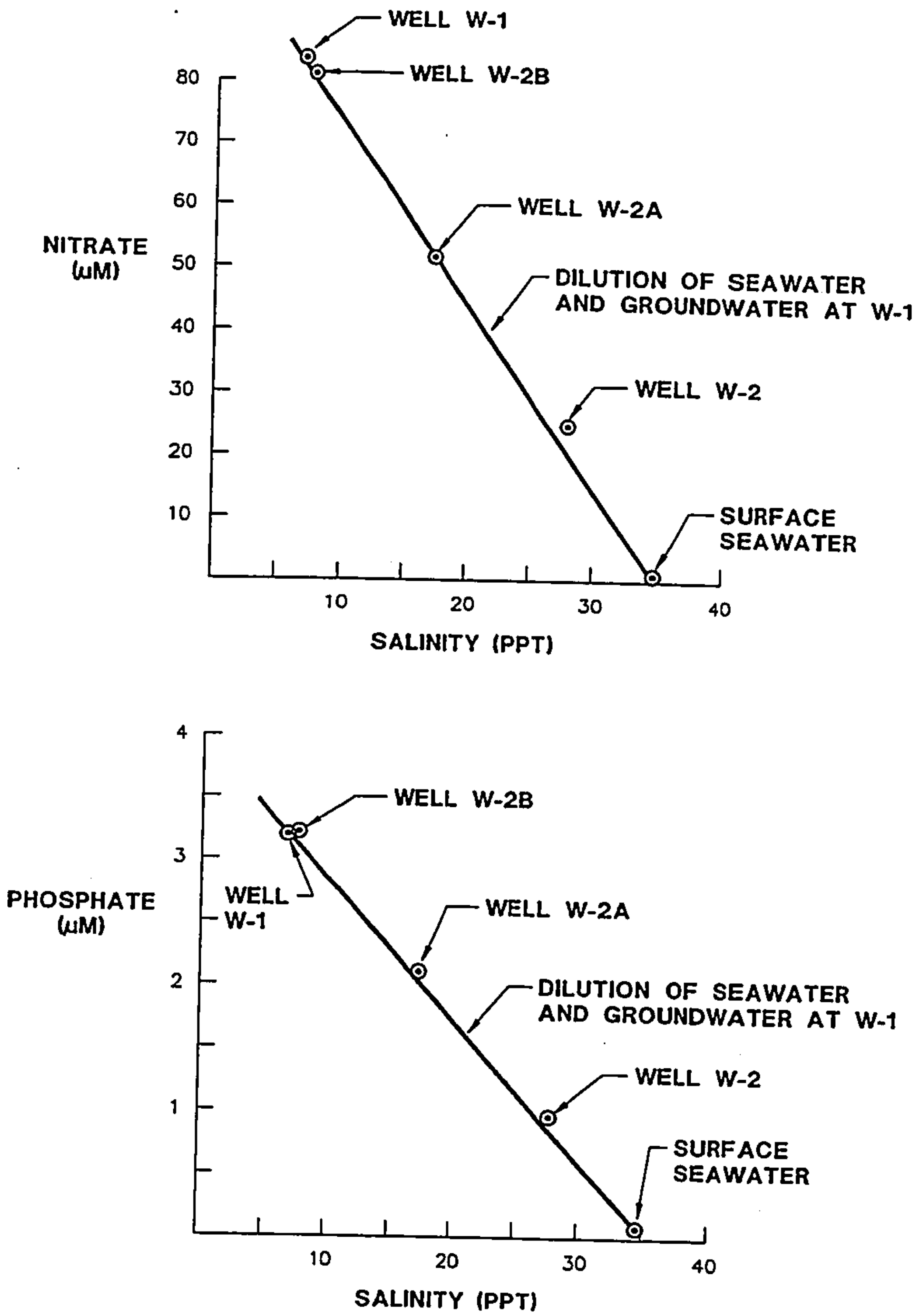
Table 3

Vertical Variation of Selected Chemical Constituents in Groundwater

Chemical Constituent	Units	Brackish Basal Lens			Saline Groundwater
		Surface	Mid-Depth	Bottom	
Salinity	PPT	7.62	17.19	28.08	33.6
Nitrate	µM	81.30	51.60	24.7	2.46
Ammonia	µM	0.15	0.17	0.2	0.23
Total Dissolved Nitrogen	µM	82.50	52.80	25.14	- -
Phosphate	µM	3.22	2.10	0.97	1.30
Total Dissolved Phosphorous	µM	3.62	2.77	1.51	- -
Silica	µM	663	504	283	268
Temperature	°C	20.7	19.9	18.9	- -

Notes:

1. The brackish basal lens samples are from NELHA monitoring wells W-2B (surface), W-2A (mid-depth), and W-2 (bottom). Sampling was done August 8, 1990 and is reported in NELH (1990).
2. The saline groundwater sample is from Waikoloa well 5552-02 in June 1990.



NOTE: DATA POINTS ARE FROM AUGUST 7 TO 8, 1991 SAMPLING IN NELHA (1990).

FIGURE 4
RELATIONSHIP OF NITROGEN, PHOSPHOROUS, AND SALINITY IN THE BRACKISH BASAL LENS

greater depth and the thinner basal lens, can be expected to be less than three percent and could be one percent or even lower.

Water Quality Within the Lagoons

Water in the lagoons must have an aesthetically pleasing clarity, provide a healthy environment for the aquatic fish and plant life, meet human health requirements in the two ponds to be used for swimming, and not create adverse environmental effects as it seeps from the lowest pond into groundwater next to the shoreline. The effectiveness of the circulation system in achieving these objectives can be evaluated by measurements of turbidity, suspended solids, organic and dissolved nutrient concentrations, bacteria counts, and the uniformity of physical and chemical properties throughout the lagoon system.

Water from the supply wells is likely to be low in dissolved oxygen and would need to be aerated by cascading waterfalls, fountains, and/or mechanical aerators. Nutrients in the well water, hopefully at concentrations as low as seawater, would be utilized in biological processes in the lagoon system. Nitrates and phosphates will be taken up by benthic algae and by phytoplankton as these plants grow within the system. These plants will be eaten by herbivores (fishes and invertebrates) or, upon their death, be utilized by bacteria. These processes produce biomass, waste products such as ammonia, and particulate and dissolved organics. It is expected that nitrogen and phosphorous entering the system in well water will exit the system in several dissolved forms in the seepage water or become bound in organic and particulate matter, some of which would be retained and the balance of which may also be lost through seepage.

A saltwater lagoon system with single-pass circulation which is in operation at a South Kohala resort is the best available example of the chemical and physical changes saline groundwater supply may undergo prior to its disposal by seepage. Although this particular system is smaller than proposed for O'oma -- its ponds total 1.5 acres and contain a little over one million gallons -- the system is similar in all other respects. It is supplied by saline groundwater from a nearby well, its lagoons contain a diversity of marine life, it has a turnover rate of about 10 hours, and its disposal is by seepage. Table 4 summarizes selected water quality parameters of its influent (well) supply and its effluent which percolates back to groundwater from its lowest pond. Measurements were made throughout a day and their geometric mean values are reported in the table. It appears that most of the nitrate and about half of the phosphate entering the system in well water is taken up by plants. Some of this nitrogen can be accounted for in the effluent water as ammonia. Presumably the balance is contained in particulate and dissolved organics. The slight variations in total nitrogen and total

Table 4

Geometric Mean Values Selected Water Quality Parameters From a Lagoon System Supplied by Saline Groundwater

Constituent	Units	Well Supply	Effluent Disposal
Number of Samples Analyzed	--	8	12
Temperature	°C	21.7	23.4
Dissolved Oxygen	MGL	5.4	7.3
Nitrate and Nitrate Nitrogen	MGL as N	0.088	0.002
Ammonia	MGL as N	0.001	0.007
Total Nitrogen	MGL	0.165	0.175
Phosphate	MGL as P	0.043	0.024
Total Phosphorous	MGL as P	0.044	0.037
Chlorophyll a	MGL	--	2.58

Notes:

1. Some mechanical mixing may have influenced the dissolved oxygen in the well and effluent samples.
2. The effluent samples were taken at three locations in the disposal pond.
3. The chlorophyll a mean value is based on only three samples.

phosphorous between inflow and outflow (a gain in one and loss of the other) are most likely due to the variability in the limited data set.

The well supply for this smaller scale lagoon system has a salinity of 33.5 ppt, comprised of 96 percent seawater (at 34.8 ppt) and 4 percent brackish groundwater (at 4.0 ppt). Its nutrient concentrations reflect a straightforward dilution of these two sources. As noted previously, the wells at O'oma are expected to have an even smaller fraction of groundwater in the well supply. In other words, their salinity will be higher and nutrient levels will be lower than in the South Kohala resort example cited above.

Water System for the Ocean Science Center

The ocean science center will include a large (200,000-gallon) tank to exhibit indigenous Hawaiian marine life and other tanks to display marine species from locations around the Pacific Rim (such as Alaska, Malaysia, Mexico, Japan, and New Zealand). Seawater supply for these exhibits is most likely to be from NELHA's surface ocean intake system, although onsite saline wells would be a practical alternative. Circulation rates through these tanks will be much faster than the 10-hour residence time in the system of lagoons. As such, they must be operated independently.

For the 200,000-gallon Hawaiian marine life tank, a flow-through rate of about 2,200 GPM is recommended to achieve a residence time of about 90 minutes. For this rapid turnover, the quality of water discharged from the tank is expected to be quite good. Although very little actual data is available to quantify these changes, they can be reasonably estimated from typical fish densities and feeding practices in aquariums in Hawaii and on the mainland. The following assumptions can be used:

- Tank Volume = 200,000 Gallons (26,740 cubic feet)
- Supply/Disposal Rate = 2,200 GPM
- Living Animal Biomass @ 0.2 lb./ft^3 = 5,350 lbs. in 26,740 ft^3 tank
- Feeding Rate @ 1.0% of biomass weight/day = 54 lbs.
- Nitrogen Production in Fish Waste = 0.54 lbs./day
- Phosphorous Production in Fish Waste = 0.027 lbs./day

If all nitrogen and phosphorous is carried in solution in the outgoing water, then this addition would increase the nitrogen concentration by 1.4 μM (micromolar) and its phosphorous level by 0.03 μM. These levels are far less than in the receiving groundwater and comparable to nearshore surface seawater. Verification of the correct magnitude of the estimate for nitrogen is available from limited Sea Life Park and Honolulu Aquarium data. Both indicate that ammonia increases of 1.5 μM are typical.

Such small increases would not preclude disposal of this water into the 7-acre water recreation park. Alternatively, disposal could be done separately in a series of shallow wells located between the ocean science center and the shoreline.

The display tanks containing exotic species of marine life from around the Pacific Rim should have a different approach to water management to avoid the risk of introducing exotic species into Hawaiian waters. A closed, recirculating system would be most appropriate. Make-up supply could be provided by the NELHA surface seawater system or by onsite saline wells. Water would be recirculated through permanent media filters, treated with ozone, and degassed. A sidestream through bacterial filters to reduce ammonia would also be appropriate. Filter backwash should be subjected to a secondary treatment, including chlorination or ozonation, prior to disposal in shallow wells.

REGIONAL GEOLOGY AND HYDROGEOLOGY

Geological logs for drill holes in the NELHA property immediately north of the O'oma site portray a sequence of lava flows with layers of clinker, vesicular, and vugular basalt. Layer thickness ranges from 1 foot to more than 20 feet, with porosity varying from low (in vugular basalt) to very high (in clinker zones). The nature of the lay down sequence of flow lavas gives rise to significant anisotropy. Ratios 200:1 horizontal to vertical permeability are expectable.

Groundwater beneath the project and in the near vicinity occurs as a thin basal lens of brackish water (described in Table 5 below). Salinity profiling undertaken in NELHA's monitoring wells W-1, W-2 and W-3 show that the salinity of shallow groundwater ranges from 5 ppt at the inland extent of the project site to 9 ppt near the coast. The salinity also increases with depth (refer back to Figure 3). The brackish lens is separated from saline groundwater by a transition (mixing) zone.

Table 5
Basal Lens Levels and Thicknesses Based on Salinity Profiles

NELHA Well	Distance Inland (Feet)	Thickness of the Lens (Feet)	Apparent Mean Water Level (Feet msl)
W-2	300	17	0.42
W-1	5,200	26	0.65

Based on a hydrologic budget analysis for the watershed area tributary to a three-mile wide segment of this coastline centered on the project site, recharge of groundwater by rainfall is estimated to be between 1.0 and 3.0 MGD per coastal mile. For this study, a flow of 2.0 MGD per mile has been used. This is one-quarter to one-third of the rate estimated for South Kohala and only about half the rate which prevails in the area around Keauhou Bay. The low flowrate in the vicinity of O'oma is primarily the result of its far smaller inland watershed area, although the relatively low rainfall rate on the watershed is also a contributing factor.

AQUIFER HYDRAULICS

Monitoring of tidal responses in the NELHA monitoring wells was done in June 1991 to provide estimates of permeability in the flow lavas in the Keahole area. Water level recorders were installed in monitoring wells W-1, W-2, W-2A, W-3A, W-5A and W-6B and observed tidal responses were compared to predicted and measured ocean tides. Table 6 summarizes the tidal attenuation and lag in these wells, along with resulting calculations of shore to well aquifer permeability. For these calculations, it was assumed that the effective aquifer thickness and specific yield are 1,000 feet and 0.15, respectively.

Table 6

Estimated Permeability From Tidal Response Data

Well	Distance Inland (Feet)	Tidal Attenuation (Hx/Ho)	Permeability From Atten. (Feet/Day)	Tidal Lag (Day)	Permeability From Lag (Feet/Day)
W-1	5,200	0.42	33,900	0.075	28,700
W-2	300	0.76	1,100	0.032	500
W-2A	300	0.75	1,000	0.034	500
W-3A	2,180	0.66	25,900	0.038	19,600
W-5A	275	0.84	2,350	0.012	3,100
W-6B	220	0.86	2,000	0.016	1,100

The calculated permeabilities are based on speculative estimates of effective aquifer thickness. It is possible that this thickness increases with distance from the shore due to aquifer anisotropy. If this is the case, the variation in computed permeabilities shown in the table above would be less. However, permeability values would still be lower for the nearshore wells as compared to wells further inland.

NUMERICAL MODELING OF THE AQUIFER

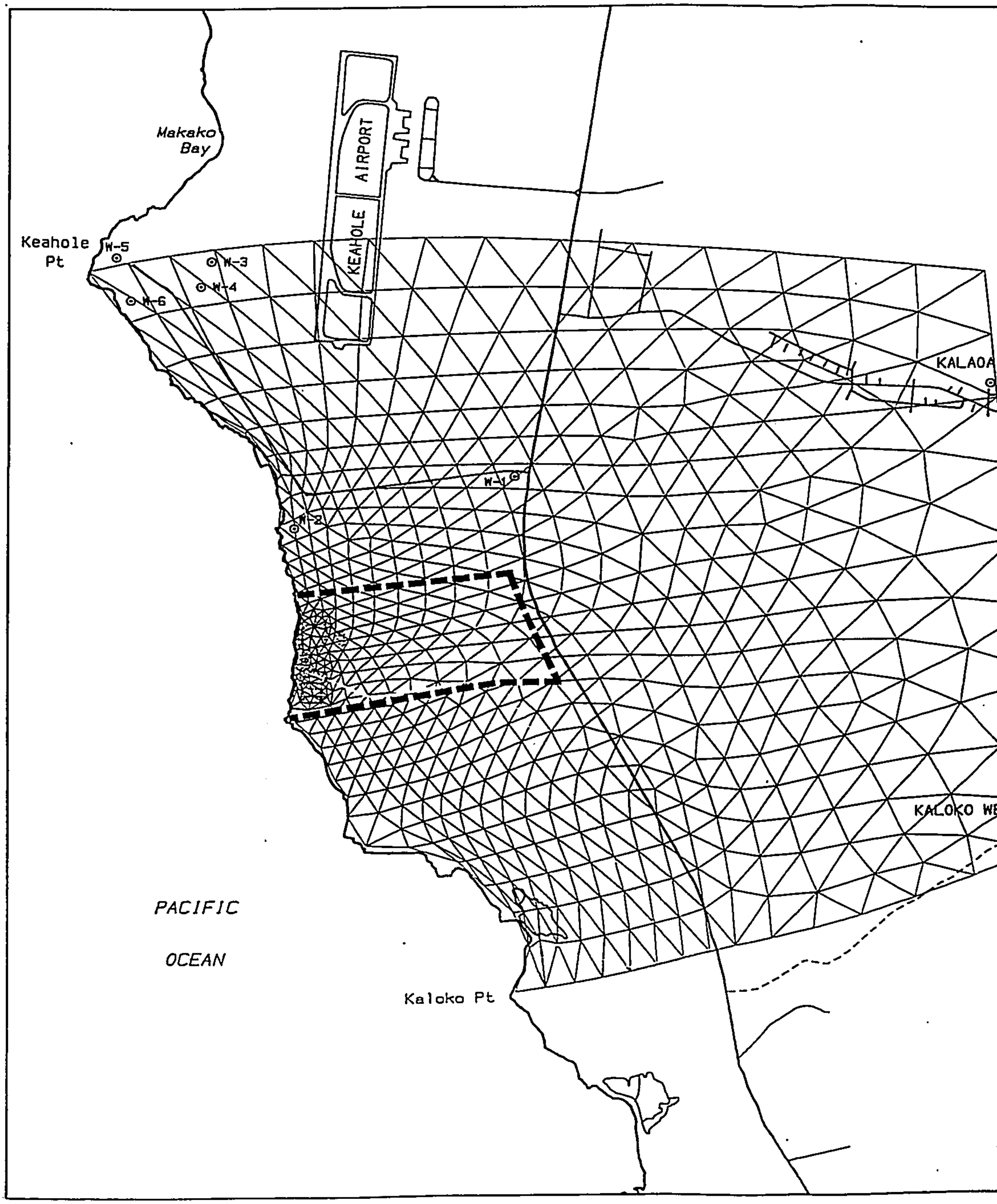
It is difficult to assess the relative contribution of the various components in a hydrogeologic system using classical analytical methods. These methods generally assume aquifer homogeneity in the form of 1-dimensional equations and are more applicable in the assessment of local aquifer response. With a computer based numerical model, however, it is possible to simulate regional conditions and to assess the effect of land use and water budget changes by introducing spatial and temporal variability. Numerical modeling also facilitates sensitivity analyses which will identify the dominant parameters and mechanisms and define areas where additional data should be sought to achieve a more accurate simulation.

For this investigation, areal hydraulic simulations and areal solute transport modeling have been done. Calibrated hydraulic parameters were employed to assess the likely groundwater level changes and salinity distribution resulting from seepage of saline groundwater from the 7-acre water recreation park. The nutrient distribution in groundwater likely to result from golf course percolation has also been simulated.

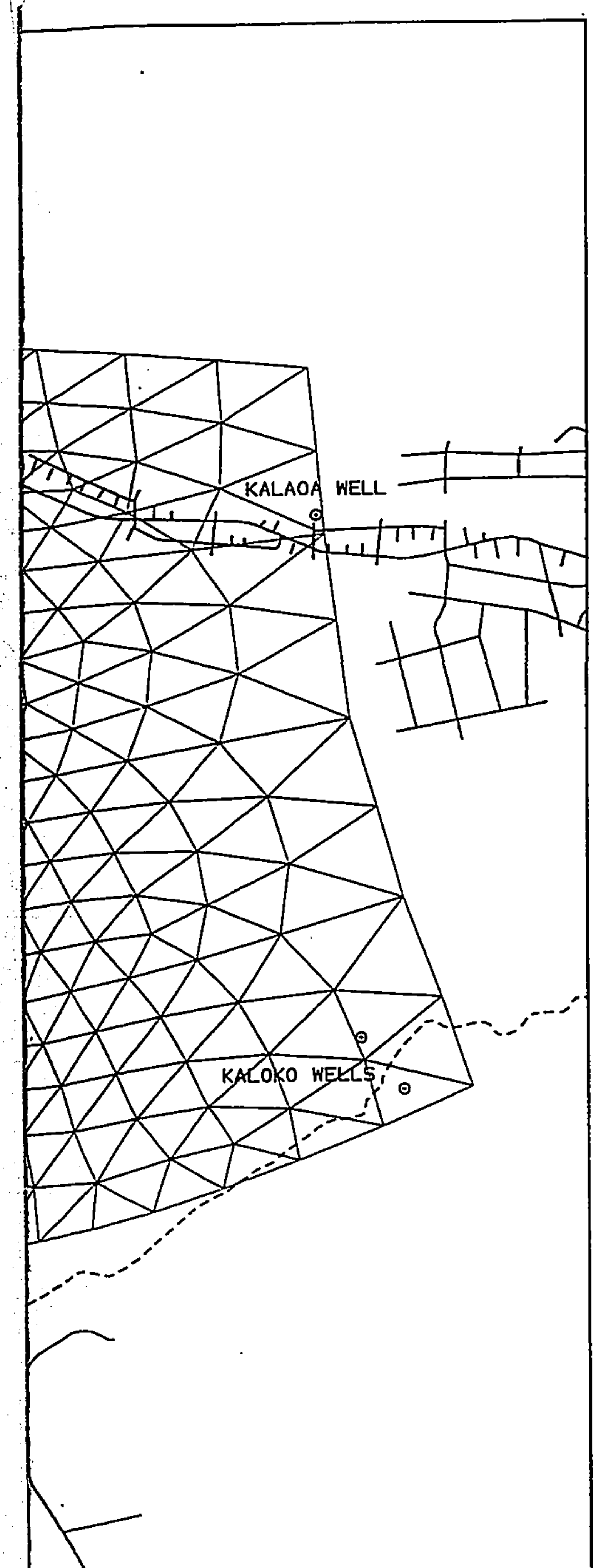
Regional Hydraulic Model

A distributed parameter finite element type scheme (AQUIFEMN, Townley, 1990) was established to simulate the shallow (brackish) groundwater system. The study region was discretised into triangular elements, each capable of simulating vertical fluxes (such as rainfall, infiltration, and percolation from the golf course), aquifer hydraulic properties, and the response of groundwater levels to water management strategies. The regional grid used for this study is comprised of 1097 triangular elements described by 586 nodes at their respective vertices (Figure 5). The finite element mesh utilizes coarse elements at distance from the 7-acre pond to simulate regional conditions and responses. The mesh is finer in the vicinity of the pond to permit a more accurate representation of the localized effects of pond seepage.

The shoreline is the western boundary of the model and its nodes were assigned a constant piezometric head of 0.02 feet. Tidal water level variations at the shoreline were not considered. The model boundaries to the north and south were aligned with regional flow lines (streamlines), meaning that groundwater flows along these boundaries but not across them. The inland boundary of the model is approximately three miles from the coast. This boundary was assigned a uniform flux (groundwater inflow) of 2.0 MGD/mile. During the model calibration process, the sensitivity to this inflow rate was evaluated. Rainfall recharge occurring within the modeled area is not significant and has not been specifically included.



Makako Bay
AIRPORT
KEAHOLE
Keahole Pt
W-5
W-3
W-4
W-6
KALAOA
W-1
W-2
KALOKO WE
PACIFIC
OCEAN
Kaloko Pt



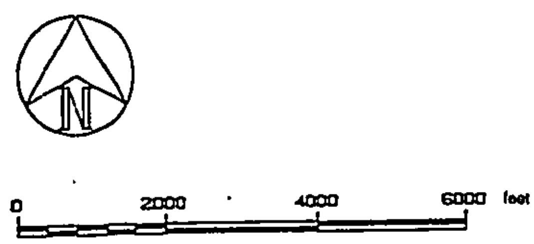
O'OMA II PROJECT
NUMERICAL MODELING OF THE GROUNDWATER SYSTEM

On Behalf Of

TOM NANCE
WATER RESOURCES ENGINEERING

LEGEND:
- Coast
- Roads
- Tracks
- Ponds
- Monitoring Well
- Finite Element Mesh

NOTE:
Base map from US Department of the Interior, Geological Survey, 7.5 minute series (topographic)



FINITE ELEMENT MESH

FIGURE 5

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GROUNDWATER ENGINEERS

For this study, a single-layer representation of the brackish section of the aquifer was used. Aquifer thickness is calculated by the model as a function of the piezometric head assuming that a Ghyben-Herzberg lens exists over all of the modeled region. This assumes that the interface between fresh and salt water is sharp. Although a transition zone from brackish to saltwater is known to exist, a number of studies have shown that the sharp interface assumption is a reasonable approximation for highly transmissive aquifers (Volker, 1980).

Initial efforts to calibrate the numerical model assumed that aquifer permeability was uniform across the modeled area. However, the shape and hydraulic gradients of the basal lens, as defined by data from the NELHA monitoring wells, are not consistent with uniform aquifer permeability. Monitoring of the transmitted tidal signal provides additional evidence that there are significant variations in aquifer permeability. Incorporation of this field data into the numerical model during successive calibrations enabled reasonable matching of field conditions to be achieved. Figure 6 presents the calibrated and observed groundwater surface profiles as a function of distance from the coast. Included for comparison is a profile generated using uniform aquifer permeability. The differences are quite significant. The calibrated permeability increases with distance inland from the coast, reaching a maximum value of 35,000 feet per day. These values are comparable to the magnitude and variation of permeability computed from tidal signal monitoring (Table 6).

Regional groundwater levels for existing conditions as produced by the model are presented in Figure 7. These show low hydraulic gradients over most of the study area and steeper gradients in the several hundred feet next to the shoreline. Water levels predicted at the Kalaoa and Kaloko wells near the inland boundary of the model are approximately 1 foot above sea level. Actual levels measured for these wells, although not considered reliable, are between one and two feet. The influence of coastal embayments and headlands on the path and discharge of groundwater is also evident. Groundwater flow is focused towards coastal embayments (most noticeable immediately north of Kaloko Point) and diverges from headlands (at Keahole Point, for example). Corresponding groundwater flow directions for existing conditions are presented in Figure 8. Vector length on this drawing is in proportion to relative amounts of flux through the aquifer.

Regional Solute Transport Modeling

Extension of the areal hydraulic model to simulate solute transport was achieved by defining appropriate concentrations for each of the boundary conditions specified in the hydraulic model. To simulate existing conditions, salinities are determined by the inflow salinity at the inland boundary, which was set at 8.0 ppt. Since the natural mixing of brackish and salt water in the aquifer was not simulated, the model reproduces this influent salinity everywhere in the model. In other words, the

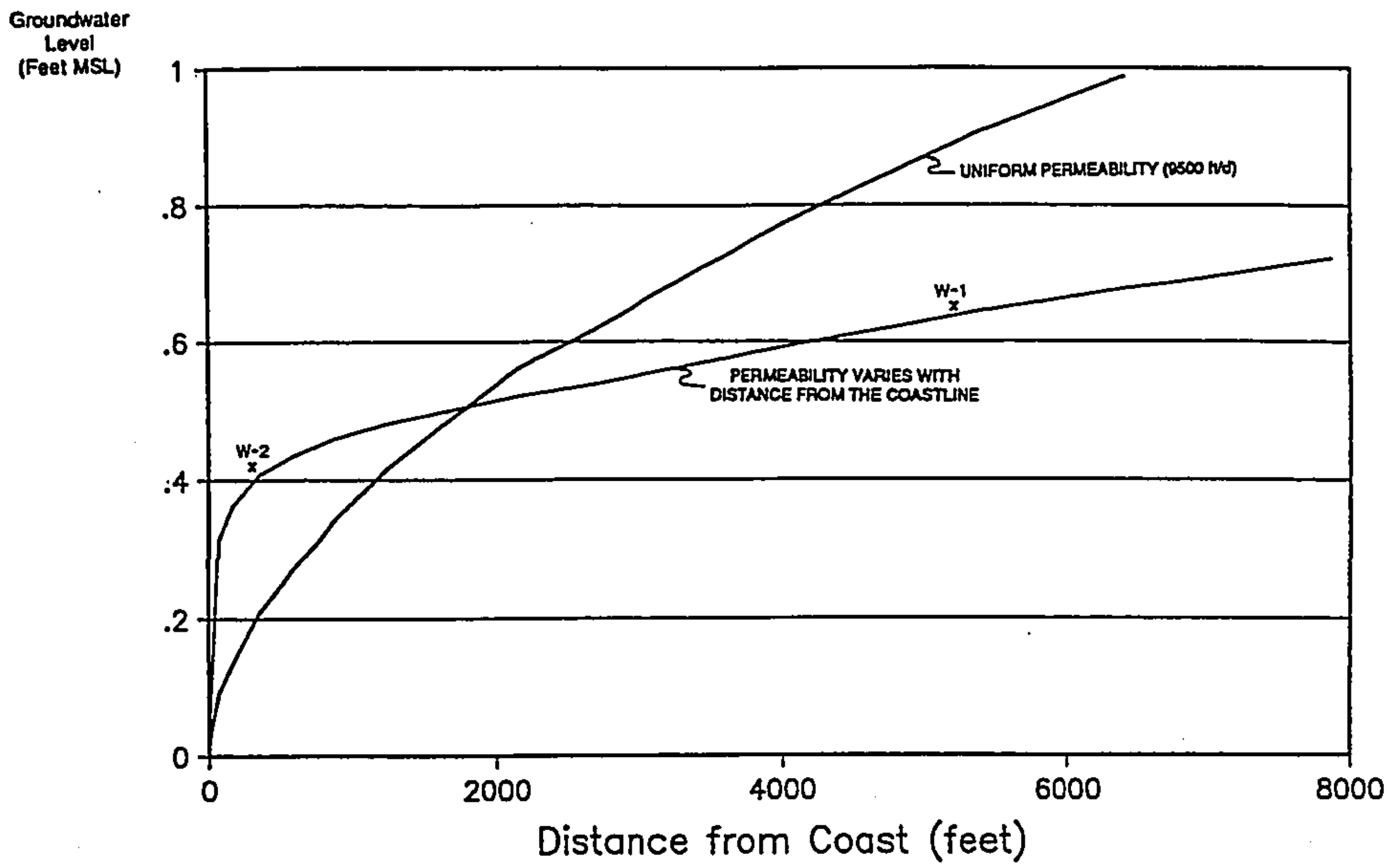
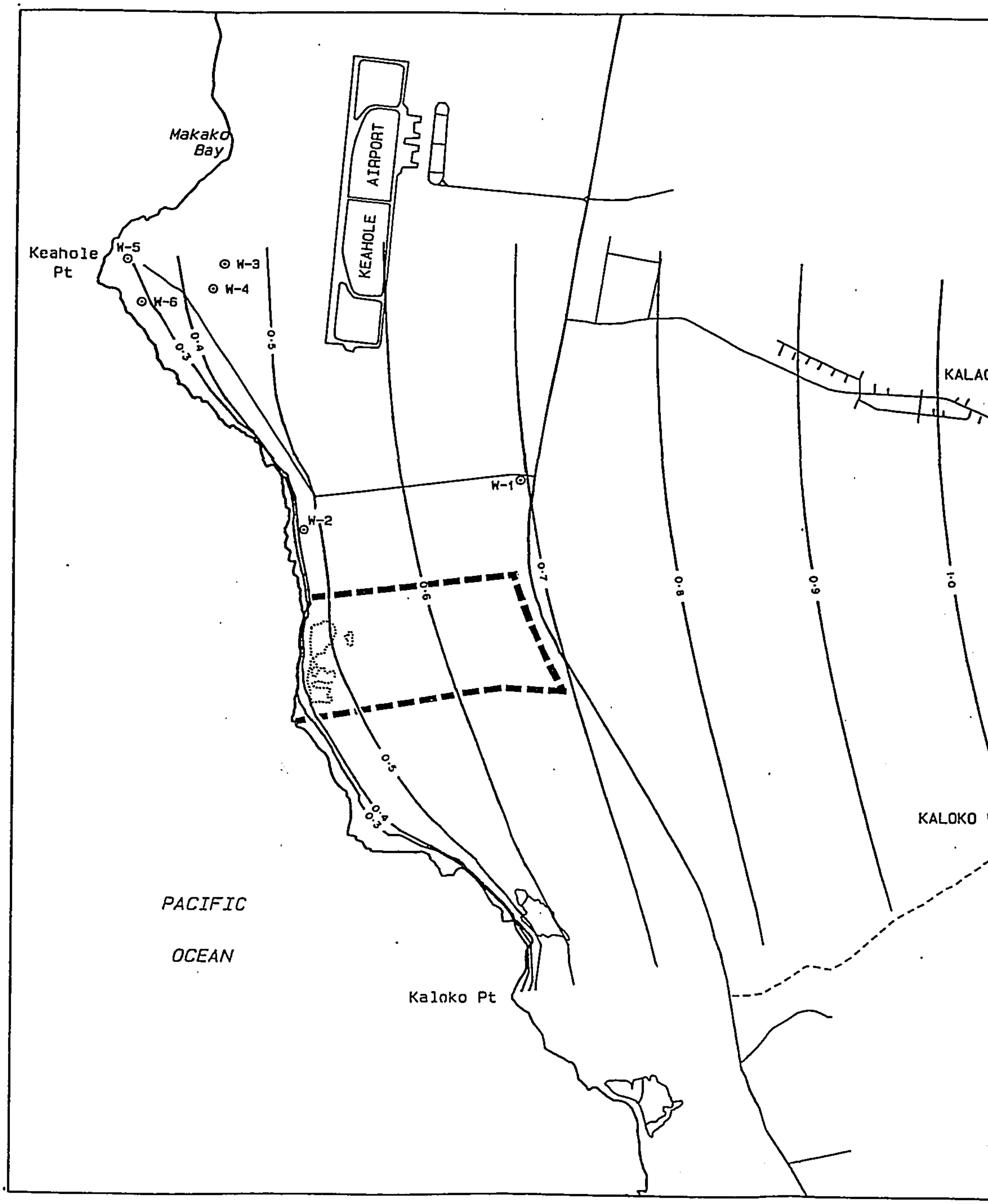
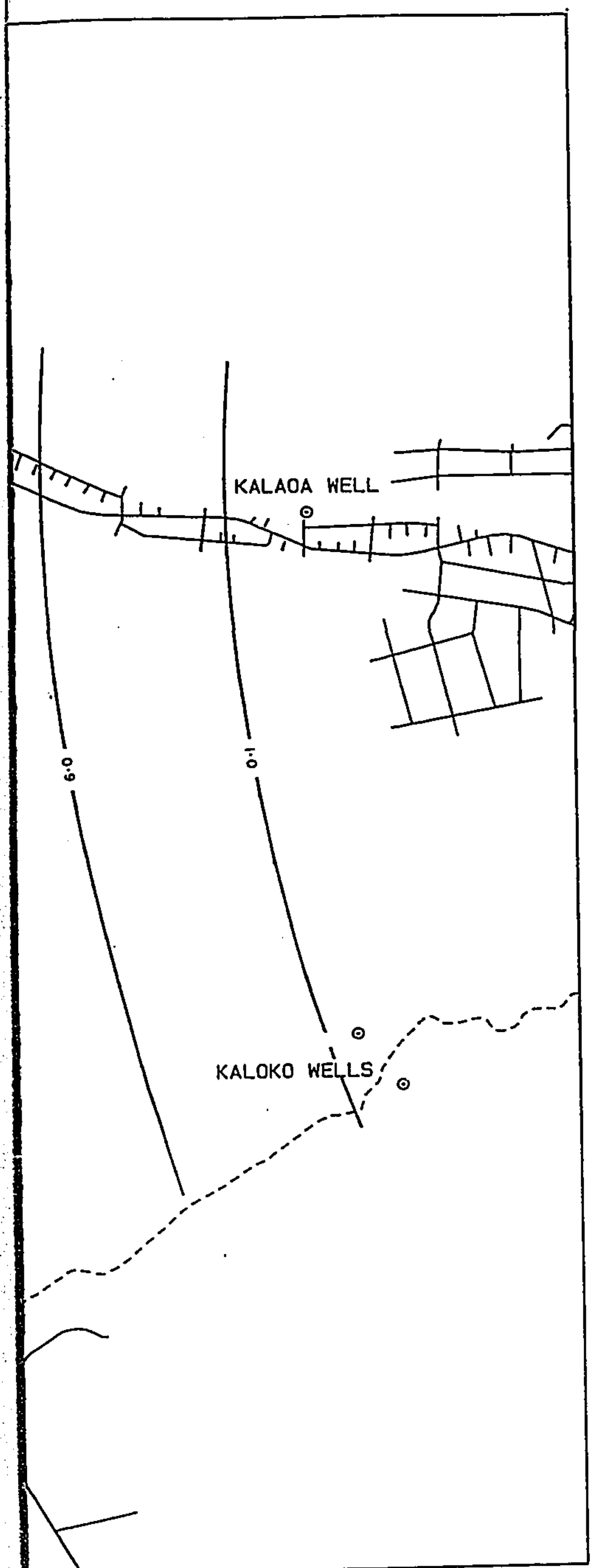


FIGURE 6

MODEL'S CALIBRATED GROUNDWATER LEVEL AS A FUNCTION OF DISTANCE FROM THE SHORELINE


Makako Bay
KEAHOLE AIRPORT
Keahole Pt
W-5
W-3
W-4
W-6
W-1
W-2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
KALAO
KALOKO
PACIFIC
OCEAN
Kaloko Pt



O'OMA II PROJECT
NUMERICAL MODELING OF THE
GROUNDWATER SYSTEM

On Behalf Of

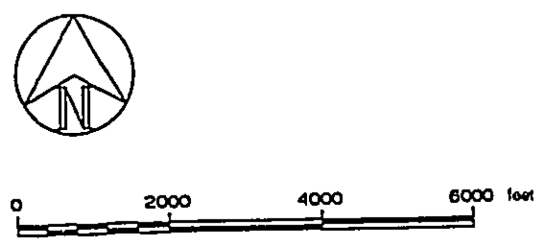
TOM NANCE
WATER RESOURCES ENGINEERING

LEGEND:

- Coast
- Roads
- Tracks
- Ponds
- Monitoring Well
- Water Level Contour (ft MSL)

NOTE:

Base map from US Department of the Interior, Geological Survey, 7.5 minute series (topographic).



PREDICTED GROUNDWATER LEVELS
FOR EXISTING CONDITIONS

FIGURE 7

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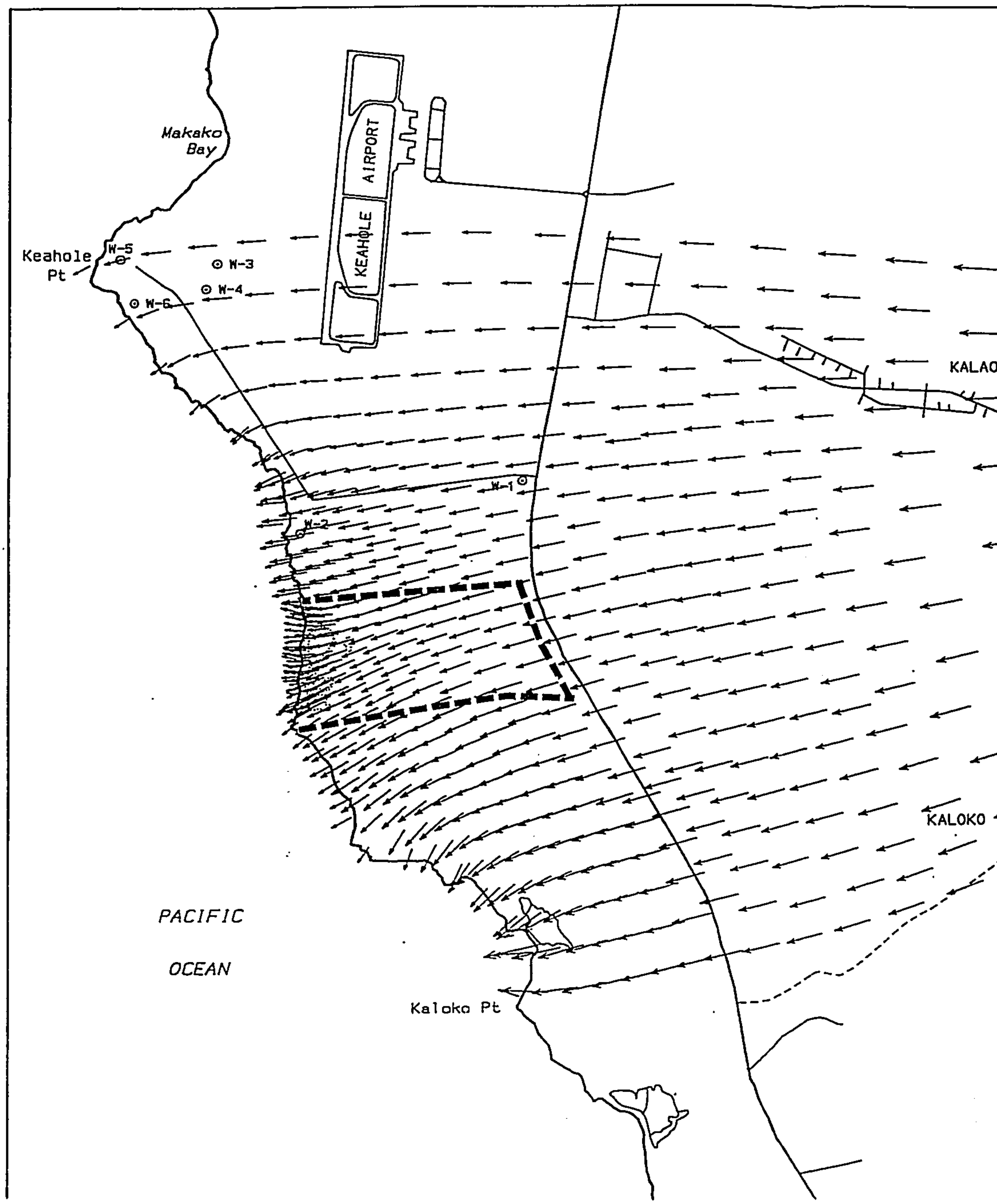
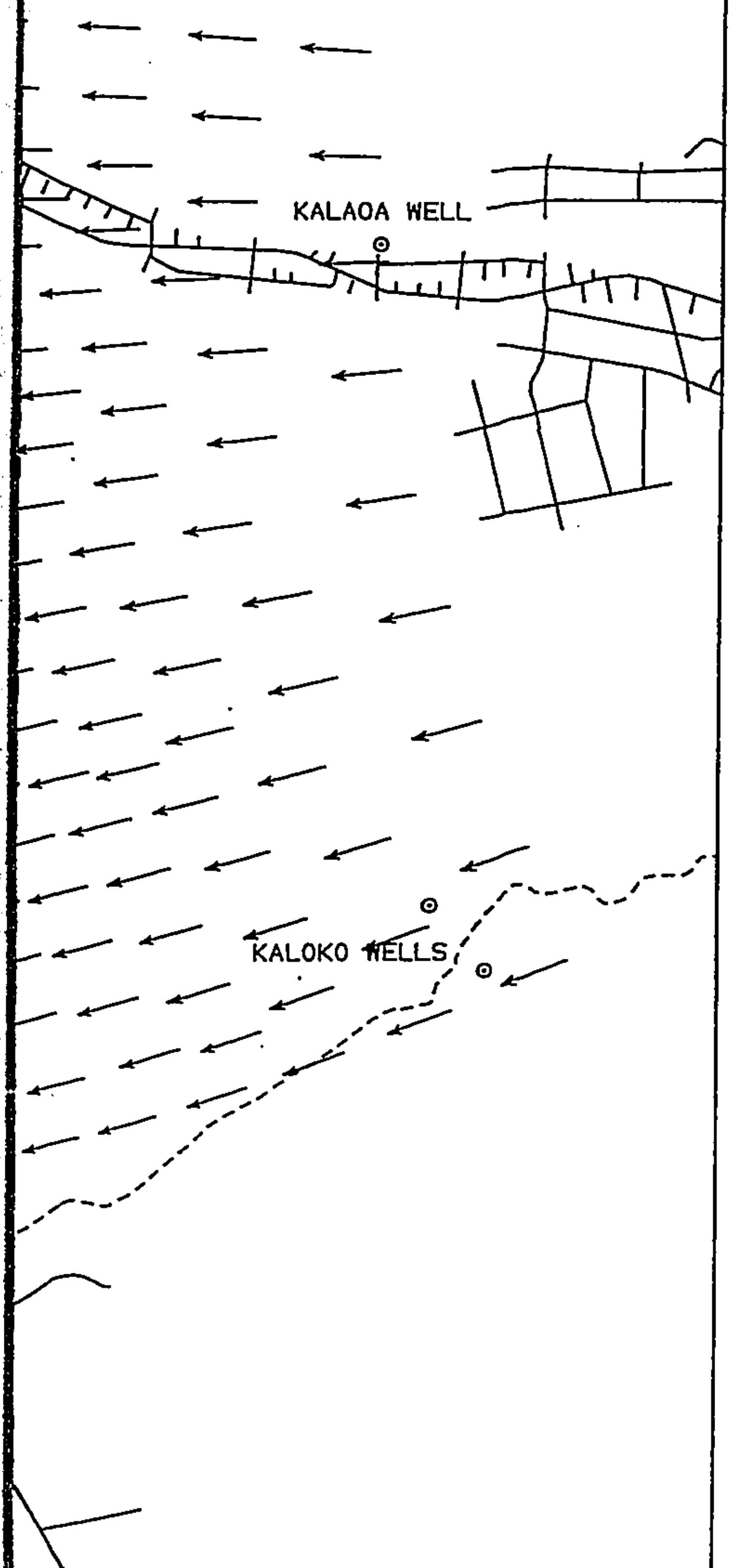
GROUNDWATER ENGINEERS



Makako Bay
Keahole Pt
W-5
W-3
W-4
W-6
AIRPORT
KEAHOLE
KALAO
W-1
W-2
KALOKO
PACIFIC
OCEAN
Kaloko Pt



O'OMA II PROJECT
NUMERICAL MODELING OF THE GROUNDWATER SYSTEM

On Behalf Of

TOM NANCE
WATER RESOURCES ENGINEERING

LEGEND:
- Coast
- Roads
- Tracks
- Ponds
- Monitoring Well

NOTE:
Base map from US Department of the Interior, Geological Survey, 7.5 minute series (topographic)

0 2000 4000 6000 feet

VECTOR SCALE → 50 cu.ft/day/ft

GROUNDWATER FLOW DIRECTIONS FOR EXISTING CONDITIONS

FIGURE 8

Mackie Martin & Associates

actual gradation of salinity which exists in the aquifer, with salinity increasing toward the shoreline and with depth, is not reproduced by the model.

ASSESSMENT OF POTENTIAL GROUNDWATER EFFECTS

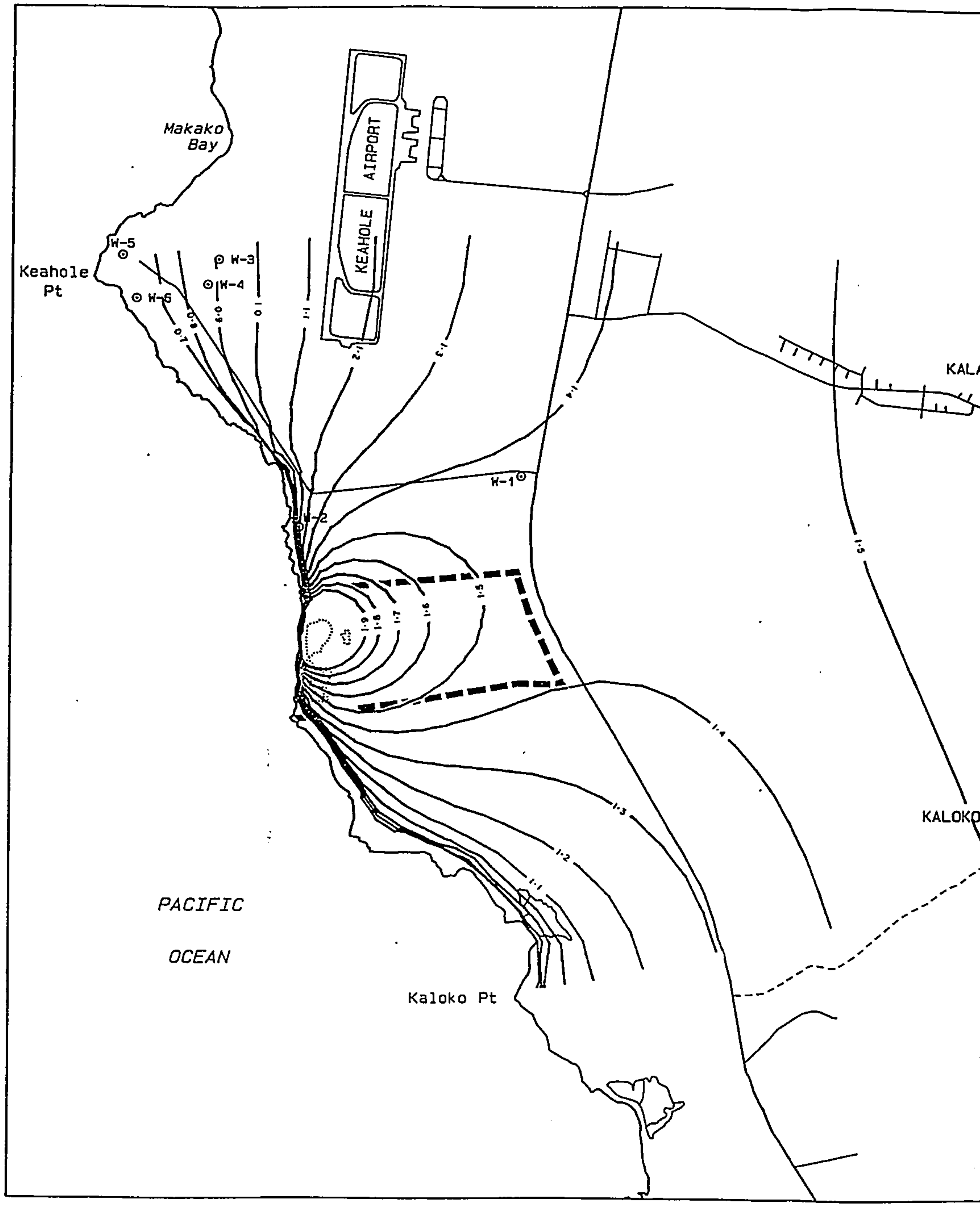
Water Levels and Salinity Distributions

To simulate the effect of seepage from the 7-acre water recreation park next to the shore, it has been assumed that the pond fully penetrates the aquifer. Pond elements were defined as having infinite permeability and a storage coefficient of 1.0. While this ensures that predicted pond levels are physically realistic, it also permits the pond's seepage to occur over the entire aquifer thickness. Another key assumption is that pumping from the supply wells at depth can be achieved without influencing the overlying brackish lens. This assumption draws from experience with similar deep, saline wells elsewhere along the West Hawaii coastline.

Three scenarios have been modeled to demonstrate the potential effect of pond seepage on the brackish lens. Scenario 1 simulates seepage at 25,000 gallons per minute from the 7-acre pond using the calibrated permeability distribution discussed above. Predicted groundwater levels and flow directions for this scenario are presented on Figures 9 and 10, respectively. Local mounding of groundwater as a result of this seepage results in a water level rise 2.4 feet above the existing groundwater level in the pond itself. The seeping water moves away from the pond in all directions. This includes movement inland to a stagnation point, whereupon the water turns and flows toward the shoreline. Water level rise at the inland end of the model is about 0.5 feet (compare Figures 7 and 9). The flux vectors (Figure 10) show the stagnation point to be approximately 7,000 feet inland. The natural flow of brackish groundwater toward the shoreline is diverted north and south around the "mounding" effect of pond seepage.

Mixing saline water seeping from the 7-acre pond (assumed to be 34.5 ppt) with the natural flow of brackish water moving toward the shoreline (at 8.0 ppt) would result in the salinity distribution presented on Figure 11. The mixing zone is approximately 16,000 feet wide for this scenario. This zone of influence extends beyond the property bounds of the O'oma site by 6,500 feet on the north (in the NELHA property) and 6,100 feet to the south (in the Kohanaiki property).

Scenario 1 is based exclusively on the model's calibrated regional permeabilities. As such, it does not reflect, smaller scale effects, specifically lava tubes, shrinkage cracks, clinker zones, and/or seams between lava flows, which are likely to significantly influence the local flow regime between the 7-acre pond and the shoreline. Scenario 2 was created to include such effects, thereby demonstrating



Makako Bay
Keahole Pt
KEAHOLE AIRPORT
W-5
W-6
W-3
W-4
W-1
W-2
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
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1.4
1.3
1.2
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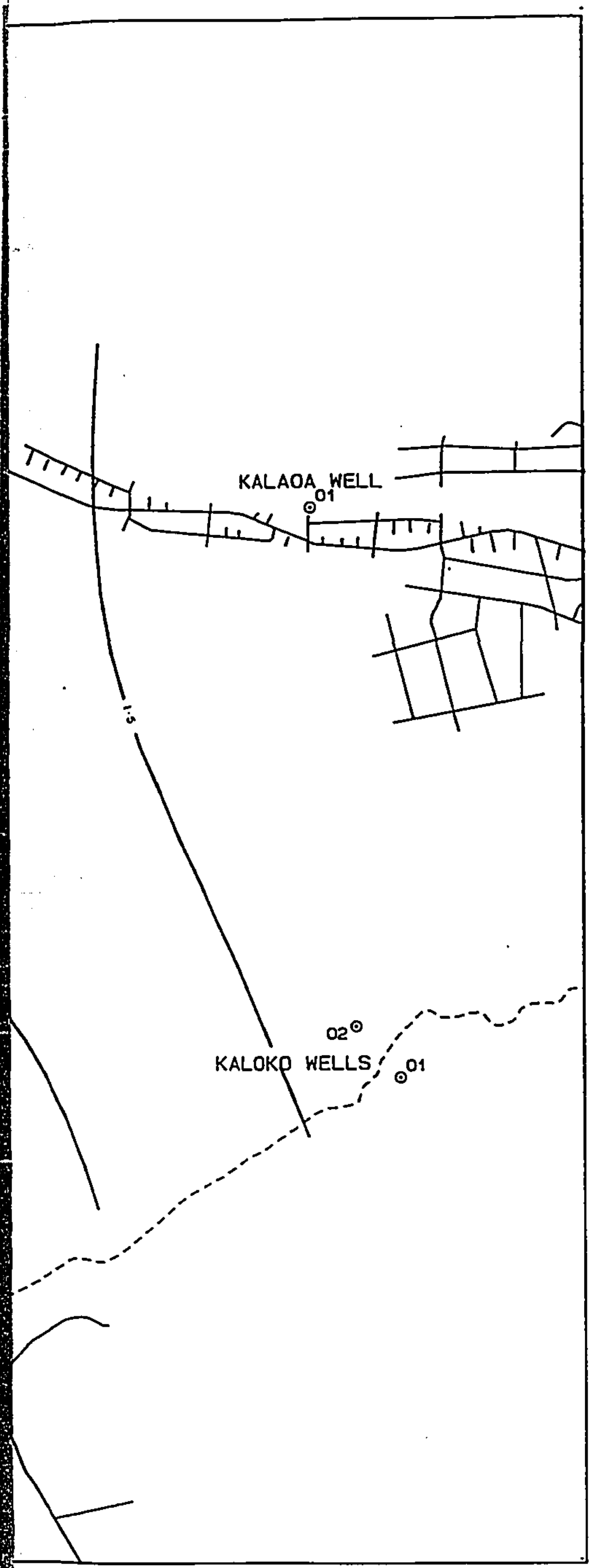
KALA
KALOKO
PACIFIC
OCEAN
Kaloko Pt



O'OMA II PROJECT
NUMERICAL MODELING OF THE
GROUNDWATER SYSTEM

On Behalf Of

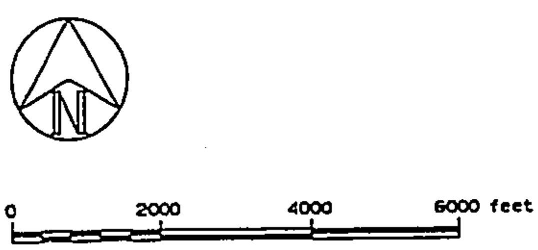
TOM NANCE
WATER RESOURCES ENGINEERING

LEGEND:

- Coast
- Roads
- Tracks
- Ponds
- Monitoring Well
- Water Level Contour (ft MSL)

NOTE:

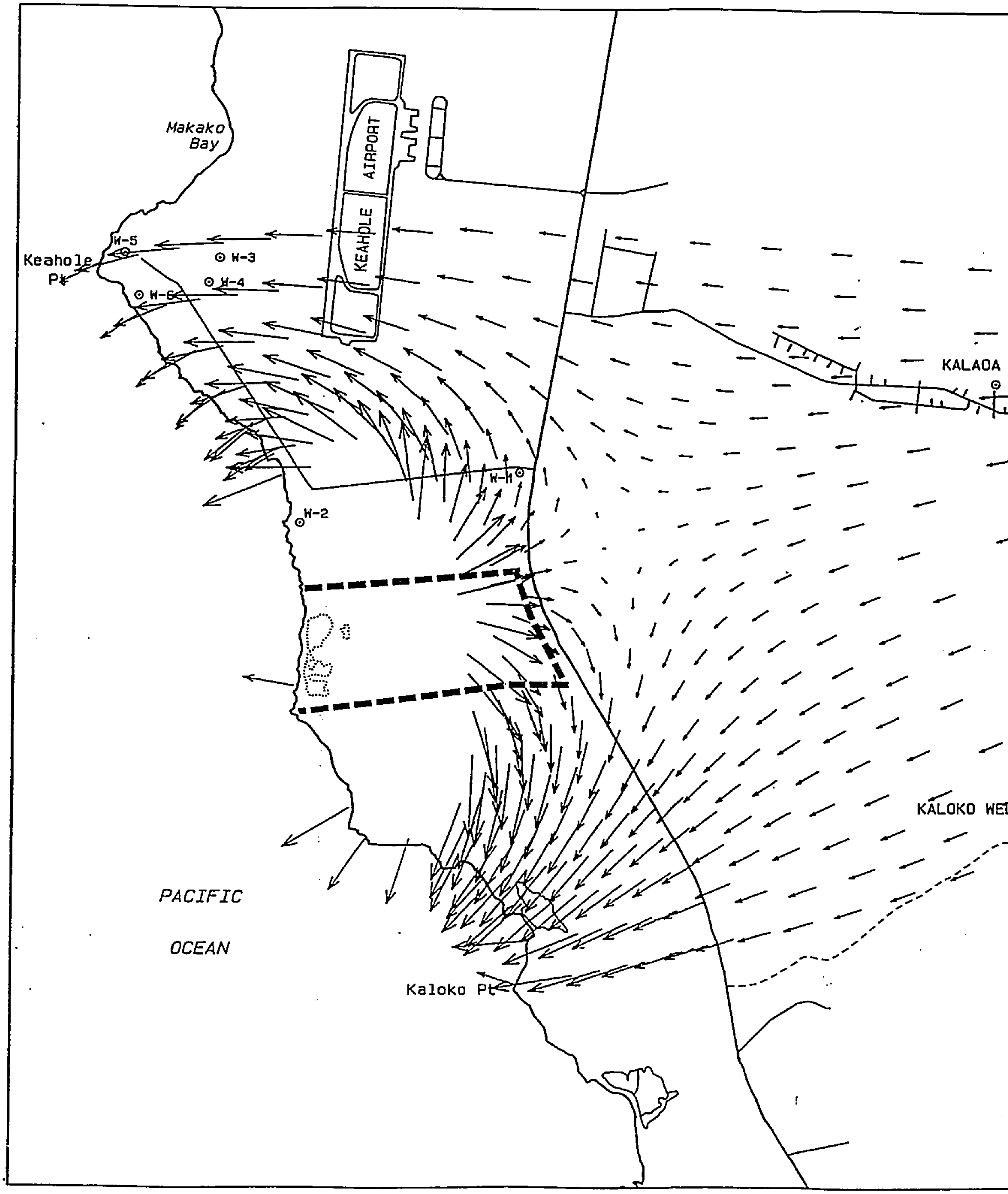
Base map from US Department of the Interior, Geological Survey, 7.5 minute series (topographic).



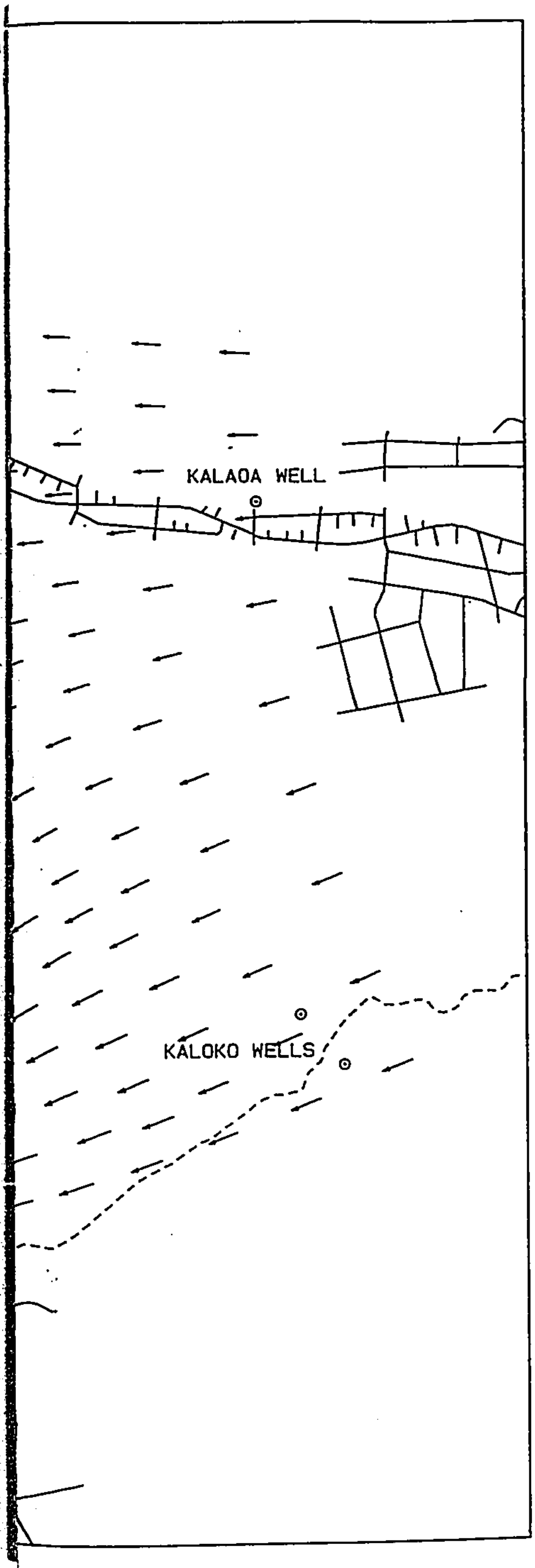
SCENARIO 1
PREDICTED GROUNDWATER LEVELS
AT 25,000 GPM SEEPAGE FROM POND NO. 1

FIGURE 9

Mackie Martin & Associates
GROUNDWATER ENGINEERS



Makako Bay
AIRPORT
KEAHOLE
W-5
Keahole Pt
W-3
W-4
W-6
KALAOA
W-1
W-2
KALOKO WE
PACIFIC
OCEAN
Kaloko Pt



O'OMA II PROJECT
NUMERICAL MODELING OF THE
GROUNDWATER SYSTEM

On Behalf Of

TOM NANCE
WATER RESOURCES ENGINEERING

LEGEND:
- Coast
- Roads
- Tracks
- Ponds
- Monitoring Well

NOTE:

Base map from US Department of the Interior, Geological Survey, 7.5 minute series (topographic).

0 2000 4000 6000 feet

VECTOR SCALE ⟶ 50 cu.ft/day/ft

SCENARIO 1
GROUNDWATER FLOW DIRECTIONS
AT 25,000 GPM SEEPAGE FROM POND NO. 1

FIGURE 10

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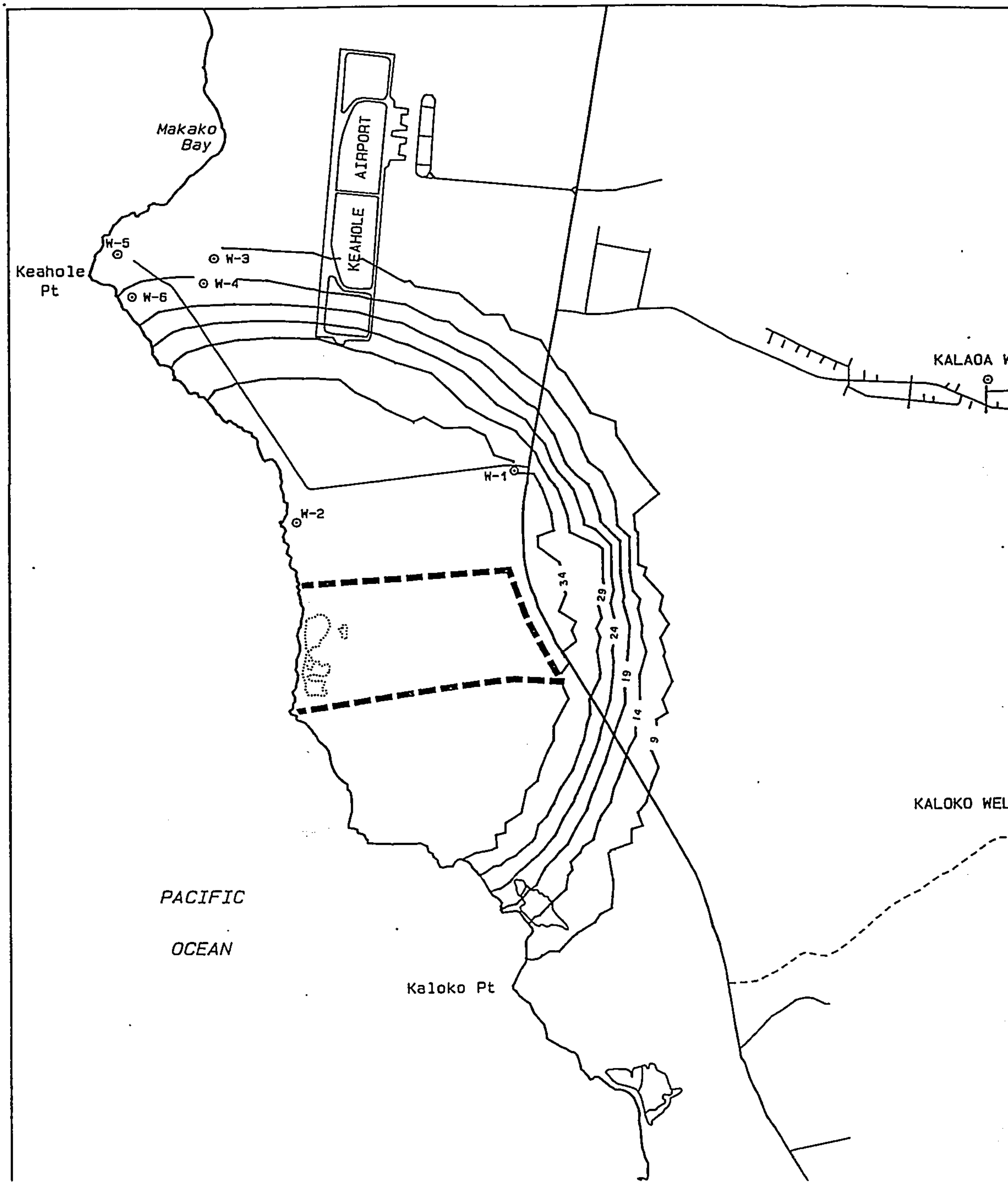
GROUNDWATER ENGINEERS



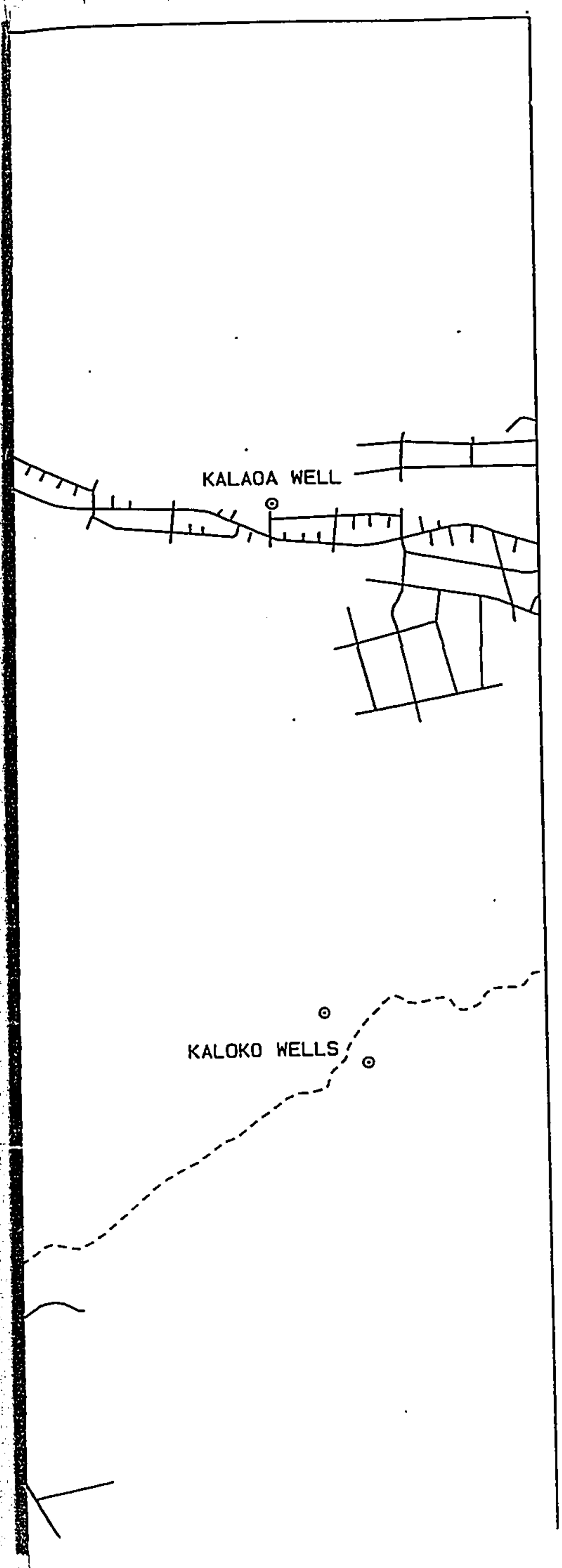
Makako Bay
AIRPORT
KEAHOLE
Keahole Pt
W-5
W-3
W-4
W-6
W-1
W-2
KALAOA
KALOKO WEL
34
29
24
19
14
9
PACIFIC
OCEAN
Kaloko Pt

O'OMA II PROJECT
NUMERICAL MODELING OF THE GROUNDWATER SYSTEM

On Behalf Of

TOM NANCE

WATER RESOURCES ENGINEERING



LEGEND:

- Coast
- Roads
- Tracks
- Ponds
- Monitoring Well
- Salinity Contour (ppt)

NOTE:

Base map from US Department of the Interior, Geological Survey, 7.5 minute series (topographic).

0 2000 4000 6000 feet

SCENARIO 1
PREDICTED SALINITY DISTRIBUTION
AT 25,000 GPM SEEPAGE FROM POND NO. 1

FIGURE 11

Mackie Martin & Associates
GROUNDWATER ENGINEERS

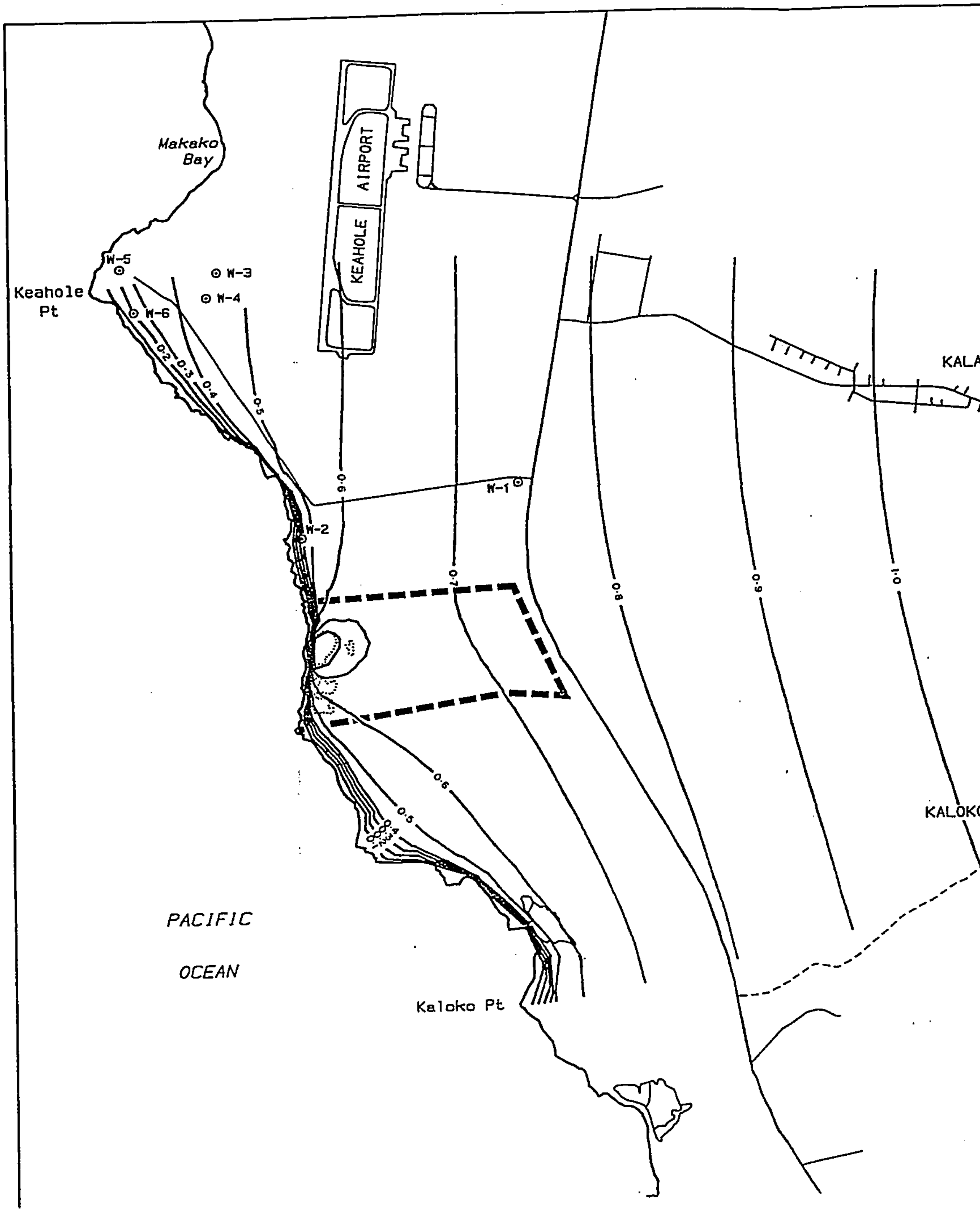
more realistic head build-up and salinity responses in the receiving groundwater. This was achieved by including more permeable elements in the model between the pond and the shoreline to simulate the impact of local scale voids, cracks, and lava tubes. The regional influence of such voids is generally limited because these features are not typically interconnected over great distances. At the local scale, however, groundwater movement is substantially influenced by such features.

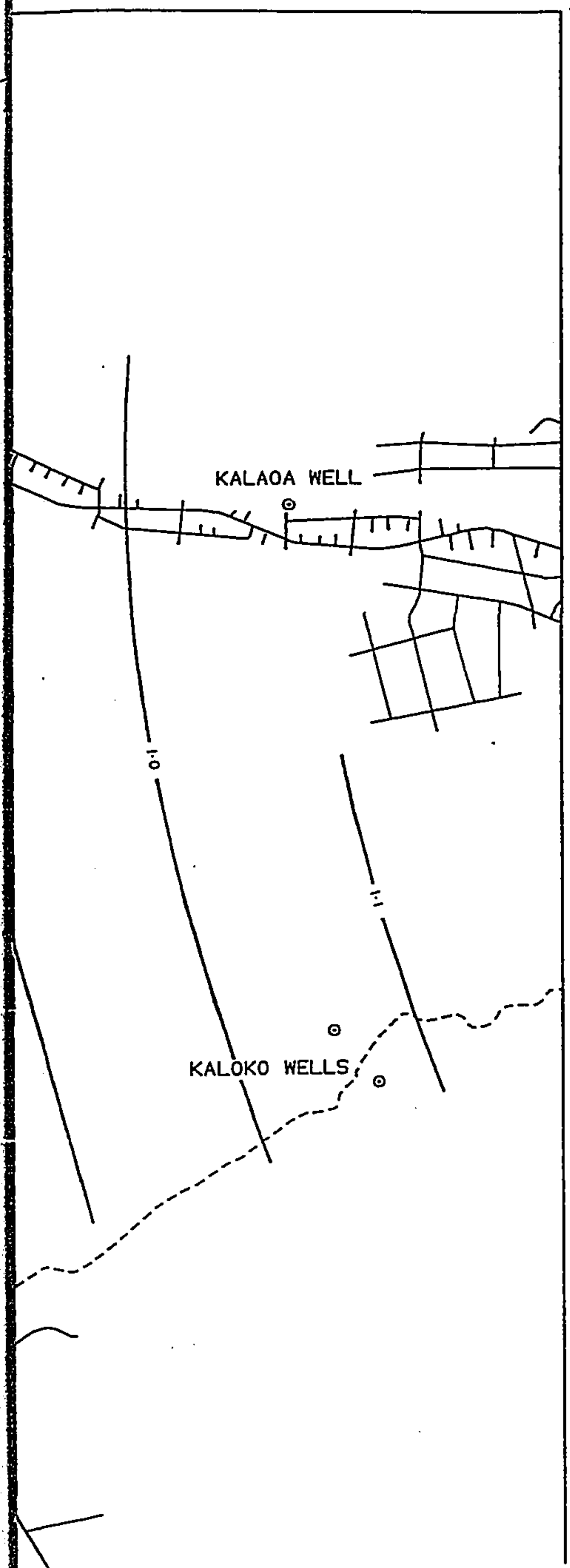
When these local scale effects are considered, a significantly smaller response in groundwater to pond seepage results. A number of simulations were completed to evaluate the sensitivity of regional water levels to the presence of such local scale voids. This was achieved by incorporating a 200-foot wide zone of higher average permeability (the width of one element) between the pond and the shore. These elements were assigned a permeability of 250,000 feet per day (as compared to the inland regional permeability of 35,000 feet per day). The resulting water levels are shown on Figure 12. The rise in the pond would be less than 0.4 feet (as compared to 2.4 feet for Scenario 1). The rise in groundwater level at the inland boundary of the model would be 0.1 feet (versus 0.5 feet for Scenario 1). Corresponding groundwater flow directions, presented in Figure 13, show a stagnation point approximately 2,000 feet inland. The streamlines separating the seepage water flow from diverted brackish groundwater flow are 1,100 feet north and 1,900 feet south of the O'oma property.

The predicted salinity distribution for Scenario 2 is illustrated on Figure 14. It shows a much reduced impact of pond seepage on the brackish lens salinity. For example, a salinity increase of 2 to 3 ppt is predicted at NELHA monitoring well W-2. For Scenario 1, predicted salinity at this location is 34 ppt.

In the absence of site specific information on local scale effects, the simulations of Scenario 2 are considered to reasonably portray probable effects on groundwater by seepage of 25,000 GPM. Although these effects are modest and would not create an adverse impact, the predicted area of influence would extend beyond the O'oma II project bounds. Because of this, a third scenario was created to establish the magnitude of seepage that could occur from the 7-acre pond without influencing groundwater beyond the O'oma II property. The local-scale effects incorporated in Scenario 2 were also included in this scenario.

Simulation of this scenario indicates that groundwater changes could be confined to the project's property at a seepage rate of approximately 10,000 GPM. The water level in the pond would be approximately 0.1 feet above the existing groundwater level and the "mounding" effect of seepage would be as shown on Figure 15. Corresponding flow vectors and salinity distributions are shown on Figures 16 and 17, respectively. All groundwater effects would be essentially confined to the O'oma II property.


Makako Bay
KEAHOLE AIRPORT
Keahole Pt
W-5
W-6
W-3
W-4
W-1
W-2
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
KALA
KALOKO
PACIFIC OCEAN
Kaloko Pt



O'OMA II PROJECT
NUMERICAL MODELING OF THE
GROUNDWATER SYSTEM

On Behalf Of

TOM NANCE
WATER RESOURCES ENGINEERING

LEGEND:

- Coast
- Roads
- Tracks
- Ponds
- Borehole
- Water Level Contour (ft MSL)

NOTE:

Base map from US Department of the Interior, Geological Survey, 7.5 minute series (topographic)

N

0 2000 4000 6000 feet

SCENARIO 2
PREDICTED GROUNDWATER LEVELS
AT 25,000 GPM SEEPAGE FROM POND NO. 1

FIGURE 12

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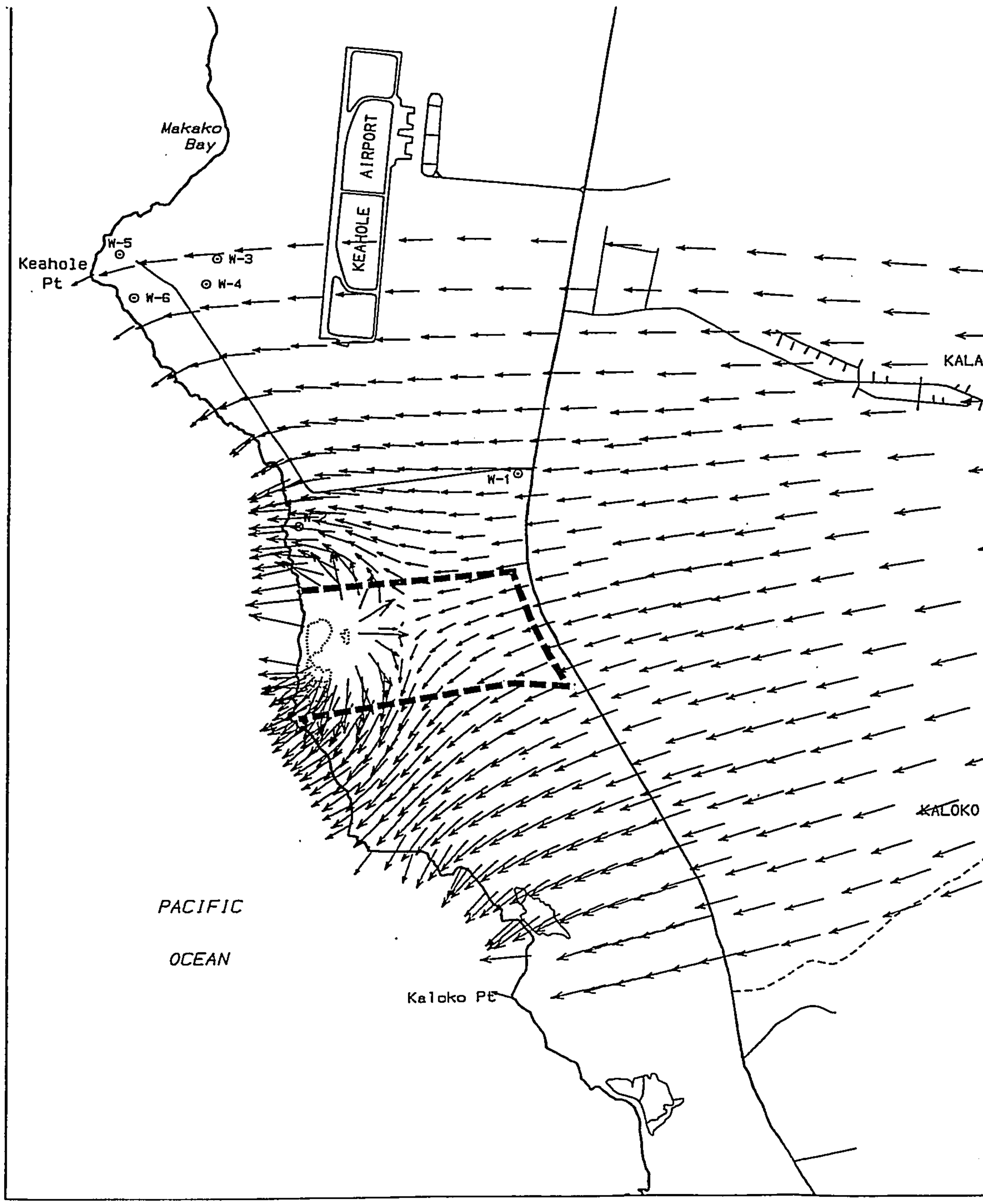
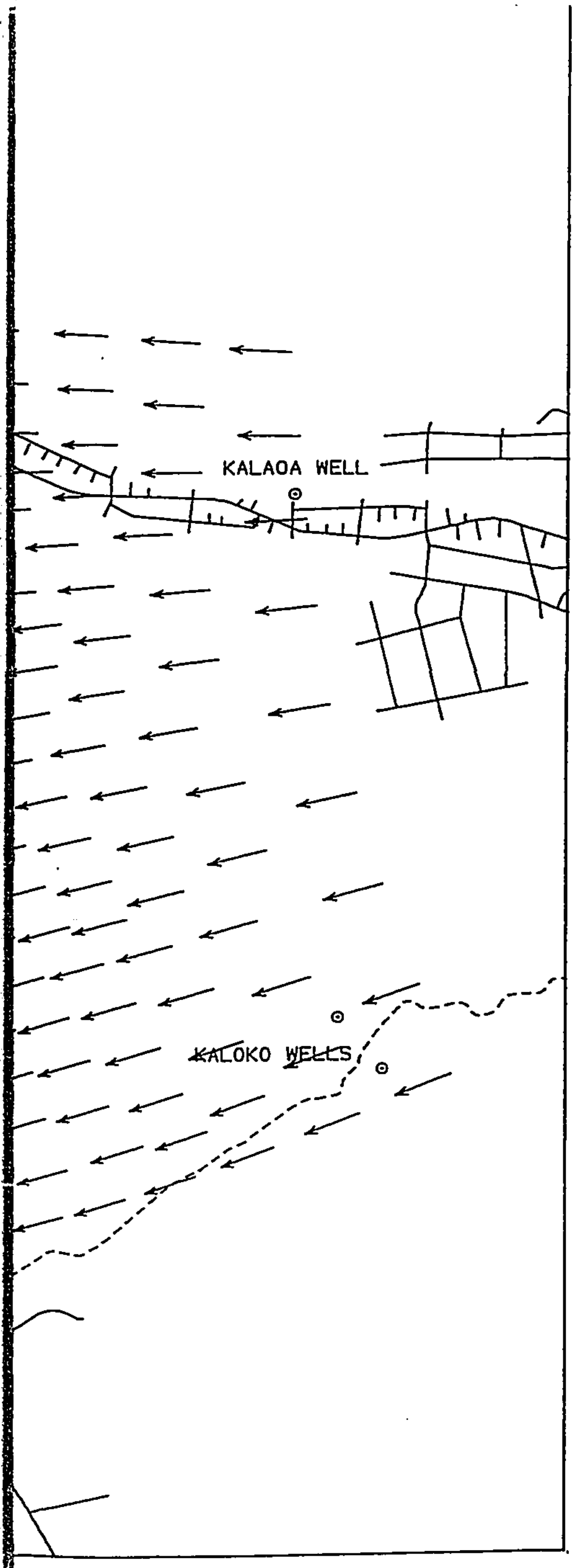
GROUNDWATER ENGINEERS



Makako Bay
Keahole Pt
W-5
W-3
W-4
W-6
KEAHOLE AIRPORT
KALA
W-1
W-2
KALOKO
PACIFIC OCEAN
Kaloko Pt



O'OMA II PROJECT
NUMERICAL MODELING OF THE GROUNDWATER SYSTEM

On Behalf Of

TOM NANCE
WATER RESOURCES ENGINEERING

LEGEND:
- Coast
- Roads
- Tracks
- Ponds
- Monitoring Well

NOTE:

Base map from US Department of the Interior, Geological Survey, 7.5 minute series (topographic)

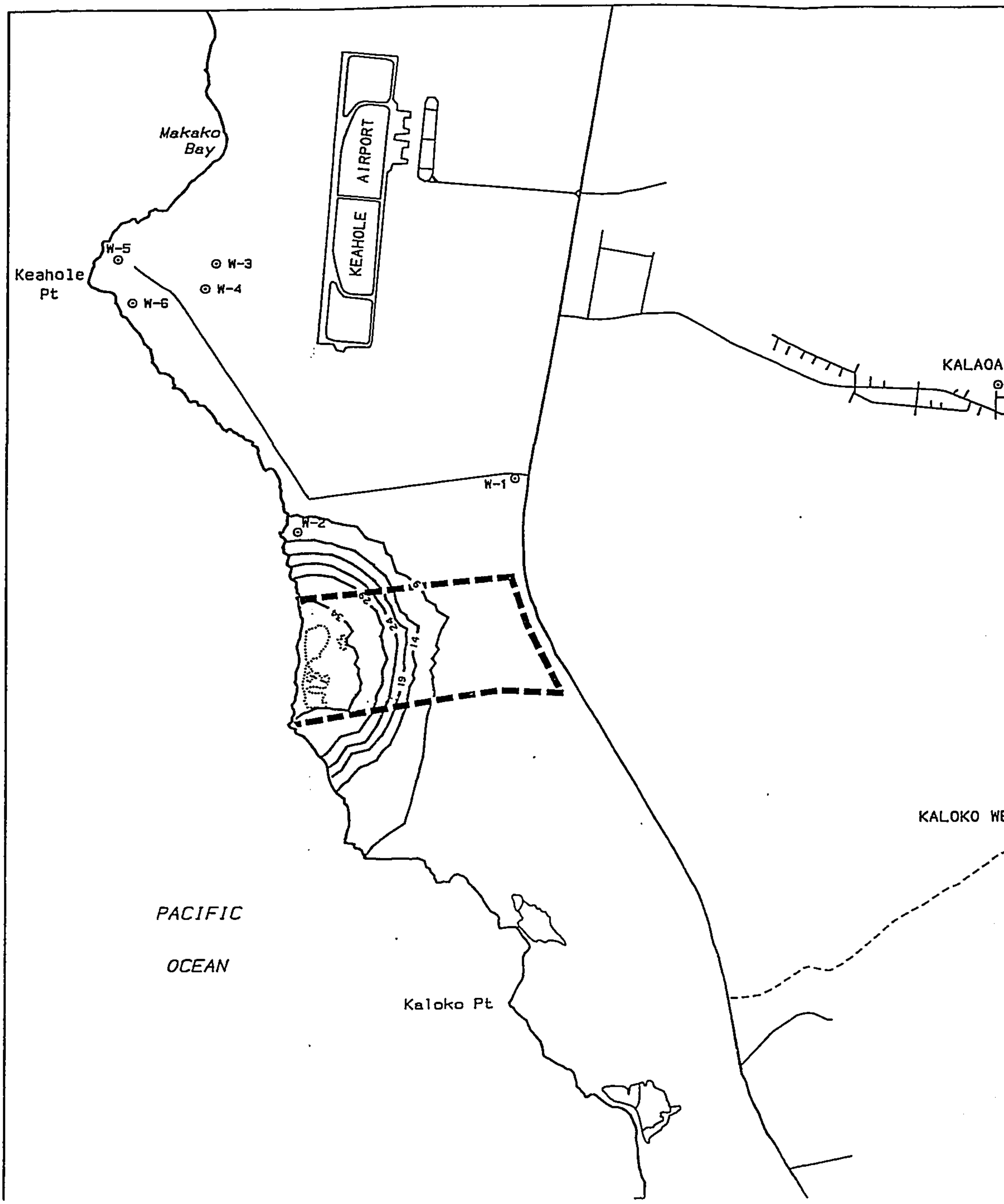
0 2000 4000 6000 feet

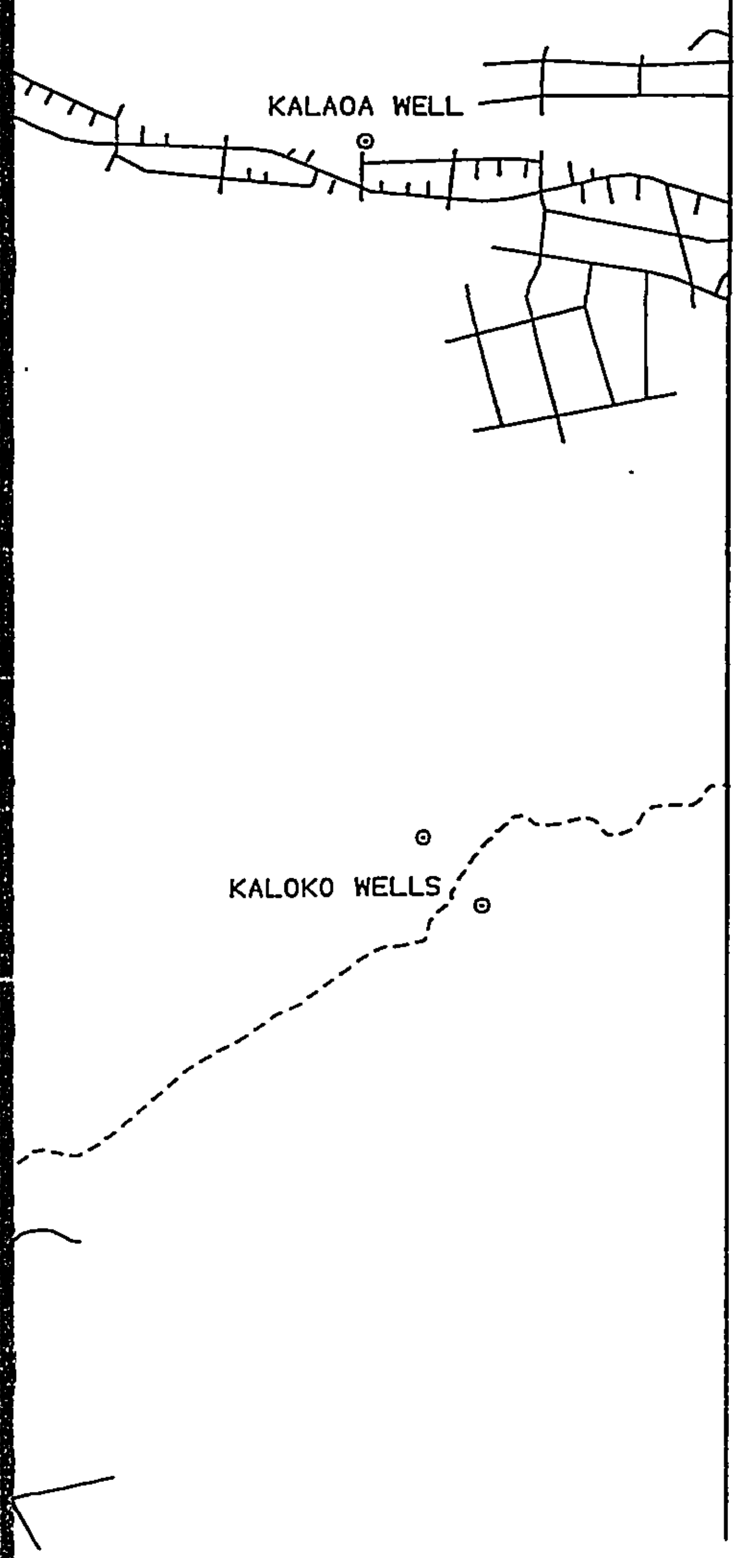
VECTOR SCALE ⟶ 50 cu.ft/day/ft

SCENARIO 2
GROUNDWATER FLOW DIRECTIONS
AT 25,000 GPM SEEPAGE FROM POND NO. 1

FIGURE 13

Mackie Martin & Associates
GROUNDWATER ENGINEERS


Makako Bay
KEAHOLE AIRPORT
Keahole Pt
W-5
W-3
W-4
W-6
W-1
W-2
KALAOA
34
29
24
19
14
PACIFIC OCEAN
Kaloko Pt



O'OMA II PROJECT
NUMERICAL MODELING OF THE
GROUNDWATER SYSTEM

On Behalf Of

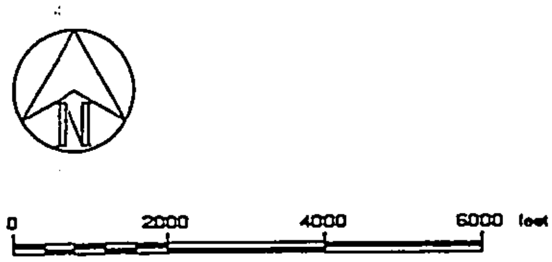
TOM NANCE
WATER RESOURCES ENGINEERING

LEGEND:

- Coast
- Roads
- Tracks
- Ponds
- Borehole
- Salinity Contour (ppt)

NOTE:

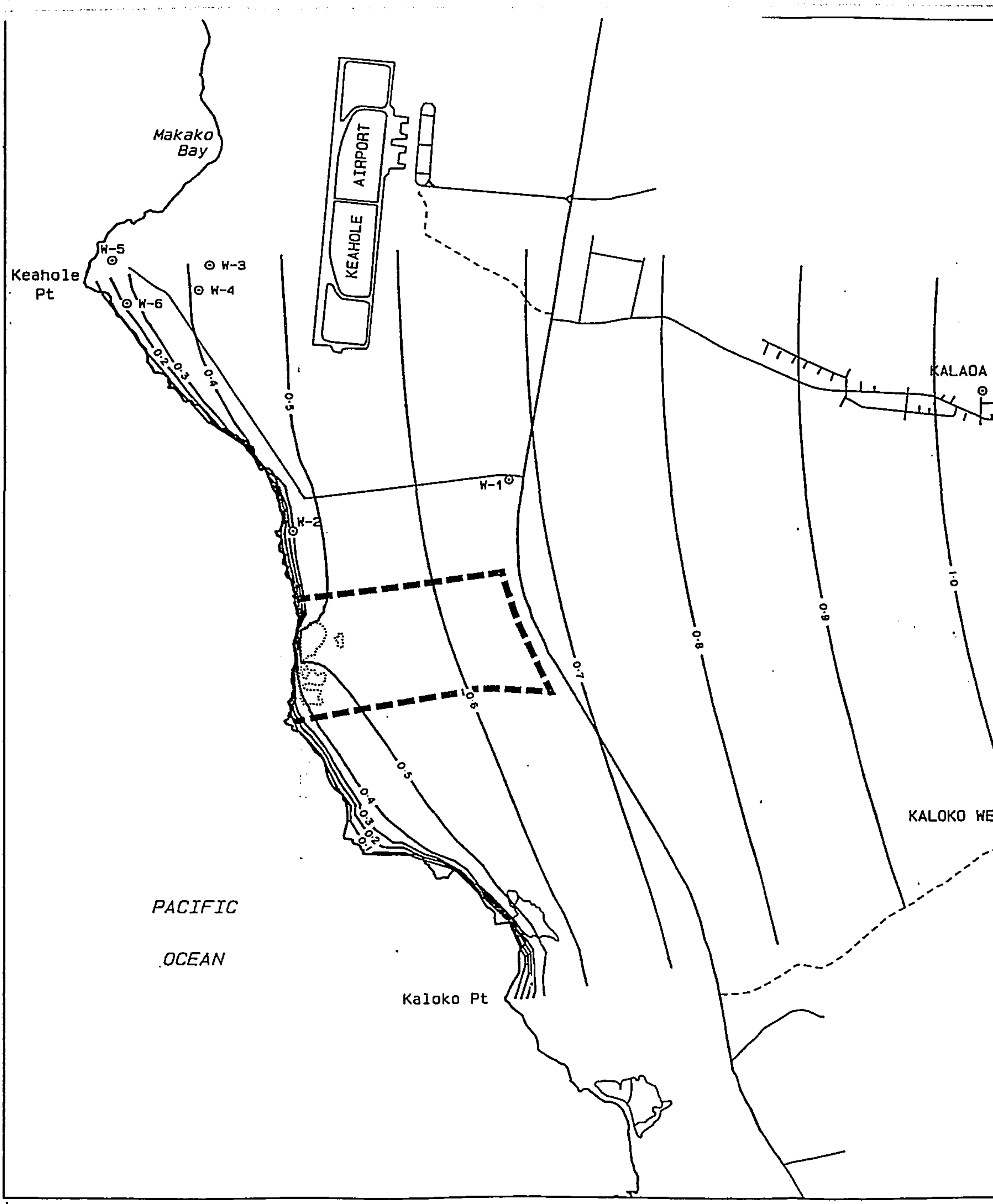
Base map from US Department of the Interior, Geological Survey, 7.5 minute series (topographic)



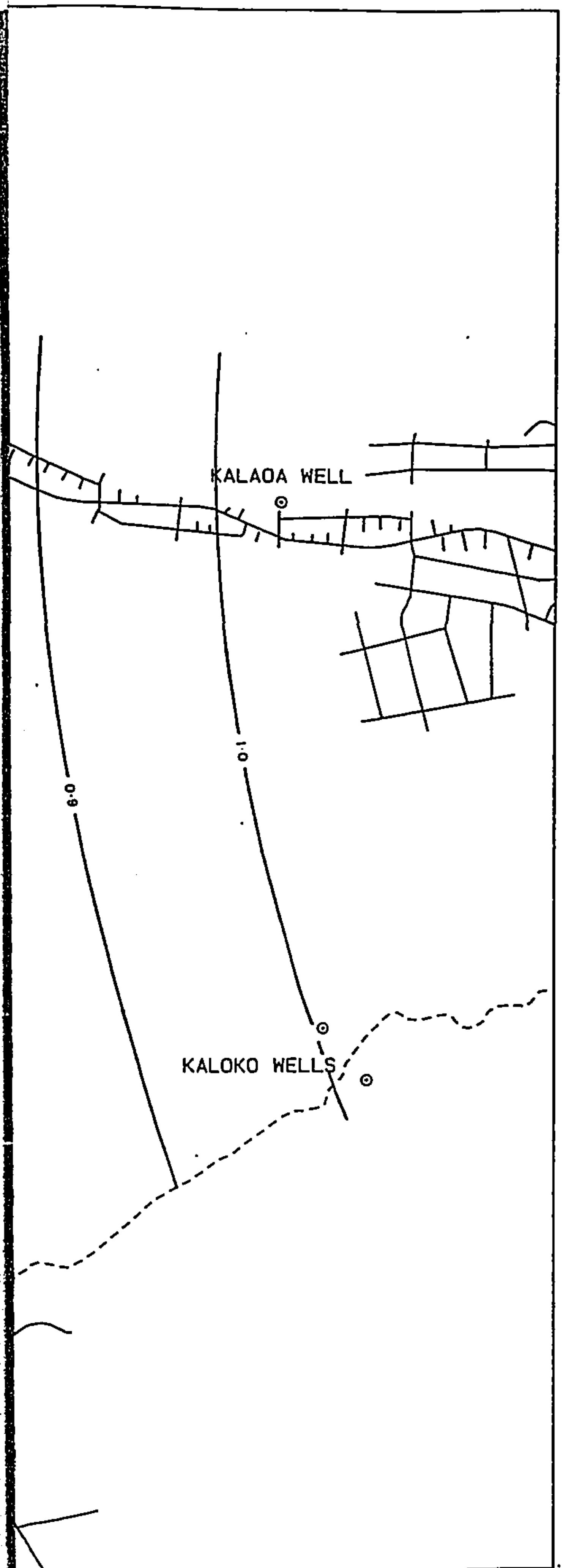
SCENARIO 2
PREDICTED SALINITY DISTRIBUTION
AT 25,000 GPM SEEPAGE FROM POND NO. 1

FIGURE 14

Mackie Martin & Associates



Makako Bay
KEAHOLE AIRPORT
Keahole Pt
W-5
W-6
W-3
W-4
W-1
W-2
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0.1
KALAOA
KALOKO WE
PACIFIC OCEAN
Kaloko Pt



O'OMA II PROJECT
NUMERICAL MODELING OF THE
GROUNDWATER SYSTEM

On Behalf Of

TOM NANCE
WATER RESOURCES ENGINEERING

LEGEND:
- Coast
- Roads
- Tracks
- Ponds
- Borehole
- Water Level Contour (ft MSL)

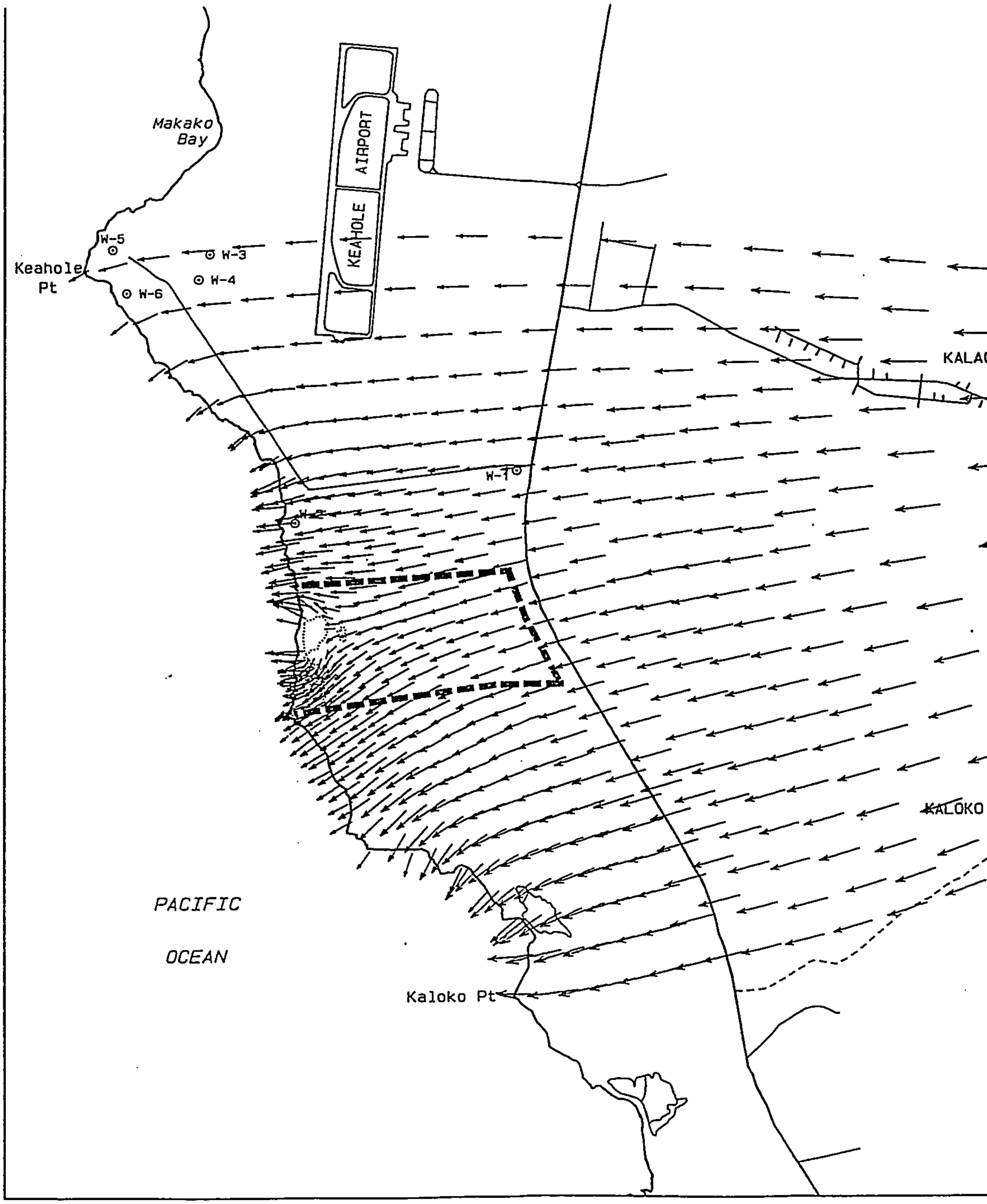
NOTE:
Base map from US Department of the Interior, Geological Survey, 7.5 minute series (topographic).

0 2000 4000 6000 feet

SCENARIO 3
PREDICTED GROUNDWATER LEVELS
FOR SEEPAGE OF 10,000 GPM
FROM POND NO. 1

FIGURE 15

Mackie Martin & Associates
GROUNDWATER ENGINEERS

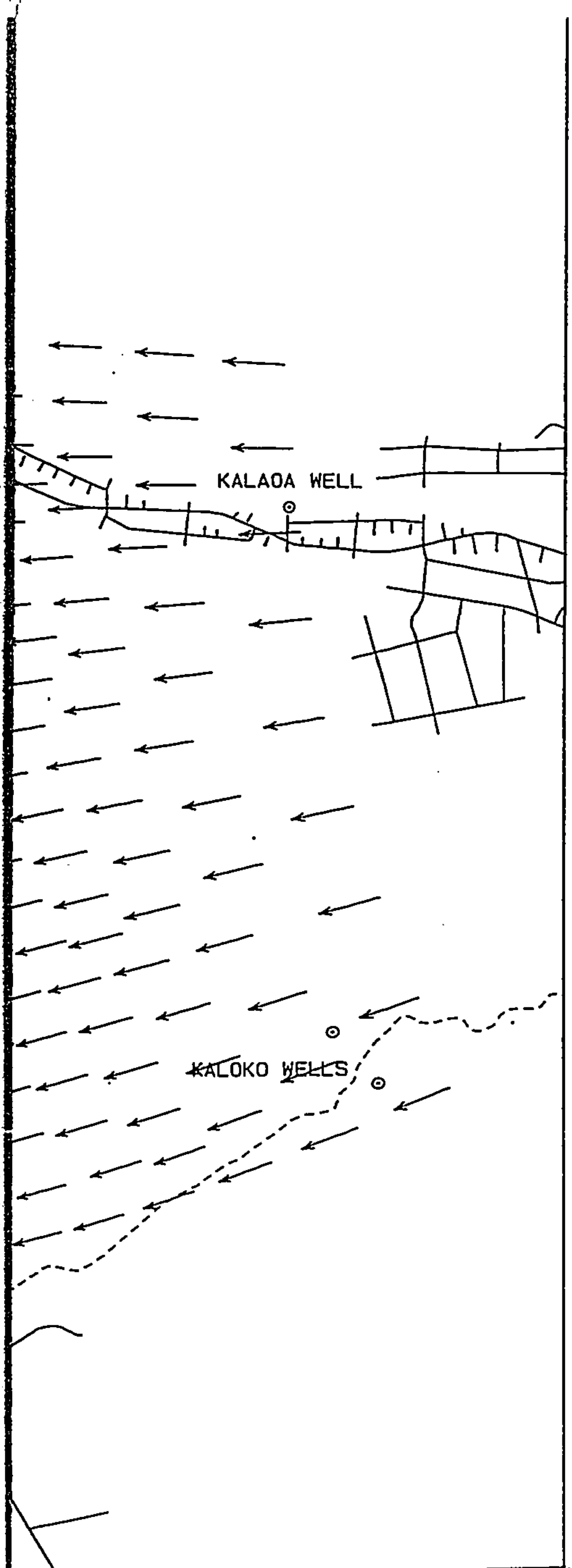

Makako Bay
KEAHOLE AIRPORT
W-5
W-3
W-4
W-6
Keahole Pt
W-7
W-2
KALAO
KALOKO
PACIFIC
OCEAN
Kaloko Pt

O'OMA II PROJECT
NUMERICAL MODELING OF THE GROUNDWATER SYSTEM

On Behalf Of

TOM NANCE

WATER RESOURCES ENGINEERING



LEGEND:

- Coast
- Roads
- Tracks
- Ponds
- ⊙ *Monitoring Well*

NOTE:

Base map from US Department of the Interior, Geological Survey, 7.5 minute series (topographic).

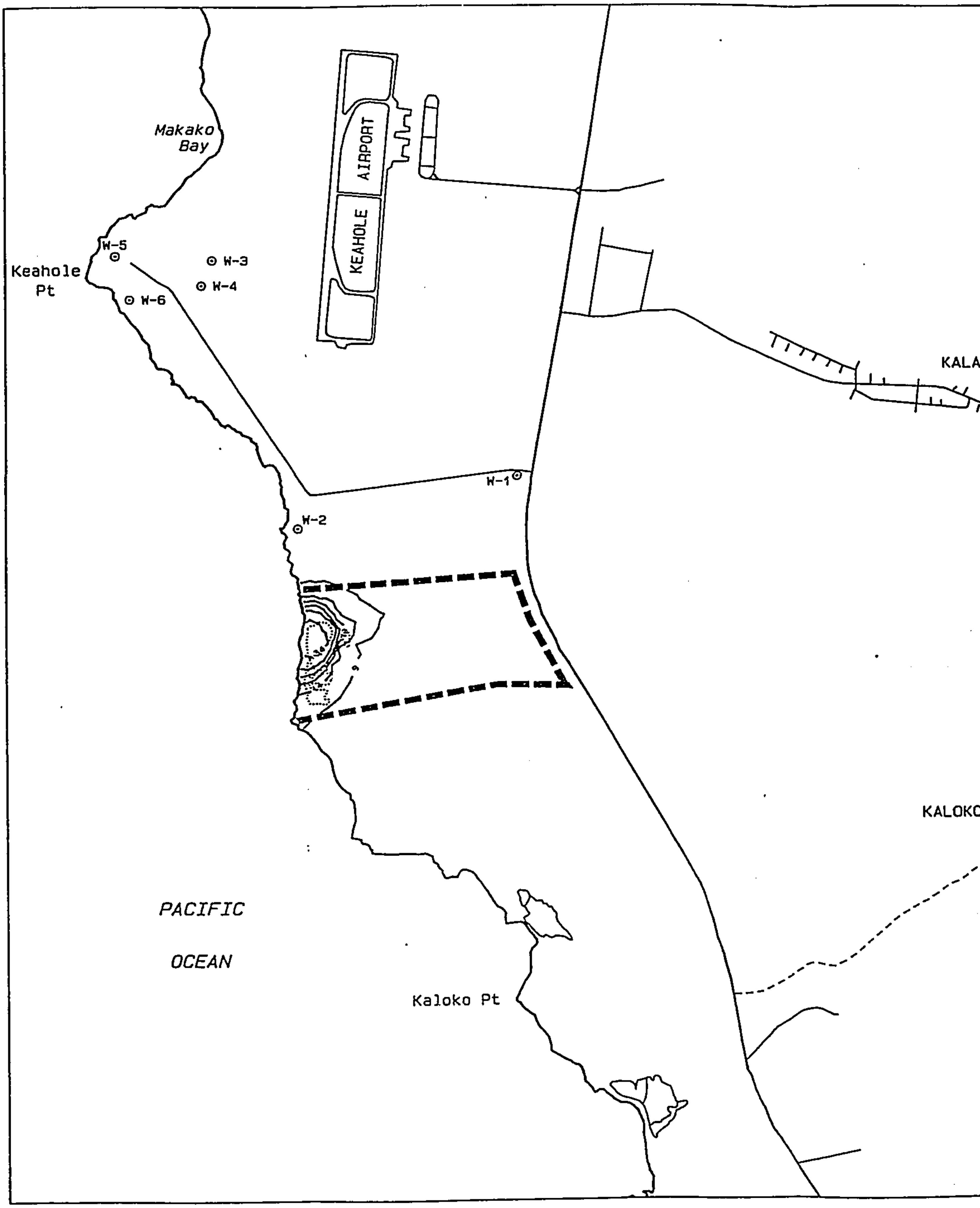
0 2000 4000 6000 feet

VECTOR SCALE ⟶ 50 cu.ft/day/ft

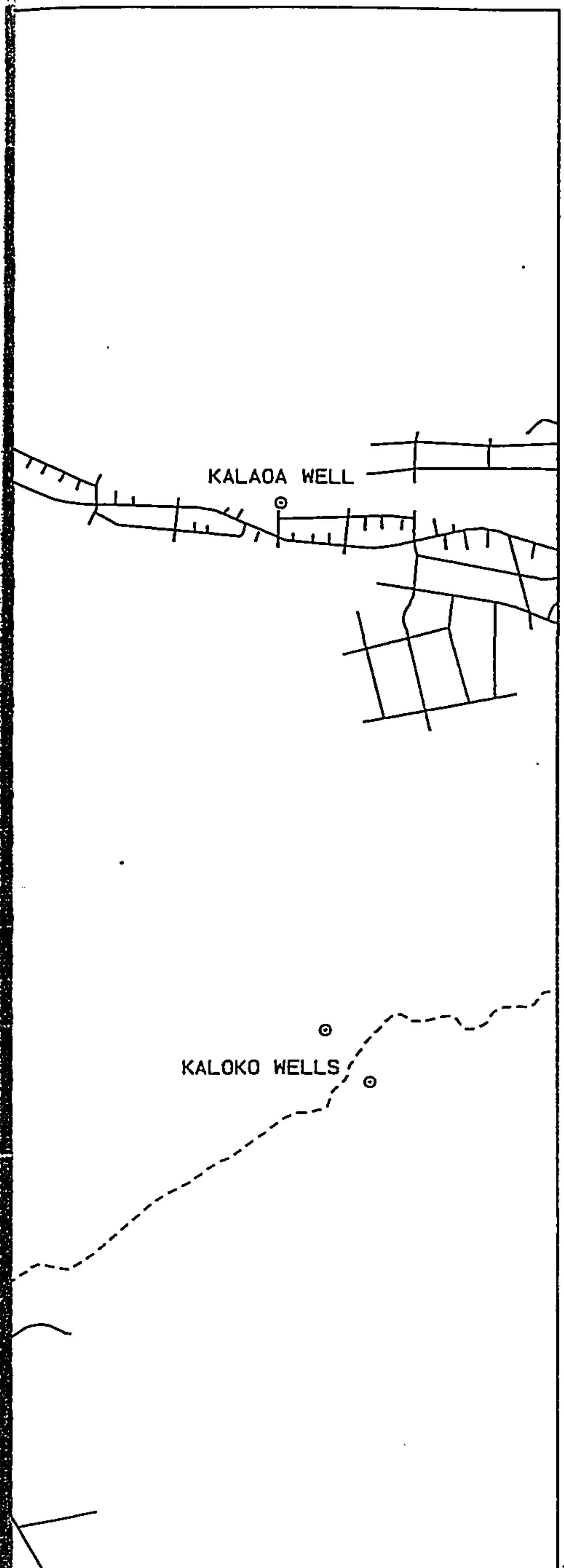
SCENARIO 3
GROUNDWATER FLOW DIRECTIONS FOR SEEPAGE OF 10,000 GPM FROM POND NO. 1

FIGURE 16

Mackie Martin & Associates
GROUNDWATER ENGINEERS



Makako
Bay
KEAHOLE
AIRPORT
Keahole
Pt
W-5
W-3
W-4
W-6
W-1
W-2
KALA
KALOKO
PACIFIC
OCEAN
Kaloko Pt



O'OMA II PROJECT
NUMERICAL MODELING OF THE
GROUNDWATER SYSTEM

On Behalf Of

TOM NANCE
WATER RESOURCES ENGINEERING

LEGEND:
- Coast
- Roads
- Tracks
- Ponds
- Monitoring Well
- Salinity Contour (ppt)

NOTE:

Base map from US Department of the Interior, Geological Survey, 7.5 minute series (topographic).

0 2000 4000 6000 feet

SCENARIO 3
PREDICTED SALINITY DISTRIBUTION
FOR SEEPAGE OF 10,000 GPM
FROM POND NO. 1

FIGURE 17

Mackie Martin & Associates
GROUNDWATER ENGINEERS

Effect of Nutrients in Water Percolating From the Golf Course

Dissolved nutrients in water percolating from the project's golf course may affect the concentrations of these constituents in the receiving groundwater. Nitrogen is the most heavily applied and most mobile of these nutrients. Environmental Turf Services, Inc. (1991) has evaluated the amount of nitrogen which may be leached. Its most realistic estimate is 2.6 percent of the amount applied or 1,100 pounds per year; its worst case situation is 10 percent of applied nitrogen or 4,200 pounds per year. If the average percolation rate from the golf course is 0.1 MGD, the average concentration of this downward flow would be 255 μM and 980 μM, respectively, for the realistic and worst case estimates. Since the concentration in the receiving groundwater is 80 μM, the percolating water would elevate nitrogen levels to at least some extent.

Figures 18 and 19 simulate the effect of 2.6 and 10 percent leaching, respectively, without *including* the effect of seepage from the 7-acre water recreation park. The dilution effect as the percolate is mixed into the groundwater flow is obvious in both of these figures. At the 2.6 percent leaching rate, groundwater concentrations would be elevated to a modest extent. In fact, the 90 and 100 μM levels shown on Figure 18 are within the natural variability of groundwater itself. The range of this variability is from 60 to 100 μM. The larger effect 10 percent leaching (Figure 19) is expectable. Its nitrogen loading would be four times greater than the 2.6 percent leaching rate.

Inclusion of saltwater seepage from the 7-acre water recreation park would dilute the effect of nitrogen leaching from the golf course. For such seepage at 25,000 GPM and with nearshore permeability as modeled in Scenario 2, the effects of the 2.6 percent nitrogen leaching rate would be fully diluted before reaching the shoreline (see Figure 20). At 10 percent leaching, a nitrogen increase of 20 to 40 μM would occur in groundwater reaching the shoreline (refer to Figure 21).

Summary Conclusions and Recommendations

Investigations summarized in this report identify the most practical circulation scheme for the proposed system of ponds at O'oma and analyze potential effects of this circulation on underlying brackish groundwater. The most important conclusions are listed below. Also included is a recommendation of additional data acquisition to enable the prediction of groundwater effects to be further refined.

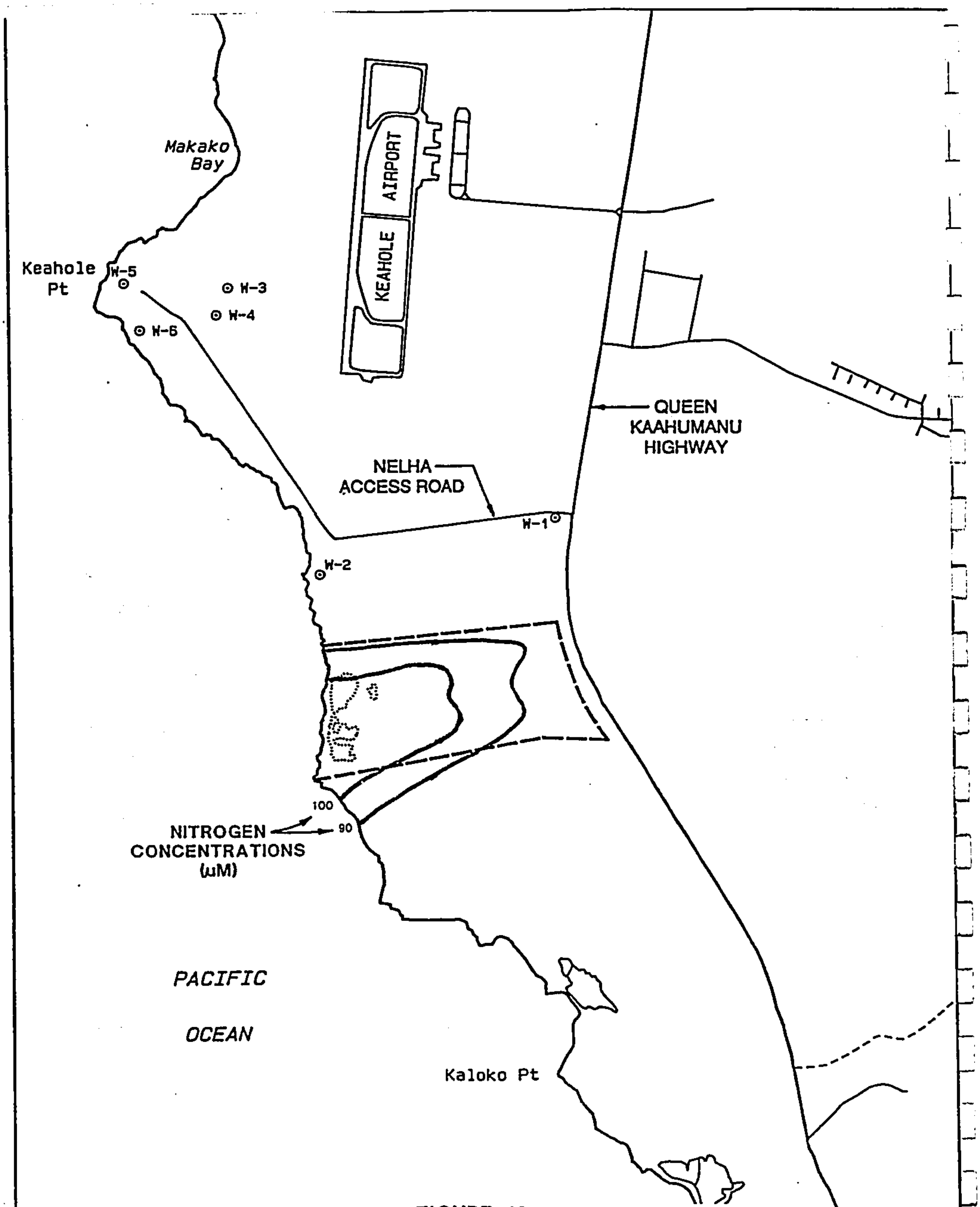


FIGURE 18
EFFECT OF LEACHING 2.6 PERCENT OF APPLIED NITROGEN
FROM THE GOLF COURSE

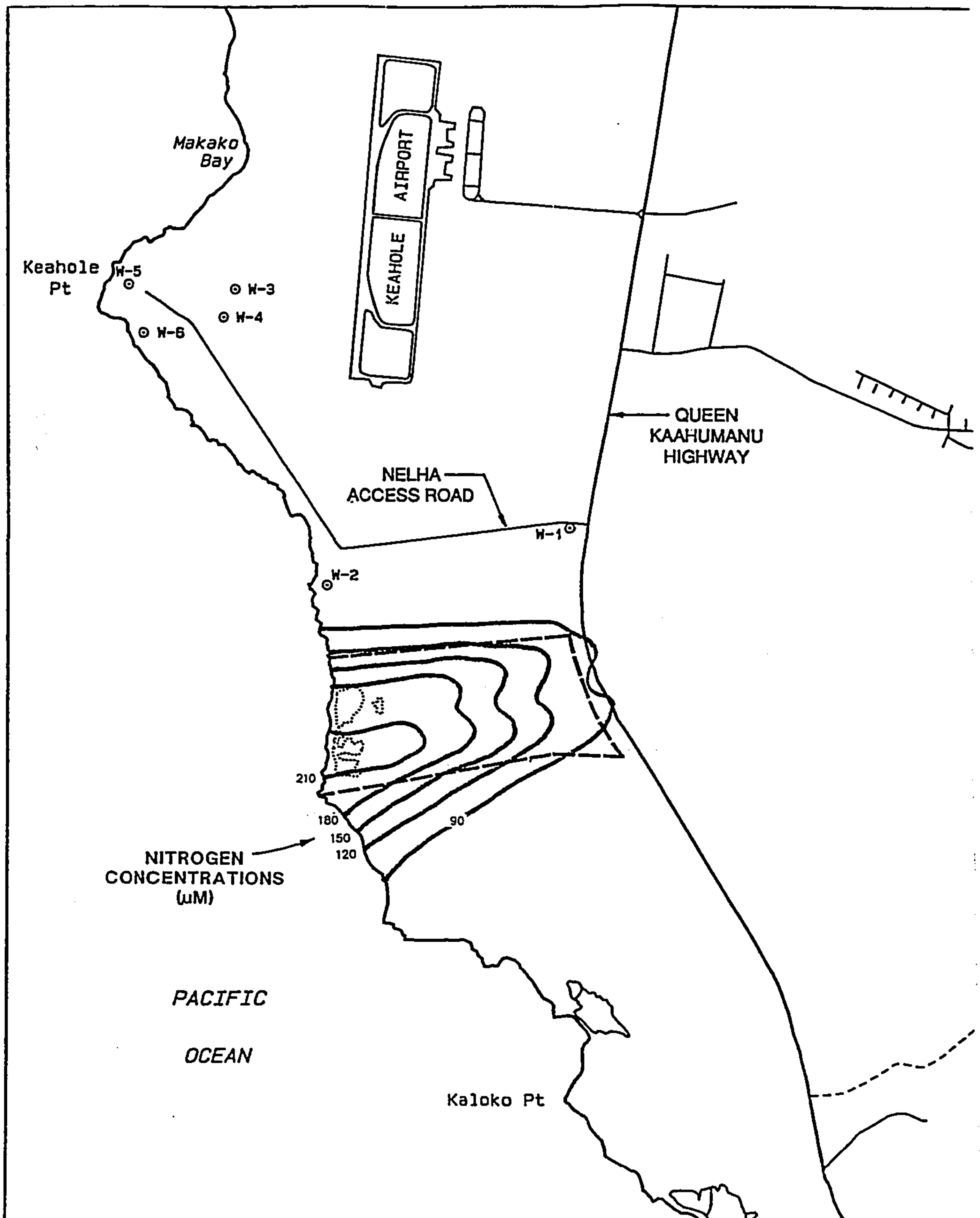


FIGURE 19
EFFECT OF LEACHING 10 PERCENT OF APPLIED NITROGEN FROM THE GOLF COURSE

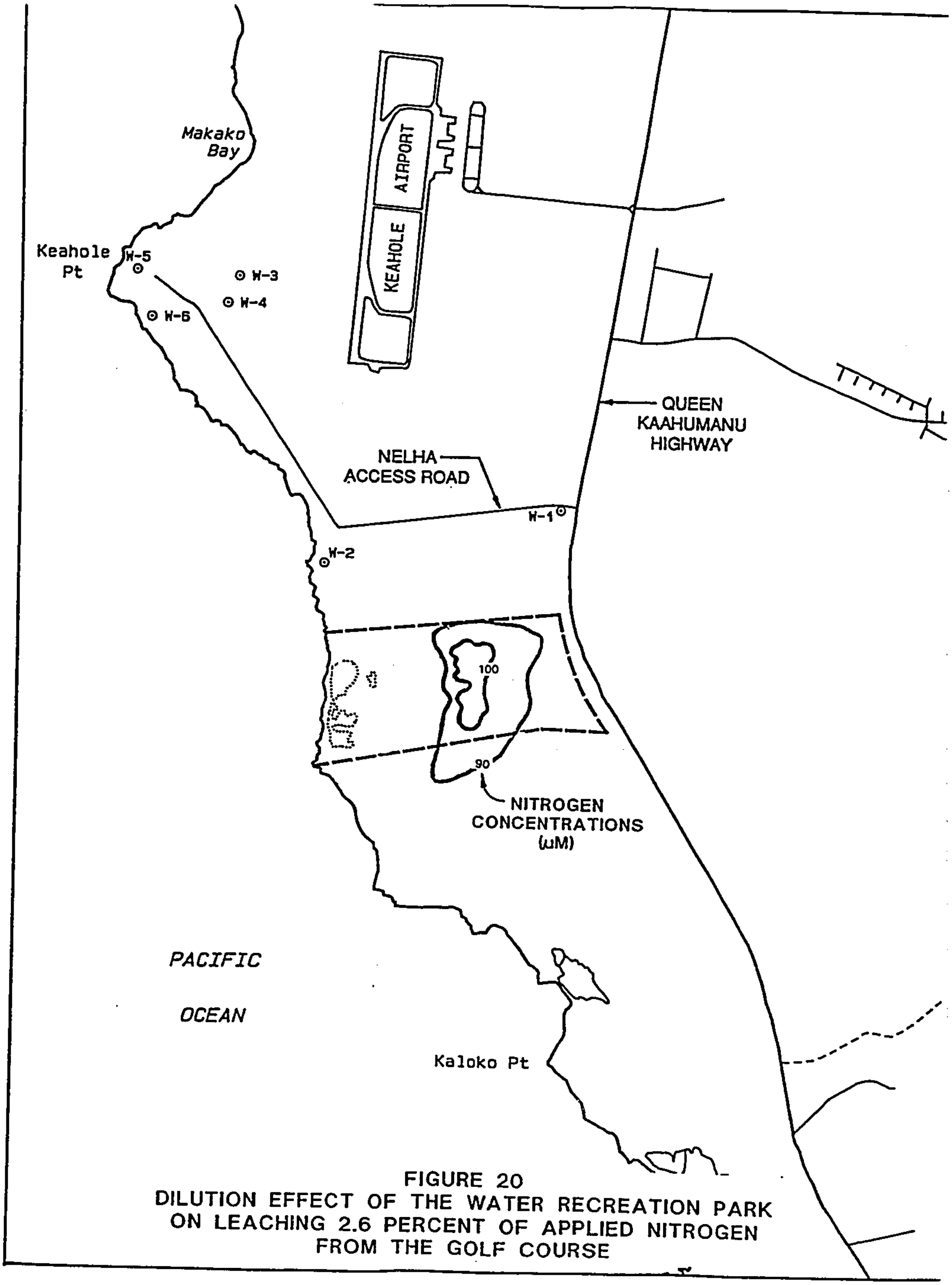


FIGURE 20
DILUTION EFFECT OF THE WATER RECREATION PARK
ON LEACHING 2.6 PERCENT OF APPLIED NITROGEN
FROM THE GOLF COURSE

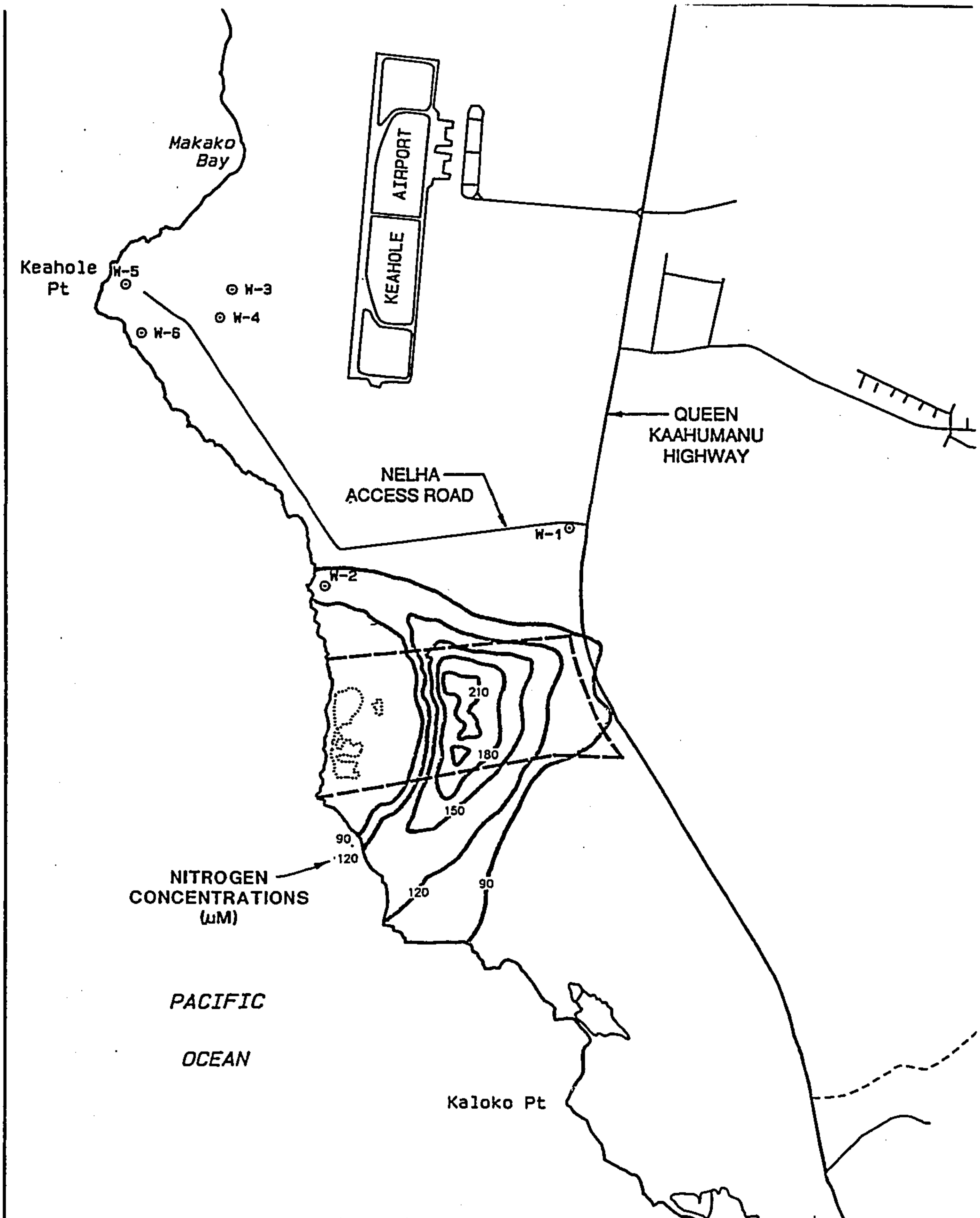


FIGURE 21
DILUTION EFFECT OF THE WATER RECREATION PARK ON LEACHING 10 PERCENT OF APPLIED NITROGEN FROM THE GOLF COURSE

1. Single Pass, Flow Through Circulation. A single pass, flow through circulation system is recommended. It can provide acceptable water clarity and limit algae growth if the water supply has low nutrient concentrations (similar to adjacent surface seawater) and if the residence time from well head to seepage disposal of not more than 10 hours.

2. Sources of Supply. On-site saline wells are the most appropriate source of supply. If all of the lagoons are included in this circulation scheme, a total supply rate of 25,000 GPM would be needed to achieve a 10-hour turnover time. The wells should be designed to draw water from the saline zone below the brackish lens. Five to eight wells would be needed to produce the required flowrate.

3. Method of Disposal. The lowest of the ponds, the 7-acre water recreation park, should be excavated below the water table and remain unlined. The entire influent well supply would circulate through the other ponds first and then flow to this lowest pond. Seepage from the sides and bottom of the pond would percolate to the underlying groundwater lens and move from there to the shoreline.

4. Quality of Water Percolating From the 7-Acre Pond. Among the benefits of developing a low nutrient source of supply and achieving rapid turnover through the system of ponds is that the quality of water seeping from the lowest pond would be similar to the incoming well supply. In effect, the proposed circulation system would amount to a recirculation of seawater. This conclusion is supported by data from a similar, albeit smaller scale, system which is operating at a South Kohala resort.

5. Effect of Seepage Disposal on Groundwater. Computer based numerical modeling has been used to portray the effect of seepage from the lowest pond. Three scenarios are presented to illustrate the range of possibilities. Scenario 2 is considered to be the most realistic representation of a 25,000 GPM seepage rate. It incorporates calibrated regional aquifer parameters and some judgement as to the influence of local scale features (lava tubes, shrinkage cracks, and seams between lava flows) which are likely to be present between the 7-acre pond and the shoreline. Figures 12, 13, and 14 illustrate water levels, flow directions, and salinity increases that would result from this seepage. The effect on groundwater, although not considered to be adverse, would extend beyond the O'oma property to the north and south. Scenario 3 was constructed to determine the greatest magnitude of seepage for which the effect on groundwater would be confined within the O'oma II property. That rate is approximately 10,000 GPM and its effects are depicted on Figures 15, 16, and 17. If the supply and disposal rate is limited to this amount, then the golf course and hotel ponds should

not be included in the circulation scheme. It would also be necessary to scale down the water volume 7-acre water recreation park pond to achieve a 10-hour turnover time.

6. Recommended Additional Investigation. The contrast in predicted effects on groundwater between Scenarios 1 and 2 show the importance of quantifying the influence of small scale features in the lava between the pond and shoreline. If cracks and lava tubes are present, water seeping from the pond will readily escape directly to the shoreline and the effect of seepage from the pond would be greatly diminished. Numerous cracks, lava tubes, and other void spaces are known to exist throughout the site but data is not available to quantify their influence. Drilling a number of small, shallow boreholes should be undertaken. Monitoring water level responses in these boreholes to the ocean tide will enable the permeability between the 7-acre pond and the shoreline to be quantified. With this information, further calibration of the computer-based numerical model can be done and more accurate predictions of the effect of seepage on groundwater can be made.

BIBLIOGRAPHY

AECOS, Inc. 1988. A water quality assessment of the lagoon at the Mauna Lani Terrace Condominium, Mauna Lani Resort, South Kohala, Island of Hawaii. Prep. for: Assoc. of Apt. Owners of Mauna Lani Terrace. No. 504: 36 p.

Bathen, K.H., R.M. Kamins, D. Kornreich, and J.E.T. Moncur. 1975. An evaluation of oceanographic and socio-economic aspects of a nearshore ocean thermal energy conversion plant in subtropical Hawaiian waters. Cited in The Traverse Group, Inc., 1985.

Bruland, K.H. 1983. Trace elements in Sea-water. Chap. 45, In: Chemical Oceanography, Vol. 8 (J.P. Riley and R. Chester). Academic Press, London.

Environmental and Turf Services, Inc. 1991. Environmental Risk Assessment for the Golf Course at the Proposed O'oma II Project. Manuscript report prepared for Kahala Capital Corporation.

Halbig, J.B., W.M. Barnard, S.A. Bartlett, R.W. Overfield, and L.L. Abbott. 1986. A baseline study of ground water geochemistry in the Kawaihae and Hilo areas on the Island of Hawaii. Dept. of Planning and Economic Development, State of Hawaii Marine Mining Program, Honolulu. 74 p.

Kay, E.A., L.S. Lau, E.D. Stroup, S.J. Dollar, D.P. Fellows, and R.H.F. Young. 1977. Hydrological and ecological inventories of the coastal waters of West Hawaii. Water Resources Research Center, Univ. of Hawaii, Honolulu. Tech. Rept. 105: 94 p.

Marine Research Consultants. 1990. Assessment of chemistry of nearshore waters in the vicinity of the O'oma II Development, North Kona, Hawaii. Prep. for Helbert, Hastert & Kimura (Honolulu) and Kahala Capital Corporation (Kailua-Kona). 13 p.

Natural Energy Laboratory of Hawaii Authority. 1990. Annual Report for the Comprehensive Environmental Monitoring Program. Data report prepared by the NELHA Water Quality Lab Staff.

Swain, L.A. 1973. Chemical quality of ground water in Hawaii. U.S. Geological Survey and State of Hawaii, Dept. of Land and Natural Resources, Division of Water and Land Development, Honolulu. Rept. R-48: 54 p.

Townley, L.R., AQUIFEM-N: A Multi-N: A Multi-layered Finite Element Aquifer Flow Model. CSIRO Division of Water Resources, Perth, Western Australia, 1990.

The Traverse Group, Inc. 1985. Final environmental impact statement, High Technology Development Corporation development plan for the Hawaii Ocean Science and Technology Park and expansion of the Natural Energy Laboratory of Hawaii, Keahole, North Kona, Hawaii. Prep. for State of Hawaii, High Technology Development Corporation, Honolulu, Hawaii.

Volker, R.E. 1990. Predicting the Movement of Sea Water into a Coastal Aquifer. Australian Water Resources Council, Technical Paper No. 51.

APPENDIX G

GOLF COURSE ENVIRONMENTAL RISK ASSESSMENT

Environmental & Turf Services, Inc.

ENVIRONMENTAL RISK ASSESSMENT

AND

INTEGRATED GOLF COURSE MANAGEMENT PLAN

FOR THE GOLF COURSE AT

THE PROPOSED O'OMA II

COMPLEX ON THE KONA COAST

<u>For:</u>

Kahala Capital Corporation
Kailua-Kona, Hawaii
Los Angeles, California

<u>By:</u>

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Thomas E. Durborow
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Vermont

Kim Warner, M.S.
Research-Assistant
University of Maryland-Solomons Island,
Maryland

September 11, 1991

EXECUTIVE SUMMARY

Kahala Capital Corporation is planning to develop a 300 acre recreational/residential/scientific complex on the Kona Coast. The name of the proposed site is O'oma II. It is bounded on the north by the Natural Energy Laboratory of Hawaii Authority (NELHA), on the east by Queen Kaahumanu Highway, on the south by the planned Kohanaiki resort complex, and on the west by the ocean. The proposed site is currently undeveloped, with minimal vegetation and extensive pahoehoe lava flows. The site is located on open coastline with strong surf and currents. An assumption is that 2 MGD of ground water discharges per mile of coastline at the site to the well-mixed coastal waters.

The developer is concerned that the surrounding environment not be adversely impacted by the O'oma II facilities. Therefore Kahala Capital Corp. retained Environmental & Turf Services, Inc. (ETS) to conduct a risk assessment that focuses on turf chemical use on the proposed golf course.

This is a multifaceted assessment that addresses a wide range of concerns. First, potential sensitive receptors were identified. Then the potential for turf chemical pathways to those receptors was delineated. As part of this process, an Integrated Golf Course Management Plan was developed, pesticide mobility, persistence, and human and aquatic toxicity were evaluated, and state-of-the-art computer modeling was conducted to assess the potential for off-site transport.

Potential Sensitive Receptors

The area of greatest concern is the NELHA site. The site--which contains the Hawaii Ocean Science and Technology park (HOST Park) and the Natural Energy Laboratory of Hawaii -- contains a variety of tenants that focus on aquaculture technology. Surface

seawater is obtained from depths of 20 ft, 49 ft, and greater, approximately 100 ft-1300 ft off Keahole Pt. Brackish water is pumped from wells on site. Potable water is obtained from sources several miles away.

Although there is obviously no possible threat to the sea water intakes or the wells near Keahole Point, it is likely that future aquaculture ventures would be located immediately to the north of O'oma II. Therefore an assessment of ground water and spray drift impacts was conducted.

Integrated Golf Course Management Plan

The proposed site is in an area with good air circulation, dry conditions, and sunny days. These conditions reduce the potential for pest and disease outbreaks. Also, the use of brackish water in the irrigation system (combined with sewage effluent) would mitigate certain pest/disease outbreaks. Thus the IGCMP only contains recommendations for use of 19 pesticides, one of which is "organic" (Safer●Soap). In addition, it is highly unlikely that all 19 pesticides would have to be used in any given year. A more likely scenario is that less than six of the pesticides would be used in a year. The wider selection of 19 is provided to give the superintendent a broad array of options in the first several years of operation.

A variety of cultural and mechanical controls are recommended to ensure the growth of healthy turf, which further reduces the need for pesticides. For example, use of aerification, proper mowing heights, and potassium reduce the need for fungicides.

Some pest infestation thresholds for pesticide application are suggested; i.e., guidance is provided so that the superintendent would not automatically apply pesticides at the first sign of weed, disease, or insect pest outbreaks.

The IGCMP also recommends that 70%-80% of the applied nitrogen fertilizers be in the slow release form, which minimizes ground water contamination potential of nitrates.

This Integrated Golf Course Management Plan therefore constitutes additional restrictive but feasible guidance for an industry that is already heavily regulated.

Several soils were investigated for their potential use at the site. A sugar cane refuse soil seems to show the most promise when one considers drainage and pesticide retention. It is also a good use of a material that many consider to be a waste product. However, it would likely contain an unacceptable concentration of weed seeds. Therefore the soil would probably have to be fumigated with methyl bromide before shipment to the site. More research is needed on this issue.

The following bermudagrass turfgrass species should be used due to disease resistance, low water usage, pest resistance, and other factors:

- Tifdwarf on greens;
- Tifgreen 328 on tees; and
- Tifway II on fairways, roughs, aprons, and for sod stabilization.

There is almost a complete lack of data on the efficacy of the limited number of "organic" turf products available for use on Hawaiian turf. "Organic" is defined here as implying relatively safe products derived from natural materials with minimal or no chemical processing. Therefore it is recommended that O'oma II make available small areas for research proposed by university and corporate researchers (e.g. Ringer's Corp.).

The IGCMP also provides guidance on safe handling, storage, and disposal of turf chemicals.

The average water need for the proposed golf course is projected to be 650,000 GPD. The projected water need for the average peak week is likely to be less than 1,000,000 GPD.

<u>Risk Assessments</u>

Sophisticated computer simulation modeling was conducted to evaluate ground water, ocean water, and spray drift contamination potential. A combination of conservative assumptions as well as realistic assumptions were used. In addition, an uncertainty analysis was conducted to estimate confidence intervals around the predicted pesticide concentrations.

Pesticides were modeled using a new linked version of two established, EPA - sponsored leaching models. The Pesticide Root Zone Model (PRZM) and the Vadose Zone Finite Transport Model (VADOFT) were used to estimate pesticide masses and concentrations leaching to ground water. Daily weather records were used for a five-year simulation. In addition, ground water concentrations were estimated by assuming conservative behavior (no degradation, no binding to rock/sand/soil), based on the results of ground water modeling for nitrate nitrogen by Nance (1991).

Six priority pesticides were selected for detailed computer modeling. The pesticides were chosen from herbicide, fungicide, and insecticide classes and represent a wide range of mobility, persistence, and human and aquatic toxicity characteristics. The pesticides are chlorpyrifos, bensulide, trichlorfon, 2,4-D, metribuzin and metalaxyl. (It is interesting to note that trichlorfon, among other insecticides, is sometimes used in aquaculture to control salmon lice.)

Average concentrations of pesticides in ground water reaching the shoreline, anchialine ponds, and NELHA property are estimated to be between four and ten orders of magnitude (powers of ten (i.e. 1/10,000th - 1/10,000,000,000th)) below human Health Advisory

Levels (HALs). Likewise, average values are estimated to be two to seven orders of magnitude below levels of concern for marine organisms (1/10th the LC_{50} of the most sensitive species tested). At the upper 95% confidence limits, predicted concentrations are generally orders of magnitude lower than 1/100th of the HAL and 1/10th of aquatic levels of concern. Therefore there is no concern for pesticides migrating off-site in toxicologically significant concentrations. However, it is recommended that leachate (drainage) from greens be diverted to surface areas where it can undergo further attenuation as an additional measure of engineered insurance. (Greens are the most heavily managed parts of the golf course.)

A realistic expectation is that 2.6% of the fertilizer nitrogen (N) that is applied to the golf course may leach to ground water. A worst case expectation is for 10% of the N to leach. In neither case is there expected to be an impact on off-site water quality. However, it is still recommended that the superintendent follow the guidance in this document, which primarily recommends use of slow-release nitrogen fertilizers. These are less likely to leach to ground water.

Pesticide Spray Drift

The Agricultural Dispersal Model (AGDISP) was used to simulate pesticide drift at the site under a series of reasonable-case and reasonable worst-case conditions. It was determined that drift would not be likely to occur beyond 50 ft with cross winds less than 5 mph. Drift would likely occur beyond 50 ft in cross winds of 10 mph or greater if no windfoil-style shrouded sprayer is used; therefore one is recommended for wind speeds between 5 mph and 20 mph. Additional precautions to prevent drift are listed below, but it should be noted that wind speed in the vicinity of the site is less than 14 MPH 95% of the time.

A lava rock or similar berm should be constructed that is at least 15 ft high along the O'oma II property boundary line near sensitive areas.

A vegetative buffer should be planted on the downslope on-property side of the berm. The complete buffer should be 100 ft wide. Vegetation planted in this buffer should be watered with drip irrigation. Local palm trees should be planted that have a history of no significant insect or disease problems. If necessary, insecticides should only be applied through direct or deep root injection. Otherwise, no pesticides should be applied in the 100 ft buffer strip.

Effluent

Approximately half of the golf course irrigation water may come from sewage effluent. It is known that microbes can survive standard secondary treatment systems. This effluent/brackish water mix would be applied with high pressure spray heads, which means there would be the potential for microbial drift if no other precautions are taken.

Extensive spray drift precautions have been recommended. However, possibilities of even small amounts of microbial drift into nearby aquaculture facilities should not be taken lightly. Therefore it is recommended that Kahala Capital adopt California's 2 NTU standard for use of effluent water in turf irrigation. ("NTU", nominal turbidity unit, is a measure of the turbidity or cloudiness of the solution.) Adoption of this strict pre-chlorination clarity standard would mean that O'oma II's wastewater would be classified as class B--suitable for human contact with no buffer areas. It also means that clarification, flocculation, and coagulation processes may be necessary in the sewage treatment plant, in addition to standard oxidative processes.

Ciguatera Toxin

There is no linkage between ciguatera toxin outbreaks and turf chemical applications. There is no valid hypothesis that has been advanced by competent scientists to suggest this linkage. Ciguatoxin outbreaks usually occur where there are no golf courses.

Pesticide Storage Facility

A pesticide storage facility (PSF) is an integral part of any golf course. We recommend for safety and environmental concerns that the guidelines in this document be incorporated into the design and operation of the pesticide storage facility at the O'oma II site.

Termiticides

Subterranean termite control may be needed at the site. There are several effective pesticides that may be used safely if handled properly. However, these chemicals are generally toxic to fish and, due to sensitivities of neighboring sites, it is recommended that a non-chemical termite control agent be evaluated for its feasibility for use at the site. This agent is a basaltic sand barrier, which has been used successfully for several years in Hawaii.

Table of Contents

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I. INTRODUCTION AND PURPOSE

Kahala Capital Corporation is planning to develop a 300 acre recreational/residential/scientific complex on the Kona Coast. The name of the project is O'oma II. The complex will include a golf course and ornamental trees, both of which may require applications of pesticides and nutrients. The site is adjacent to the shoreline, and south of the Natural Energy Laboratory of Hawaiian Authority (NELHA) property. Since both of these areas could contain organisms potentially sensitive to pesticides and nutrients, Kahala Capital requested Environmental and Turf Services, Inc. (ETS) to conduct this risk assessment. The specific objectives follow.

- Develop an integrated golf course management plan (IGCMP) that specifies pesticides, fertilizers, irrigation, cultural practices, and other information required to establish and maintain healthy turf in an environmentally sound manner. Much of the information in the IGCMP form the basis for the following risk assessments.

- Evaluate soils that may be imported onto the site for golf course construction.

- Evaluate pesticide mobility in soil, persistence, human toxicity and aquatic toxicity.

- Flag the chemicals of greatest concern and evaluate their potential to leach to ground water and migrate to the ocean. This task is accomplished using the PRZM-VADOFT model (described in section VI).

- Assess the potential for pesticides to drift in air to the proposed Hawaiian Ocean Science and Technology Park (HOST Park), which is located on the NELHA property.

- Evaluate the use of effluent water for irrigation.

- Assess what is known about causes of ciguatera toxin outbreaks.

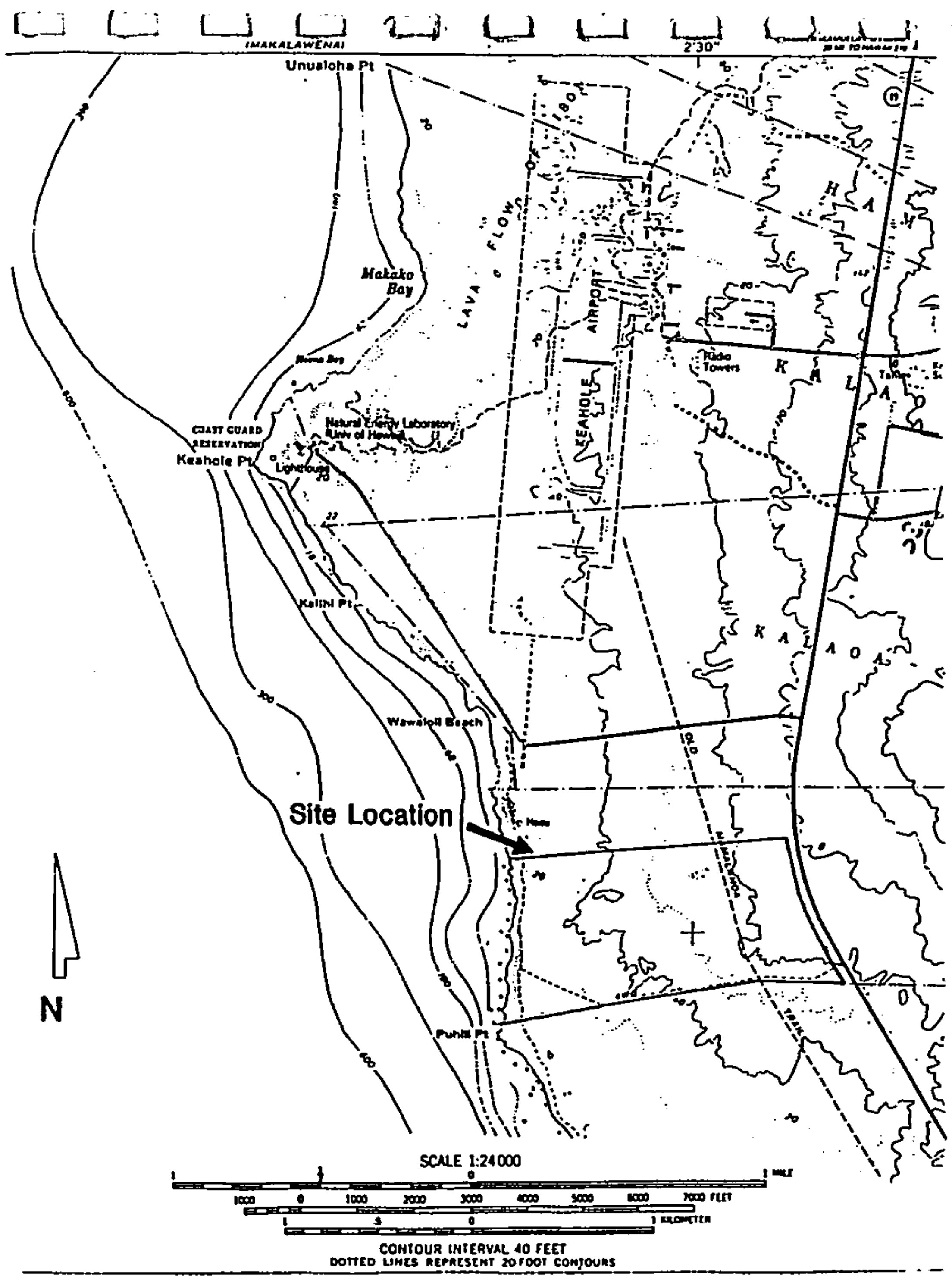
- Recommend certain practices or designs to minimize environmental risks.

II. SITE LOCATION, DESCRIPTION AND PROJECT OVERVIEW

The O'oma II project is proposed for a 300 acre parcel on the Kona Coast of the Big Island, south of Keahole Point (19°42'30"N, 156°2'30" W). The site is between Highway 19 (Queen Kaahumanu Hwy) and the ocean adjoining the south boundary of the NELHA property (Figure 1). The site elevation range is 0-110 ft.

• The site is mostly covered with pahoehoe lava, with a small amount of aa. There is a beach at the shoreline, with some sand dunes behind the beach. Scrub vegetation is spotty, and clustered mostly behind the beach, although some grasses are growing in the pahoehoe. There is very little soil on the site.

Figure 1. Site Location Map



O'oma II would be a recreational/residential/scientific facility. The main features are:

- Golf course and clubhouse -- 18 holes, 176 acres, with driving range, practice greens, clubhouse with pro-shop, restaurant, pool, and cart barn;
- Ocean science center (tentative) -- 12-15 acres, indoor and outdoor tanks, tide pools, archaeological sites/exhibits, restaurant, small theater, and parking;
- Hotels and retail shopping center;
- A conference center;
- A sewage treatment plant and other features

Figure 2 depicts the master plan for O'oma II.

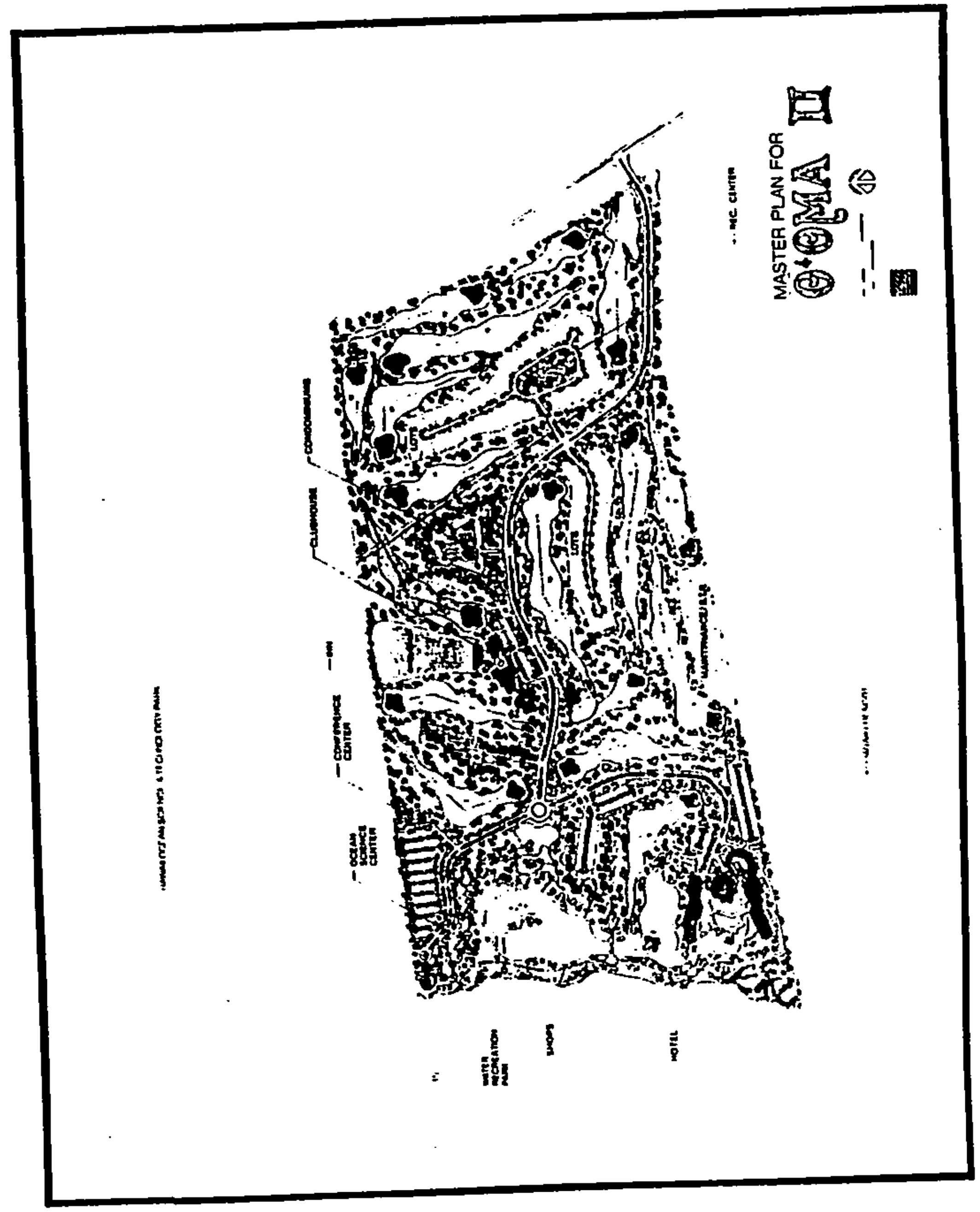


Figure 2. Master Plan for O'oma II
(from Helber, Hastert, & Kimura Planners, Honolulu)

III. IDENTIFICATION OF POTENTIAL PATHWAYS TO SENSITIVE RECEPTORS

The proposed O'oma II complex would lie between the NELHA property to the north, the planned Nansay Hawaii/Kohanaiki complex to the south, and the ocean to the west.

The nearshore marine environment adjacent to O'oma, North Kona has been previously described (Marine Research Consultants, 1990) as a typical West Coast Hawaiian coral reef community separated from the shore by a high energy intertidal zone. The intertidal area is dominated by sea urchins, seaweeds, and juvenile reef fish. Sixteen species of coral were identified in the reef community with Porites lobata dominating 60% of total coral cover. Benthic invertebrates include 8 species of sea urchins, 3 species of sea cucumbers, 3 species of starfish, a mollusc, and several sponge species. Eighty-nine species of reef fish were identified including juveniles, plantivorous damsel fishes, herbivores, rubble dwellers, swarming tetrodonts, and surgezone fishes. The reef fish assemblage was described as being typical of undisturbed Hawaiian reef environments. It was the authors' belief that the proposed development and secondary impacts due to runoff would not cause alteration to the marine ecosystem under proper management practices*. Any unexpected adverse impacts due to development would be negligible in contrast to changes imposed by dominating natural forces, such as storm waves. (Note also that the site is open coastline with strong surf and currents, rather than an enclosed embayment where ground water inputs could be focused.)

NELHA has warm and cold seawater intake pipes approximately 100 ft - 1300 ft offshore at Keahole Point. The shallow (warm water) intakes are located at 6 m, 15 m, and 20 m (20 ft. 49 ft and 69 ft) (Hachmuth, 1991). There are also deep cold water

*Also, since the slope of the project site is less than 3 percent (3%) runoff does not impose a threat to the marine environment. The makai dunes create a surface boundary which also protects the ocean from any potential runoff.

intakes approximately 1/4 mile offshore. There is a potential for this seawater to be used for various aquaculture programs at the proposed HOST Park. Many of these programs would be sensitive to pesticide inputs. Further, the current flows south to north, from O'oma II to Keahole, 90-99% of the time (Anderson, 1991). Therefore assessment of the potential for discharge of contaminated ground water to the ocean is indicated. The focus of the assessment was on the shallower intakes due to the incalculable dilution that would occur at greater depths.

In addition, winds at the site are variable and generally light, although gusty conditions are possible. It is possible that new aquaculture programs could grow aquatic vertebrates and invertebrates sensitive to impacts of pesticide or effluent drift. Also, there are anchialine ponds to the southwest on the Kohanaiki site. Therefore an assessment of pesticide and irrigation effluent drift is indicated.

Finally, future tenants to the north of the planned O'oma II project may install wells to obtain brackish water for use in aquaculture. Even though the area is below the Underground Injection Control line, where parties with a permit may inject liquid wastes directly into ground water, the potential for off-site migration of contaminated ground water should be examined as well.

IV. INTEGRATED GOLF COURSE MANAGEMENT PLAN

A. INTRODUCTION

The Integrated Golf Course Management Plan is an outline of proposed methods and materials recommended for use in managing the O'oma II Golf Course.

This plan was developed around the probable pests which are noted as problems on the golf courses along the Kona Coast. The degree to which we project these pests to impact the proposed O'oma II golf course will be addressed in the Integrated Golf Course Management Plan.

The following report recommends the use of effective and low impact methods and materials to successfully build and operate the golf course in an environmentally responsible way.

This plan should be considered as a guideline with the understanding that as conditions change, and as newer, safer and more efficient materials and methods are developed the plan will adjust and expand to include the newest and best technology.

B. STRUCTURAL CONTROL PROGRAM

Purpose of Structural Controls

The proposed structure of the O'oma II Golf Course has been designed to improve drainage, eliminate microclimates, and create separation buffers. The location of fairways will reduce still air conditions that would promote growth of fungi. The reduction of potential soil compaction is also planned by the proper selection of topsoil. The well-drained soils of the greens and tees will reduce excessive moisture content and discourage algae and fungus growth. The "maintenance of well drained soil is the best control of brown patch, pythium, and many other diseases" (Lucas, 1984). In a similar fashion, providing improved fairways also will help

reduce soil moisture related problems and prevent compaction. Compacted soils tend to favor the development of weeds (Lucas, 1984).

It will be possible to encourage appropriate turf growth while simultaneously discouraging the growth of fungi, weeds, and grubs by providing replacement quantities of nutrients and controlling the soil's pH. Soil testing of the greens and fairways soil mixture should occur during the construction phase. This provides accurate provisions of correct soil amendments.

During the establishment period (grow-in) of a golf course, increased use of nitrogen, potassium, phosphorous, etc., are needed to get rapid turf cover establishment and therefore secure the soils from erosion. Sediment erosion can be a devastating problem if not avoided by a rapid, successful grow-in process. Prior to construction, an approved erosion control plan will be in place. A topographic map with silt fence overlays will be used to identify areas prone to potential erosion. Hay bales and/or strip sodding will be used to stabilize areas prone to runoff.

Below are typical standards used in the golf industry to build a modern golf course.

Fairways and Roughs

Sub-Grading

All cuts and fills shall closely follow the Designer's Contour Plan. Filled areas shall be sufficiently compacted and a choker layer installed as specified to prevent settling, and all grading shall be done in such a manner that no water-holding soil depressions are produced. Natural drainage swales shall be used wherever possible. If certain areas cannot be surface drained properly, they shall then be drained by imbedding perforated drain pipe (four inch (4") minimum) in a trench six inches (6") in width by a minimum of 18 inches in depth filled with three-eighth inch

(3/8") gravel. Trenches shall extend to non-play areas. Trenches draining into nearby level non-play areas shall surface or end in open swales or pits excavated to twelve feet long by twelve feet wide by three feet deep (12' x 12' x 3'). These pits shall be filled with greensmix material, filter fabric, and a four inch (4") layer of topsoil. All stones two inches (2") in diameter and larger shall be removed from untopsoiled areas to be grassed. This removal shall be accomplished with stone pickers, rakes or any other devices that do not disturb the finished sub-grade.

Topsoil Selection

One of the most critical decisions to be made is the selection of topsoil. The selected material must conduct desirable water and airflow through proper particle size distribution. It shall have a desirable water holding capacity and allow for proper drainage while providing a medium for adequate physical and nutritional plant support. It is critical to choose material that is relatively clean of undesirable weed seed. This will greatly reduce the need for chemical weed control (herbicides) materials. It is recommended that you use an ash/cinder mix of a yet undefined ratio or the Brewer Chemical-Hilo soil fumigated with methyl bromide. Further testing will be needed to determine the proper soil pre-mix. This material must be placed onto a properly graded surface with appropriately sized choker material.

Fine Grading-Topsoil Cleaning

After topsoil is re-spread, all stones, roots, and debris greater than three-fourth inch (3/4") in diameter shall be removed by stone pickers, rakes, or other devices that do not disturb grade or create water-holding pockets.

Tees

Sub-Grading and Compaction

Tees shall be built to follow the Designer's Contour Plan. To insure that the tee forms blend well into natural terrain, all filled areas shall be compacted to ninety-five percent (95%) as specified so that no future settling will occur. Fill soil will be tracked or sheepfooted with adequate moisture added throughout the grading process. The last three feet (3') will be placed on six inch (6") lifts with necessary tracking, sheepfooting, etc., and moisture to achieve the mandatory compaction of ninety-five percent (95%). Proper choker material must be placed below topsoil to avoid settling due to sifting, and to function as an integral part known as a "perched water table".

Fine Grading and Topsoil

Care shall be exercised that no water will be trapped around the tee. The same soil mixture used for the greens shall be used for the tees. The soil mixture depth should be a minimum of four (4) inches (when settled and floated). The soil mix shall blend into the surface mix in a pleasing manner. To assure proper grading, the Contractor will be subject to "stringlining" of all tee surfaces. Sub-grades will be constructed with sufficient pitch (one percent) to allow sub-drainage, but finished surface grades will be perfectly level unless otherwise specified by the Designer. Tile will be installed at unit price if necessary to complete sub-drainage. A maximum of 6" and a minimum of 3" of tee mix material is acceptable.

Greens

General

The Designer's instructions regarding the design of greens shall be closely followed according to field drawings. The method of construction will conform to current United States Golf Association's (USGA) "Specifications for a Method of Putting Green Construction". Slope on the pinnable areas of the green shall not exceed 1.5%.

Shaping Procedures

The putting surface should be graded with the green cavity excavated to a depth of 18 inches (12 inches if top soil is to be added later); such grade to be approved by the Designer. Once such approval is made, the Contractor is then responsible for installing the putting surface according to the specifications. The finished grade is to be replaced identically to that of the originally approved sub-grade.

Sub-Grade and Compaction

The contours of the sub-grade should conform to those of the proposed finish grade with a tolerance of plus or minus one inch (1"). The sub-grade should be compacted to ninety-five percent (95%) as specified to prevent future settling that might create water-holding depressions in the sub-grade surface and corresponding depressions in the putting surface. The last three feet (3') of sub-grade fill material will be placed on six inch (6") lifts, with necessary tracking, sheepfooting, etc., and moisture to achieve the mandatory compaction of ninety-five percent (95%).

It will be noted that layers of materials above the sub-grade consist of four inches (4") of gravel, two inches (2") of coarse sand, and twelve inches (12") of topsoil mixture. Thus, the total depth will be eighteen inches (18").

"Ringing" the Green

The 30-inch wide collar is to be constructed to the exact same specifications as the green.

Drainage

Trenches shall be excavated in a herringbone or semi-herringbone style with no lateral lines spaced more than 20 feet apart. Trenches shall be eight inches (8") in width by twelve inches (12") in depth. The bottom of the trench shall produce a constant grade of not less than zero point five percent (0.5%)

slope. The trenches and associated drain tile should extend to the surface and into non-play areas at least fifty (50) feet (as water flows) from sensitive areas (streams, wetlands, lakes, etc.). Trenches draining into nearly level non-play areas shall end by surface venting the drains.

Washed gravel of one-fourth inch (1/4") to three-eighth inch (3/8") diameter (as approved by USGA recommended testing lab) shall be evenly spread four inches (4") deep in the bottom of all trenches.

Four inch (4") diameter perforated drain pipe will be placed on the gravel blanket. Pipe shall be either ABS plastic pipe or ADS accordion style coiled plastic pipe with perforations. Otherwise, rigid pipe shall be in eight feet (8') or ten feet (10') sections, installed with holes on the bottom side. All pipe joints shall be connected by impervious sleeves.

The trenches shall then be filled with gravel and a four inch (4") gravel blanket shall be spread over the entire putting surface. All four inch (4") pipe beyond the perimeter of the collar (conduit pipe) shall be non-perforated unless exit pipe is placed in a surface flow swale from the green (particularly in front of greens). In this situation, the conduit pipe will be placed in an eight inch (8") wide by twelve inch (12") deep trench with gravel backfill similar to that used under the putting surface. Gravel is to be brought to the top of the trenches flush with adjacent finish grades.

The upper ends of all main drain tile shall be equipped with a tee joint or elbow to the surface grade beyond the greens cavity. This joint will be brought to the surface grated at its openings at the time of installation. This arrangement will enable the drain line to be flushed should it become clogged. The grate also will allow air to enter the drain lines to better facilitate drainage release. Exit points of the drains shall be surfaced in out-of-play areas and marked on the greens drainage plan as-built. Drain exit points must be kept away from non-lined lakes or streams that flow out of the course property.

Plastic Interface

To prevent capillary water movement between the greensmix and surrounding site soils, a plastic interface shall be installed to "ring" the putting surface. The plastic shall be one millimeter (1mm) in thickness and two feet (2') in width. The plastic shall be placed vertically around the cored sub-grade so that the top coincides with the height of the finished grade. The sheet shall be staked at ten feet (10') intervals to ensure that it remains in a vertical position.

Gravel Base

The entire sub-grade should be covered with a layer of clean, washed gravel or crushed stone to a uniform thickness of four inches (4"). The preferred material for this purpose is washed pea gravel (with less than 3% combined silt and clay) of one-fourth inch (1/4") to three-eighth inch (3/8") diameter (as approved by a USGA recommended testing lab). If particles of any other size are included, they shall be screened out. THIS IS IMPORTANT TO THE PROPER FUNCTIONING OF THE "PERCHED WATER TABLE".

Very Coarse Sand Layer

If a discrepancy of more than seven (7) diameters (as determined by a USGA recommended testing lab) exists between the sand topmix and gravel, the following applies: a two inch (2") layer of coarse sand is then spread over the entire gravel base. This sand should be within a range of five to seven (5-7) diameters of the gravel. Thus, if one-fourth inch (1/4") pea gravel (about six millimeters (6mm)) is used, then the particles of the overlying layer of sand should not be less than one millimeter (1mm) in diameter. To prevent movement of the sand into the gravel, the maximum allowable discrepancy shall not exceed five to seven (5-7) diameters.

Greens Mixture

The greensmix shall have particle size distribution with sieve analysis recommendations verified by a soil testing laboratory recommended by the USGA Greens Section. The analysis of the test of the mixture is to be submitted to the Designer for review and approval at the time the Bid for Contract is submitted. The Designer has the right to vary this mixture to meet any special needs of the grass type being utilized.

Percolation rates approved by the Designer must be met with the completed mix. Variations of ten percent (± 5% of standard) will be allowed with the percolation rate. All mixing of materials shall be done off-site unless specifically authorized by the Designer. After mixing, samples taken under the supervision of the Owner's representative will be sent to a USGA testing lab to insure that the mix meets the original specifications. This will be done prior to any placement of the materials on the greens. The greensmix shall be spread over the putting surface area to the compacted, uniform, minimum depth of twelve inches (12").

Soil Covering Placement, Smoothing and Firming

When soil has been thoroughly mixed off-site, it shall be transported to the green site and dumped at various points around the perimeter. The soil can then be moved more easily from the edges to the center. Many techniques are acceptable for spreading the soil, including shovels, boards, and small equipment. A small crawler-type tractor suitably equipped with a blade, for example, is useful for pushing the soil mixture out onto the prepared base. If the tractor is always operated with its weight on the greens mixture that has been moved on the site, the base of the green will not be disturbed. Under no circumstances will loaded rubber-tired vehicles or dump trucks in excess of one (1) ton be allowed on the gravel base before or during the spreading of the topmix. Existing tile drains must be clearly marked so that they are not crushed by sand trucks or other equipment.

Grade stakes spaced at frequent intervals on the green site will be helpful in indicating the finished depth of the soil mixture. Finish grade will require the use of a level or transit.

- When the soil has been spread over the surface of the putting green, it should be compacted or firmed uniformly. A roller is not satisfactory because it "bridges" the soft spots. "Footing" or trampling the surface will best eliminate the soft spots. Raking the surface and repeating the footing operation will result in having the seedbed uniformly firm. The raking and footing must be repeated until uniform firmness is obtained. Sufficient and repeated watering must be included in the settling process.

<u>Fine Grading</u>

The entire green area shall be fine graded and floated so all contours blend into fairways, bunkers and mounds as shown on the Greens Plans or as directed by the Designer. No water-holding pockets shall remain.

> [<u>Note</u>: If the Designer's Final Specifications for construction differ from the text above, the Designer's Specifications must be considered as alternatives from those provided above.]

<u>Physical Barriers</u>

The project does not have a finalized golf course design at present. In an effort to help eliminate any concerns of pesticide or effluent aerosol drift or migration onto the site of the neighboring aqua-culture farming, it is suggested that the chosen designer be directed to integrate into the design physical barriers of both elevation and width. These can be tall berms with areas of water or sand integrated into the element of design. The goal would be to create a tall berm (greater than 15') with a non-vegetation buffer 100' or more, depending on the aerosol drift model, from the neighbors borders. Trees, shrubs or palms with a

local history of requiring pesticides should be eliminated in areas within 500' of the neighbors' property line. This will greatly eliminate the potential risk of pesticide aerosol migration.

C. <u>TURFGRASS SELECTION</u>

<u>Selection of Turfgrass</u>

The intensity of the management of a golf course is far greater than any supposedly similar situation that may be encountered in agriculture or forestry. This is due to the intensity of the intended use and the need for the turfgrass to resist and recover from damage incurred during play and maintenance.

The following criteria was used for deciding the appropriate turfgrass species for the O'oma II Project:

1. Resistant to disease
2. Resistant to weeds and insects
3. Low water usage
4. Tolerant to high salt conditions
5. Climatological conditions of the site
6. Efficient in soil stabilization
7. Desirable for golf in the intended playing situation
8. Quality nursery sprigs and sod available for course planting
9. Stock material that is clean of harmful pests and grown in accordance with good turf growing practices

The grasses which are proposed for use on the project are:

Greens..................Tifdwarf Bermudagrass
Tees....................Tifgreen 328 Bermudagrass
Fairways................Tifway II Bermudagrass
Roughs..................Tifway II Bermudagrass
Aprons..................Tifway II Bermudagrass
Sod Stabilization........Tifway II Bermudagrass

These grass species meet the criteria listed above for the specific area of use.

D. INTEGRATED GOLF COURSE MANAGEMENT

Introduction

The O'oma II Golf Course will be an 18-hole golf course and driving range. This course will be developed and managed according to the major concepts defined as Integrated Golf Course Management (IGCM). The design and construction of the golf course will allow for structural elimination of many potential problems that would typically limit the effectiveness of an IGCM plan. As a program, IGCM combines the use of physical, structural, mechanical, cultural and chemical controls of numerous pests that may attack a golf course. The goal of the IGCM program is to produce high quality turf. The objectives are to provide a turfgrassed, landscaped biological community with wildlife habitat suitable for recreation. The balance of the ecological community will be integrated in the management of the O'oma II Golf Course in order to balance turfgrass needs and preserve existing natural resources and site features.

Components of Integrated Golf Course Management (IGCM)

A golf course playing surface is a living filter that absorbs, degrades, and volatilizes most inputs from properly applied nutrient and pesticide products. An important step in IGCM is to determine the acceptable levels of degradation that can occur. The lack of a significant quantity of undesirable fungi, for example, will prevent the future loss of the grass plants due to its degenerative effect (disease).

The O'oma II Golf Course will maintain the greens as a consistent, weed-free turf that is of desirable playing quality, aesthetically appealing, and not impacted by the presence of deleterious pests. Insect damage to the greens must also be at an

absolute minimum but the greens need not be totally free of insects (Vittum, 1986).

As for the tees, a similar level of quality will be required. A limited amount of turf damage is acceptable in the apron areas of the tees provided that it does not interfere with aesthetic quality or function of the tee complex. As a routine operation, tee markers are rotated over the entire tee surface to create a uniform wear pattern across the tees. Rotation is necessary to maintain turf recovery. Therefore, the entire tee must be in a playable condition.

Allowing limited damage (weeds or insect damage) does carry a risk that the above pathogen may spread which would force the use of a broader control (Vittum, 1986).

Fairways may have a slightly greater amount of pest damage than tees. Weed control will be used in most play areas. In the rough and natural areas outside the fairways, a lower level of maintenance activity is proposed for insects and fungi.

Once the level of acceptable impairment is defined, and the corresponding level of management is instituted, a regular program of inspections is required. To maintain the turf at the O'oma II Golf Course, it will be necessary for the golf course superintendent and/or his or her management team to make daily inspections of the course. This process is essential to identify the type and presence of pests early, keep damage to an insignificant level, and to initiate the lowest level of response.

To produce high quality turf, it is not necessary to have absolute control over insects and weeds. For example, healthy turf can be sustained with as many as five white grubs per square foot if traffic (wear) is not excessive (Brandenburg, 1989; Vittum, 1986).

Use of the Concepts of Integrated Golf Course Management (IGCM)

The implementation of an IGCM program free of chemical use is constrained by the high demands placed on golf turf (Foy, 1988). "The grounds manager has to decide how much insect damage is acceptable", says Dr. Warren Johnson, professor of entomology at Cornell University in Ithaca, New York. "If he wants ninety-five percent control, he needs to understand that pesticide applications will be necessary. Integrated pest management (IPM) programs, those which rely heavily on monitoring and biological controls will not provide that degree of control" (Sports Turf, May 1988). The implementation of an IGCM program requires that all methods of control be available to the manager. Appropriate controls may then be selected for any circumstance that might cause specific turf pests. Maintaining healthy turf by the prudent use of fertilizers, soil amendments, pesticides, and cultural practices will prevent environmental degradation (Harrison, 1989).

The goal of the IGCM program at the O'oma II Golf Course project is to prevent the opportunity for the growth of pests by using structural, cultural and mechanical means. If a pest causes damage beyond acceptable limits for the particular surface, chemical treatments will be used to reduce the pest density. Following the construction of the golf course, other situations detrimental to pests will take place by the institution of specific cultural or mechanical practices. This opportunity to provide a negative environment for pests is provided by the proposed comprehensive construction program of the golf course. The Integrated Golf Course Management program will function by reducing the potential occurrence of pests and make the host resistant to pests by the modification of the turf grass environment.

The Integration of Pest Managing (IPM)

The elements of a pest prevention and control program:

- Pest may be defined as plant damaging disease, insect or weed.

- Prevention will include monitoring, forecasting, scouting, and visually searching for positive identification.

- Control will include the use of physical, cultural, biological, mechanical and chemical management.

The goals of the IPM plan for O'oma II will be:

- To establish site specific base line data on pest occurrence for a period of one year.

- To educate and develop a staff whose knowledge will be instrumental in implementing an effective and integrated golf course management plan.

- To perform experimental work regarding the testing of the effects of non-chemical practices to control pests and minimize pesticide use.

- To establish a field testing procedure to monitor the impact of the IGCM plan.

The Use of Integrated Pest Managing (IPM) Techniques

- Daily documentation with inspection of each golf hole to include weekly monitoring reports.

- Monthly reports to build a calendar identifying potential hot spots.

- Quantitative and qualitative assessments of turf areas to establish a proper mode of action.

- Adjustment of mowing heights to reduce, weeds, fungus, and insect damage.

- Rotation of routine cutting patterns to prevent excessive wear.
- Avoidance of mowing during high temperature stress.
- Use of syringing or misting during high temperature stress.
- A balanced water and nutrient program.
- Set action thresholds: a point when pest populations or environmental conditions indicate a need to take action.
- Apply pesticides only when the pest is most vulnerable and where it presents the least hazard to people, property, and the environment.
- Look towards alternative and innovative approaches to control pests. If their effectiveness is field proven, seek appropriate approval for use.

Pest Monitoring Practices

The golf course superintendent will monitor each golf hole for any indication of a reduction in turf quality. He will be responsible for the proper identification of any fungi, insects, or weeds and will be responsible for the documentation that each has been identified correctly. He will look for environmental factors that would make the site incompatible with the needs of the pest. Improving ventilation, selective removal of vegetative growth, and physical removing of small pest populations are examples of steps to be taken as a first-step approach. If a nutrient or pesticide is applied, it will be done in a manner that provides an equal balance between the need to continue a cultural practice or apply a pesticide. If for any reason a nutrient or pesticide is applied, no clippings will be removed from the site. Clippings will be mechanically worked into the target site or thatch layer. In all cases clippings will be scattered in rough areas adjacent to each

golf hole where the mowing practice takes place. No clippings will be scattered within 100' of any surface water.

Disease immunoassay kits will be used to aid in the identification of turfgrass disease. They will be used to detect a positive indication that the disease, has exceeded a level defined as a threshold limit. The kits will be used in accordance with the manufacturer's recommendation and suggested mode of action regarding pesticide usage. Currently, the kits are available for the following diseases: Brown patch, Dollar spot, and Pythium.

The use of a microscope will be used to identify the stage of development a particular pest has reached. Samples of unidentified insects, weed nematodes, or pathogens will be forwarded to a reputable laboratory for assistance in proper identification and the development of the proper procedure for control. The assistance of any environmental firm, state agency, or university specialist will be requested and alternative methods of control will be investigated.

Pest Identification

A list of known and probable weeds, insects, and fungus problems that will most likely affect turfgrass at the O'oma II Golf Course has been compiled. These pathogens were based on a site review and the past history of the existing course in the area, and input received from our work and experience in Hawaii. Due to the inherently variable nature of the environment, it must be understood that this list is not, and never will be a complete list. The extent of the weed and pest injuries listed below will greatly depend on the disease host pressure, weed and seed contaminations and weather affecting the turfgrass species at the O'oma II Golf Course site.

The pests on the O'oma II Golf Course site that are of greatest concern to the greens, and to a lesser degree the tees will be leaf contact pathogens. These pests can be identified by a combination of visual inspections and use of turf disease detection kits (Reveal or Dipstick) which will correctly identify the pest prior to it becoming a significant problem. Additionally, the use of a specialized weather monitoring station (Pestcaster) with computer integrated functions will identify weather conditions most favorable to the explosive growth of deleterious fungi. This may be considered if disease becomes a significant problem. Other pests such as goosegrass, hilograss, crabgrass, broadleaf weeds, cutworms, etc., can all be adequately identified by visual inspections.

<u>Pest Problems Associated With Turf at O'oma II Golf Course</u>

The following represents the pest problems that might be encountered at the O'oma II Golf Course site. The pests will be discussed in three groups: turfgrass weeds, disease, and insects. These pests were determined by visiting local courses, discussions with superintendents, and observation of their pest problems.

<u>Turfgrass Weeds</u>

Weed problems associated with golf course turf are divided into two categories; grassy weeds (monocotyledons) and broadleaf weeds (dicotyledons). The use of topsoil derived from fumigated Brewer Chemical-Hilo soil or from cinder and ash (not yet determined) may be placed as a final topmix so that its use will be part of an attempt to minimize the use of herbicides. The following is a discussion of each category. The extent and location of infestation over the last five years is also included.

<u>Grassy (monocotyledons) Weeds - Annual</u>

Anticipated grassy weed species are:

Crabgrass	(Digitaria sanguinalis)
	(Digitaria ischaemum)
Goosegrass	(Eleusine indica)
Swollen Finger Grass	(Chloris Inflata)
Hilo Grass	(Paspalum conjugatum)
Kikuyugrass	(Pennisetum clandestinum)
Purple Nutsedge	(Cyperus rotundus L.)
Yellow Nutsedge	(Cyperus esculentus L.)

The above species of weeds are those that are found on an annual basis. The herbicides listed in the section, Pesticide Use and Selection, are for the control of the above turfgrass weeds.

<u>Broadleaf (dicotyledon) Weeds - Perennial</u>

Dandelion	(Taraxacum officinale)
Spurge Spotted	(Euphorbia maculata L.)
Spurge Prostrate	(Euphorbia supina Raf.)
Pigweed Spiny	(Amarunthus spinosus)
Pigweed Prostrate	(Amarunthus graecizans)

<u>Turfgrass Disease</u>

The following diseases may be encountered at the O'oma II golf facility:

Algae	(Thallophyta)
Anthracnose	(Colletotrichum graminicola)
Brown Patch	(Rhizoctonia solani)
Dollar Spot	(Schlerotina homoeocarpa)
Fairy Ring	(Marasmius oreades)
Leaf Spot	(Helminthosporium biopolaris, dreschlera)
Pythium Blight	(Pythim spp.)
Take-all Patch	(Gaeumannomyces graminis)

Occurrence and the severity vary, depending on the time of year, weather conditions, and fertility levels. Cultural practices that promote healthy turf will be employed in an effort to minimize the occurrence of outbreaks. Each disease varies in their potential to infect and injure turfgrass. Cultural and curative practices will be covered later in this report.

Turfgrass Insects

The following list of insects have the ability to destroy healthy areas of turfgrass at the O'oma II golf facility. These insects are those deemed important enough to warrant regular monitoring and have the ability to destroy healthy turfgrass. However, tolerable levels below threshold limits should pose no threat to the desirable playing quality of the golf course. Each insect will be monitored for detection and an established threshold level will be set, under the Integrated Golf Course Management Plan.

Armyworm (common)	(Pseudaletia unipuncta)
Bermudagrass scale	(Odonaspis ruthae)
Cutworms	(Noctuidae family)
Rhodesgrass scale	(Antonina graminis Maskell)
Stumpy mite	(Tyroglyphus longior family)
	(Eriophyes cynodeniensis)
Sod webworm	(C. Herpetogramma phaeopteralis)

Table 1. Location and Extent of Pest Infestation

Pest Infestation Index:

Severity: 1-Low........5-High

Location Index: T=Tees F=Fairways G=Greens R=Roughs

a. Weeds	Pest Index	Location
Monocotyledons		
Crabgrass	(3)	T F G R
Goosegrass	(3)	T F G R
Swollen finger grass	(4)	T F R
Hilo grass	(3)	T F R
Kikuyugrass	(2)	T F G R
Purple Nutsedge	(3)	T F R
Yellow Nutsedge	(3)	T F R
Dicotyledons		
Dandelion	(2)	T F R
Spurge spotted	(3)	T F R
Spurge prostrate	(2)	T F R
Pigweed spiny	(2)	T F R
Pigweed prostrate	(3)	T F R

b. Disease	Pest Index	Location
Algae	(5)	T F G
Anthracnose	(3)	T F G
Brown Patch	(2)	T F G
Dollar Spot	(2)	T F G R
Fairy Ring	(1)	T F G R
Leaf Spot	(4)	T F G R
Pythium Blight	(1)	T F G
Take-all Patch	(3)	T F G R

c. Insects	Pest Index	Location
Armyworm	(2)	T G
Bermudagrass scale	(3)	T F G
Cutworms	(4)	T G
Rhodesgrass scale	(4)	T F R
Stumpy mite	(3)	F R
Sod webworm	(3)	T G

TABLE 2. Preliminary Threshold Guidelines - Turfgrass Insects

Currently there are no established industry standards for pest threshold guidelines. The following thresholds for insects and disease are established as a preliminary guide to assist the golf course superintendent in deciding when to employ and when not to employ the use of chemical controls. We fully expect that local experience will result in the refinement of these threshold guidelines.

Area	Pest	Insect Density Cultural Controls	Insect Density Curative Controls
Greens/Tees	Armyworm	3-5/sq ft	6/sq ft
Fairways		5-8/sq ft	8/sq ft
Roughs		5-8/sq ft	8/sq ft
Greens/Tees	Bermudagrass scale	1-3/sq ft	4/sq ft
Fairways		3-5/sq ft	6/sq ft
Roughs		5-8/sq ft	8/sq ft
Greens/Tees	Rhodesgrass scale	2-3/sq ft	3-5/sq ft
Fairways		3-5/sq ft	6/sq ft
Roughs		5-8/sq ft	8/sq ft
Greens/Tees	Stumpy mite	1-3/sq ft	4/sq ft
Fairways		3-5/sq ft	6/sq ft
Roughs		5-8/sq ft	8/sq ft
Green/Tees	Sod Webworm	1-3/sq ft	4/sq ft
Fairways		3-5/sq ft	6/sq ft
Roughs		5-8/sq ft	8/sq ft

TABLE 3. Preliminary Threshold Guidelines - Turfgrass Weeds (Monocotyledons)

Pest	Area	Cultural Management	Curative Control
Crabgrass	Tees/Greens	preventive	spot treat
	Fairways	preventive	spot treat
	Roughs	preventive	spot treat
Goosegrass	Tees/Greens	preventive	spot treat
	Fairways	preventive	spot treat
	Roughs	preventive	spot treat
Swollen Finger Grass	Tees/Greens	preventive	spot treat
	Fairways	preventive	spot treat
	Roughs	preventive	spot treat
Hilo Grass	Tees/Greens	mechanical removal	spot treat
	Fairways	preventive	post emergence
	Roughs	preventive	post emergence
Kikuyugrass	Tees/Greens	sod/vertical barrier	spot treat
	Roughs	preventive	post emergence
	Roughs	preventive	post emergence
Purple Nutsedge	Tees/Greens	spot treat	post emergence
	Fairways	spot treat	post emergence
	Roughs	spot treat	post emergence
Yellow Nutsedge	Tees/Greens	spot treat	post emergence
	Fairways	spot treat	post emergence
	Roughs	spot treat	post emergence

TABLE 4. Preliminary Threshold Guidelines - Turfgrass Weeds (Dicotyledons)

Pest	Area	Cultural Management	Chemical Control
Dandelion	Tees/Greens	mechanical removal	spot treat
	Fairways	spot treat	post emergence
	Roughs	spot treat	post emergence
Spurge spotted	Tees/Greens	preventive	spot treat
	Fairways	preventive	spot treat
	Roughs	preventive	spot treat
Spurge prostrate	Tees/Greens	preventive	spot treat
	Fairways	preventive	spot treat
	Roughs	preventive	spot treat
Pigweed spiny	Tees/Greens	mechanical removal	spot treat
	Fairways	preventive	post emergence
	Roughs	preventive	post emergence
Pigweed prostrate	Tees/Greens	sod/vertical barrier	spot treat
	Fairways	preventive	post emergence
	Roughs	preventive	post emergence

- Control of annual turfgrass weeds on bermudagrass varieties are best obtained with the use of a pre-emergent herbicide. The use of spot treatment will serve as a guide to those compounds modeled for use under the maximum number of acres treated per year.
- Dicot weeds may be controlled with consistent cutting heights on greens and tees. The use of topsoil with cinder and ash or fumigated Hilo soil should result in lower counts of weed infestation. Consistent monitoring and proper timing of spot treatment will result in less need for post emergent applications.

TABLE 5. Preliminary Threshold Guidelines - Turfgrass Disease

Area	Pest	Cultural Mgmt Threshold	Chemical Control Guidelines
Greens/Tees	Algae	upon detection	spot treat
Fairways		24-48 hours	72 hours
Roughs		48-72 hours	120 hours
Greens/Tees	Anthracnose	upon detection	spot treat
Fairways		48-72 hours	96 hours
Roughs		48-72 hours	96 hours
Greens/Tees	Brown Patch	24-48 hours	spot treat
Fairways		48-72 hours	spot treat
Roughs		48-72 hours	spot treat
Greens/Tees	Dollar Spot	24-48 hours	spot treat
Fairways		24-48 hours	72 hours
Roughs		48-72 hours	96 hours
Greens/Tees	Fairy Ring	24-48 hours	spot treat
Fairways		48-72 hours	96 hours
Roughs		96 hours	120 hours
Green/Tees	Leaf Spot	upon detection	spot treat
Fairways		24-48 hours	spot treat
Roughs		48-72 hours	96 hours
Greens/Tees	Pythium	upon detection	48 hours
Fairways		24-48 hours	48 hours
Roughs		24-48 hours	48 hours
Green/Tees	Take-all Patch	24-48 hours	spot treat
Fairways		24-48 hours	spot treat
Roughs		24-48 hours	spot treat

E. PEST MANAGEMENT STRATEGIES

Biological and Bacteriological Controls

No bacteriological controls are being proposed for use on the O'oma II golf facility at this time. However, the efficiency and practicality of existing products are being examined. If a potential product can show significant reduction in both the incidence of pest problems and effective treatment in their control, then test use of the product will be field tested.

Cultural Controls

Good cultural practices, properly balanced supplemental fertilization, and water management will greatly reduce the need for many pesticides. It has been proven through tests and field experience that the need for pesticides can be reduced. If the right turfgrass for the climatic zone is planted, the soil chemistry is analyzed and improved, and adequate sun exposure and air circulation is provided, then a healthier turf environment should prevent any turf pest outbreak that might cause severe damage.

Implementation of Cultural Controls

The first step in cultural control is the selection of the correct grass species for each of the play surfaces. Once the turf has been established, it must be nourished by adequate quantities of nutrients and water.

Each turf management area must be properly drained and irrigated. The O'oma II project will have its own weather monitoring station. This station will balance the addition of any irrigation water by monitoring natural precipitation rates so as not to exceed the soil holding capacity nor allow precipitation rates to create unnecessary surface run-off. The use of a state-of-the-art weather station controlled irrigation system (Maxi-V Rainbird or Toro-8000) will supply water to the plants at the replacement values of the turf, thus reducing leaching. This

system allows the superintendent to adjust flows according to unusual site specific conditions. Continuous under watering of the turf leads to the establishment of shallow root systems that correspondingly dry out rapidly during periods of hot weather (Lucas, 1984). Irrigation can be used to discourage insect growth and promote turf health. Infrequent deep watering seems to be the best practice, when possible (Daar, 1982).

As stated earlier, cultural methods will be used to control excessive thatch in order to eliminate prime habitat for insects and fungus. Thatch control will be accomplished by vertical mowing and by the collection of grass clippings from green and tee management areas. Aeration of the surface soils will be used to relieve compaction, reduce thatch and help in the exchange of gases and fluid to the turf. Vertical mowers and/or groomers will be installed on green and tee mowing equipment allowing the course to be dethatched on a regularly scheduled basis. Control of thatch promotes better water movement to the turfgrass roots, which in turn allows the turf to thrive due to the extension of turf roots from more effective water penetration. The removal of thatch also allows the turfgrass plants to dry more effectively which eliminates or reduces the chances for the grass to act as a site for algae and fungi growth (Daar, 1982).

To achieve healthy turf, which is a living filter and erosion stabilizer, one must meet the turfgrass community's biological, chemical, and physical needs. Aeration, thatch control, adequate air circulation, adequate sun exposure, proper irrigation and drainage, proper turfgrass selection, proper mowing height selection, and equipment maintenance are all part of the total program. This is called stress management.

Reducing stress in turn reduces disease, weeds, and insects. One of the most common sources of stress is soil nutrient and chemical imbalance. Soil, plant tissue, and water quality testing must be done at least twice a year to evaluate the nutrient, electrolytic balance, pH, etc., of the soil. Too much nitrogen can lead to disease. Too little nitrogen, potassium, phosphorous, etc., can lead to disease. The presence of a pH imbalance can make adequate nutrient supplies unavailable through chemical insolubility or fixation that can cause disease.

Higher potassium is needed in the summer to increase cell wall thickness. In the spring and fall, higher phosphorous is needed to increase root depth and mass. Adequate nitrogen will be needed to sustain enough growth to recover from wear but too much will increase thatch. These management steps are necessary to increase the turfgrass plant's ability to resist environmental pressures, and stress associated with its use as a playing surface for golf. Chemical controls are greatly reduced, and sometimes eliminated when the use of stress management is employed.

Below is an outline of the cultural practices expected for use on the O'oma II golf course:

Cultural Controls Outline

- Proper pH and electrolytic balance of soils will be established and maintained to provide optimum growing conditions.
- Adequate air circulation and exposure to sunlight will be analyzed and improved in areas under stress, if necessary.
- Adequate tee and green size will be provided to accommodate traffic wear and reduce areas of compaction.
- Misting by means of the irrigation system will to provide effective control on the evapotranspiration rate.
- Daily inspection by the golf course management team will be necessary to identify any potential pest problems early.

- The basic goal of cultural management is to maintain healthy turf that keeps the incidence of weeds, insects, nematodes and disease at an insignificant level. The threshold levels will be established to limit the unnecessary use of pesticides.

Summary of Cultural/Mechanical Controls

The following will be used as inter-related cultural practices:

- The use of a mechanical spiker to promote root growth, reduce the incidence of water puddling, and provide beneficial oxygen to the crown area.

- Vertical mowers to control excessive areas of thatch (more than 1 inch or 2.5 centimeters (cm) on fairways/roughs; more than 1/2 inch or 1.25 cm on tees; more than 1/4 inch or 1mm on greens).

- Mechanical brushes will be used to provide upright shoot growth and prevent matting.

- A coring machine or aerifier will be used to eliminate compacted soils and prepare the site for topdressing or overseeding.

- The use of a high pressure water injection aerifier will be used in periods of stress or when the practice may actually help reduce the need to apply a pesticide.

- A mechanical overseeder will be used to control excessive thatch and provide a protective canopy on native soils. Sprigging or sodding also will be used as a preventative means to control unwanted species of weeds wherever possible. Any playing area with insufficient vegetative growth will receive appropriate sod or sprigging as a measure to improve the quality of play. The turf type will be of the same type and quality defined in the architects specification plan for O'oma II.

- Topdressing will be applied on a weekly and a monthly basis to all tees and greens. Wear patterns on tees will be topdressed

and seeded. Markers will be moved daily to allow sufficient time for the germination of new seedlings. This practice will help to eliminate the establishment of weeds that are the result of continual play.

- Greens will be topdressed approximately every four weeks or as deemed necessary by the golf course superintendent. The rate of top-dressing will be directly proportional to the control of thatch. Topdressing material will be of the same material and organic content as specified in the original building of greens, under the golf course specification plan for new construction.

- Topdressing will be used to level playing surfaces, improve root structure when coring, control thatch, protect new seedlings, and as plant crown protection from winter injury. Spot topdressing will be the practice for those areas in fairways with exposed native soils.

Wherever possible weeds will be eliminated by hand. An ultra low-volume backpack sprayer will be used to apply spot treatment applications to those areas of disease, insects and weeds above threshold limits. Pests that are slightly above threshold levels, but not excessive in population, will be treated with a proportioned droplet applicator. This same approach will be used to control growth in and around bunkers of each golf hole.

Mechanical Control Program

In order to maintain a healthy and protective stand of turfgrass on the O'oma II Golf Course, the use of a mechanical control program is needed in conjunction with cultural control measures.

Suggested mechanical controls include the use of the following type of equipment and practices:

- Core aerification
- Shatter-Core aerification (shallow and deep tine with solid tines)
- High pressure water injection aerification
- Spiking/Slicing
- Dethatching (heavy thatch removal)
- Vertical mowing (light thatch removal)
- Grooming
- Brushing
- Proper mowing heights
- Proper mower blade sharpening
- Proper equipment repair

Aerification is the process of opening passageways from the surface of the soil into the root zone. The first four items above describe various ways that this process of improving the air, soil, and water relationship can be accomplished. Aerification is the equivalent of cultivation (plowing/discing) in agriculture. Because golf courses are subjected to traffic (walkers, carts, tractors, etc.) the upper soil profile is subject to compression (compaction) and soil pore space reduction. These reductions often restrict the passageway of air and water to the root zone which reduces growth due to the imbalance in carbon dioxide and oxygen exchanges.

All turfgrass will be maintained at the highest cutting height possible to produce acceptable playability. The following range of heights (Table 6) will be maintained for each surface of play. Consistent cutting heights will be maintained, while the frequency of cut will provide controlled growth and less impact from stress both climatic and environmental.

TABLE 6. Turfgrass Maintenance

AREA	HEIGHT OF CUT	MOWING FREQUENCY (DAYS OF WEEK)	(x) WEEKLY
TEES	3/8"-1/2"	M W F	(3)(w/baskets)
FAIRWAYS	3/8"-5/8"	M T W TH F	(5)
GREENS	1/8"-3/16"	T W TH F S S	(6)(w/baskets)
ROUGH	1" -1 1/2"	M T TH F	(4)

TOTAL SQUARE FOOTAGE ESTIMATES
(based on 125 acres)

	ACRES	SQUARE FEET
TEES/DRIVING	5.60	243,936
FAIRWAYS	35.00	1,524,600
GREENS	3.30	143,478
PRACTICE/NURSERY	0.46	20,000
ROUGHS	35.00	1,524,600
EXTREME ROUGH AND HAZARDS	45.64	1,988,078

No more than 1/3 of the leaf blade will be removed in any single mowing. Clippings will be removed from tees and greens and dispersed over the rough adjacent to each hole where they are removed. There will be no compost of removed leaf blades nor will any clippings be permitted to accumulate near the intended use of play. Any clippings used for organic decomposition will be incorporated by rototilling into a defined topsoil mixing area. Consistent mowing heights will be maintained throughout the growing season. Mowing frequency may increase during the spring and following fertilizer applications. During hot and dry periods, mowing frequency may decrease. During inclement weather reduce mowing frequency so that mechanical damage will be kept to a minimum. Each mower will be adjusted and inspected according to the manufacturer's specification in order to provide optimum cutting performance. The use of Wiehle rollers will be included on all equipment used to mow tees, fairways, and greens. This will aid in the control of excessive thatch and promote tillering of planned bermudagrass.

Greens will be maintained utilizing a walk-behind and/or triplex mower manufactured by the Jacobson Textron Company or similar manufacturer. The use of these mowers will provide a precise uniform cut with the least amount of compaction and mechanical damage. Clean up passes will be altered to allow upright growth and prevent what is known as tracking. It would be suggested that the predominant mowing equipment used on the greens are walk-behind mowers rather than the triplex mowers. While both are appropriate and effective for Tifdwarf greens, it has been proven that the use of the walk-behind mowers cause less compaction and wear than do the triplex mowers.

Equipment used to mow tees will be low compaction, light-weight hydraulic triplex mowers. They will be provided with optional grooming attachments, have five to eight blade reels, and grass catchers. In those areas prone to stress, a smaller 22-inch walk-behind mower with the above features may be used.

More than one size mower will be used to maintain fairways. The manufacturer whose design features best adapt to the characteristics of each golf hole at O'oma II site will be chosen for use. Eight to eleven blade high frequency reels, hydraulically driven, will be used to maintain the fairway playing surface. Triplex class mowers with optional buckets will be used on smaller fairways and as a means to off-set perimeter cuts. Lightweight five-gang mowers with identical features will be used on all fairways. Fairways will be mowed in the opposite direction every time they are cut to prevent matting or frequency marks.

Two types of mowers will be used to maintain roughs and general use turf. They are reel-type and rotary. Tractor drawn,

ground driven or hydraulic reel mowers will be used to maintain areas adjacent to perimeter roughs. Any areas adjacent to bunkers, greens, and tees may involve the use of a hydraulic rotary or reel driven mower. The mowers selected will be chosen on the basis of providing a uniform cut with a minimum of wear and compaction damage. They will assure quality playing conditions while removing a maximum of one third of the total leaf blade during each mowing.

Aerifications are normally performed in the spring (March-June) and again in fall (September-November) to deal with normal, routine problems. Additional aerification is sometimes used to alleviate difficult problems associated with compaction or a reduction in root structure profile throughout the year.

Aerification performed too early in the spring, or too late in the fall, can result in increased weed infestation due to inactive turf recovery and adverse weed seed competition.

Aerification performed too late in the summer can cause a great deal of heat related stress due to the exposure of the root zone mix/soil to the effects of elevated temperatures. Increased direct sun exposure, elevated evapotranspiration replacement values, etc., and the presence of soil/sand on the canopy of the leaf surface in the case of core aerifications must be considered when choosing to aerify.

Historically, spiking or shatter-core aerification was used in the summer when compacting problems warranted aerification because the risk of desiccation was too great to use core aerification. With the recent advent of high pressure water injection, summer aerification on greens and tees will be possible due to the increased safety margin.

The use of mechanical methods, to control the excessive buildup of thatch, is necessary to manage healthy turf, but some thatch on playing surfaces is desirable because of its cushioning and filtering effect. Thatch helps to shade and protect the soil, and also helps to contain or filter out fertilizers and chemicals. In addition, the proper amount of thatch will help to enhance the biological active zone which in turn helps to deactivate undesirable residual chemical and fertilizer products. In the beginning of this section various mechanical controls were discussed. Dethatching, vertical mowing, grooming and brushing are the primary methods used to control and maintain the desired thatch level.

The final and most critical part of the mechanical control portion of this IGCM program is proper mowing height adjustment and mowing (cutting) quality. Mowers must be maintained so that leaf blades are cut and not torn off. Lacerated leaf ends with extensive irregular separation provide a great deal of tissue exposure and plant tissue stress. This will increase the possibility of pathogenic invasion. Mower blades must be sharp. Proper mowing heights are also paramount to the management of healthy turf. Mowing Tifdwarf greens below 1/8" creates undue stress. Mowing Tifgreen tees below 1/4" does not provide for adequate turf recovery or repair. Tifway II fairways should be kept at or above 7/16" to get desirable color and cover.

F. Fertilizer Usage Strategies

Fertilizer Program

Even though about half of the nitrogen applied to turfgrass does end up in the plant, the other half can be found stored in the soil, lost to the atmosphere, leached into ground water, or transported as runoff into surface water. It has been shown that golf courses can be managed so nitrates from fertilizers do not contaminate ground water supplies (Petrovic, 1989).

When research does show nitrate leaching from turfgrass areas, it also shows that leaching fortunately lends itself to being

controlled by best management practices (e.g., Cohen et al., 1990). This most often occurs when one or more of the following conditions exist: excessive single nitrogen amounts are used, highly water-soluble nitrogen sources (urea, ammonium nitrate, ammonium sulfate, or potassium nitrate) are used at inappropriate times, when fertilizers are applied to turf in dormant or semi-dormant states which exhibit lower nutrient uptake and greater water percolation, and/or where irrigation or rains have caused greater amounts of leaching.

Research information, on sites like golf greens containing high amounts of sand does not support the conclusion that golf courses are prone to heavy nitrate leaching. This is especially true with today's trend toward lower nitrogen use rates and increased use of slow-release nitrogen sources. Slow-release nitrogen sources require microbial activity or hydrolysis to convert the nitrogen to a plant available form. When soluble nitrogen sources are used, the potential for ground water contamination can be reduced essentially to zero by following sound management practices. Frequent applications of lesser amounts of both fertilizers, and irrigation water can greatly reduce potential leaching. Applying fertilizers at times of rapid plant growth, enhances plant uptake, thus reducing the amounts which could potentially leach through the soil profile.

For example, a study done by Morton, et al. (1988) addressed the influence of irrigation and fertilization on nitrogen losses from turf. The study was conducted on a sandy loam soil. The authors concluded that normal fertilization and irrigation of a mix of cool-season turfgrasses resulted in nitrogen losses no different from the unfertilized controls.

Thus, with the implementation of sound management practices, the probability of ground water contamination from nitrate fertilizers on the O'oma II Golf Course can be effectively reduced to insignificant levels. Since irrigation inputs of water will be at a replacement rate only (modified penman calculation from an on-site weather station), overwatering and leaching of soluble nitrogen forms will not readily occur. When using proper amounts of irrigation water replacement during periods of active plant growth, water soluble nitrogen can be applied at rates of less than 1.0lb/N/1000 ft^2/month without any significant accumulation or leaching. Timing fertilizer application to coincide with the period of active plant growth and nutrient uptake will optimize nitrate absorption and reduce the amount of soluble nitrogen available for leaching. Slow-release fertilizers, those that do not release excessive nitrogen during heavy rain, will be the fertilizers applied during the wet months.

The proportion of highly soluble and slow-release nitrogen fertilizers used on the O'oma II Golf Course will vary with management, area, and time of year (Table 7). Roughly sixty percent (60%) of fertilizers applied to greens and tees will be in water-soluble forms, while the remaining forty percent (40%) will be of the slow-release variety. This is due to the intensive nature of area usage. Typical application rates for tees are approximately one pound of nitrogen per thousand square feet (1 lb/N/1000 ft^2) per month, and greens are fertilized at zero point seventy-five pounds (0.75 lbs N/1000 ft^2) per month. A higher proportion (up to eighty percent (80%)) of the nitrogen added to fairways will be slow-release or delayed-release formulations. Total nitrogen added per year on fairways will be approximately eight to ten pounds per thousand square feet (8-10 lb/1000 ft^2) per year. (Table 7).

TABLE: 7 NITROGEN FERTILIZER ANNUAL USAGE ON O'OMA II GOLF COURSE

I. GROUP (Greens/Tees)		
Water-Solubles[1]	**Single Application**	**Maximum Yearly**
1. Gro More 27-0-18	.10-.20 lb/N/1000 sq. ft.	Greens and Tees will receive 6-8 lbs/N/1000 sq. ft./yr of water soluble products
2. Gro More 12-62-0	.10-.20 lb/N/1000 sq. ft.	
3. Gro More 20-5-30	.10-.20 lb/N/1000 sq. ft.	
4. Gro More 12-0-45	.10-.20 lb/N/1000 sq. ft.	
5. Urea 45-0-0	.30-.75 lb/N/1000 sq. ft.	
6. Gro-Power 6-2-8	.30-.75 lb/N/1000 sq. ft.	
Water Insolubles (Primarily)		
1. Scotts 22-0-16	.50-.75 lb/N/1000 sq. ft.	Greens and Tees will also receive 4-6 add'l lbs/N/ 1000 sq.ft./yr of water insoluble products
2. Scotts 19-26-5	.50-.75 lb/N/1000 sq. ft.	
3. Scotts 15-0-30	.50-.75 lb/N/1000 sq. ft.	
4. STEP (trace elements)	.50-.75 lb/N/1000 sq. ft.	
5. Par Ex 31-0-0	.50-.75 lb/N/1000 sq. ft.	
6. Par Ex 21-3-16	.50-.75 lb/N/1000 sq. ft.	
7. Par Ex 12-3-34	.50-.75 lb/N/1000 sq. ft.	
II. GROUP (Fairways/Roughs)		
Water-Solubles		
1. Urea 45-0-0	.50-.75 lb/N/1000 sq. ft.	Fairways and Roughs will receive 1-3 lbs/ N/1000 sq.ft./yr of water-soluble products[4]
2. Calcium Nitrate 15-0-0	.50-.75 lb/N/1000 sq. ft.	
3. Ammonium Nitrate 34-0-0	.50-.75 lb/N/1000 sq. ft.	
4. Turf Royal 21-7-14	.50-.75 lb/N/1000 sq. ft.	
5. Best 16-6-8	.50-.75 lb/N/1000 sq. ft.	
6. Ammonium Sulfate 21-0-0	.50-.75 lb/N/1000 sq. ft.	
Water Insolubles (Primarily)		
1. Par Ex 31-0-0	.75-2.0 lb N/1000 sq. ft.	Fairways and Roughs will also receive 7-9 lbs N/1000 sq.ft./yr of water insoluble products[4]
2. Par Ex 24-4-12	.75-2.0 lb N/1000 sq. ft.	
3. Par Ex 10-18-22	.75-2.0 lb N/1000 sq. ft.	
4. Par Ex 28-3-8	.75-2.0 lb N/1000 sq. ft.	
5. Scott 32-3-10	.75-2.0 lb N/1000 sq. ft.	
6. Scott 22-0-22	.75-2.0 lb N/1000 sq. ft.	

[1] Formulations will be selected in accordance to field inspection, soil and tissue testing.
[2] Trace elements will be added according to soil tests.
[3] Tees typically use 20-30% more (N) fertilizer than the greens.
[4] Roughs will receive 35-40% less (N) fertilizer than the fairways.

NOTE: Water-soluble products will be used during periods of active plant growth and during periods of less frequent rains.

G. Chemical Controls

The term "curative" is used in the descriptions of the control method expected for use on the O'oma II Golf Course. The term "preventive" describes the techniques necessary to keep the inherent problem from becoming a major problem. The need for preventive measures or materials will be determined by the impending weather conditions and the use of early detection kits, such as "Reveal" (a ten minute diagnostic test kit), historic record, past experience, and visual examinations.

Tables 7 through 10 described the cultural and chemical methods recommended for use at the O'oma II Golf Course site. Tables 8 and 9 describe the probable periods of activity and Table 7 and 10 quantify the specific chemical usage and the probable number of acres to be treated.

Methods of Selecting Chemicals for IGCM Plan

The critical selection process of chemicals (pesticides) was based on local chemical effectiveness and regional experience. Safety considerations were important in selecting chemicals for this plan. Sources used to obtain product information include: scientific literature, environmental fate data EPA pesticide registration standards, and fact sheets. Manufacturers' literature (technical reports, material safety data sheets, product labels and communications with manufacturers' representatives). Pertinent information was first taken from primary and secondary scientific literature. University libraries were used as partial resources to obtain data and identify other potential literature sources obtainable through interlibrary loan networks and industry periodicals. The data coming from current literature and EPA reports were given preference over data from manufacturers. This information was used to create the IGCM plan that is illustrated in Tables 7-10.

TABLE: 8

IMPLEMENTATION SCHEDULES
FOR O'OMA II GOLF COURSE

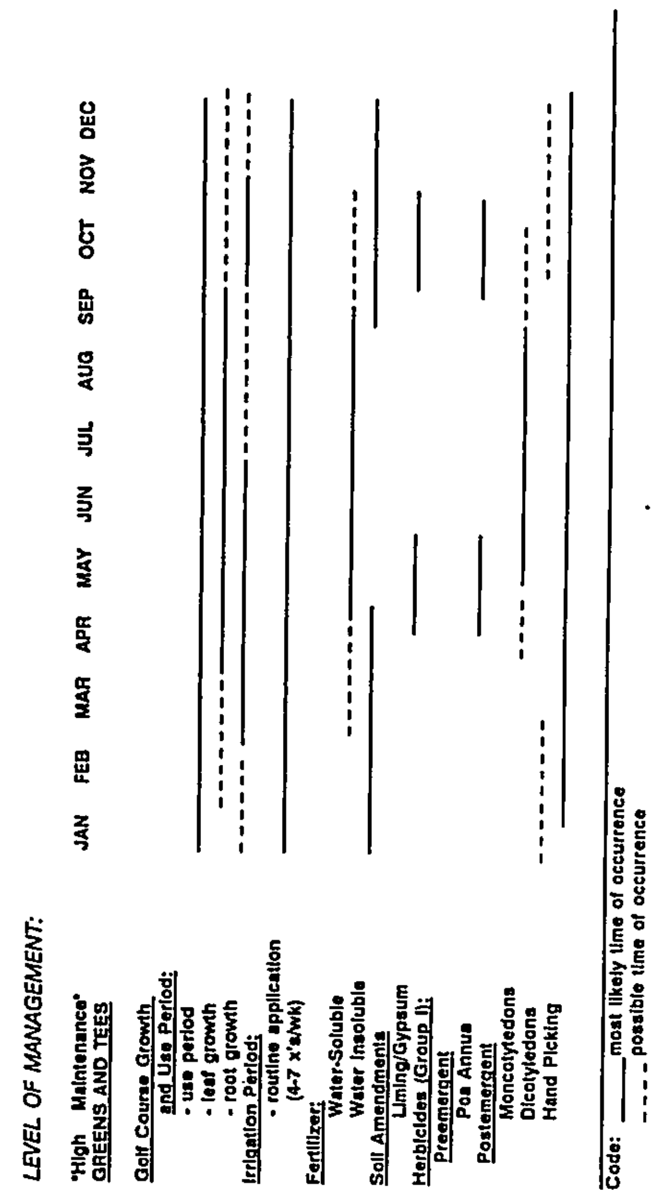
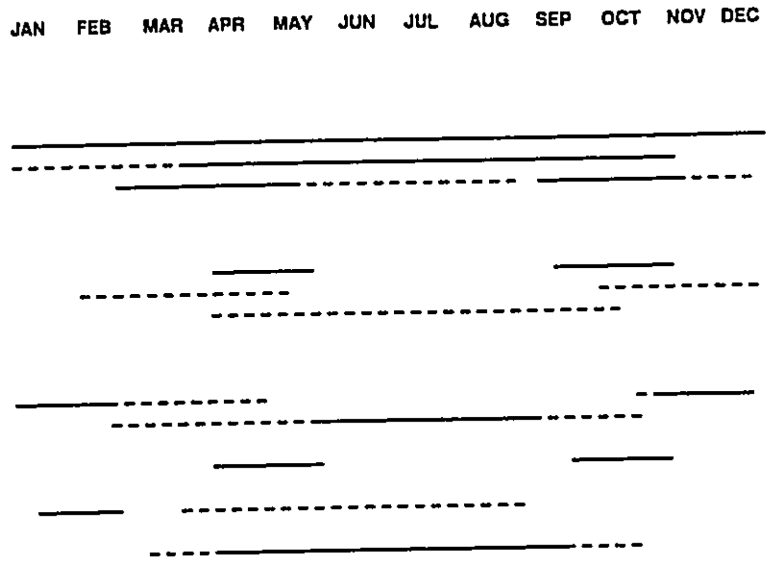


TABLE: 8 (continued)

IMPLEMENTATION SCHEDULES
FOR O'OMA II GOLF COURSE

LEVEL OF MANAGEMENT:

"High Maintenance"
GREENS AND TEES



Golf Course Growth and Use Period:
- use period
- leaf growth
- root growth

Insecticides (Group II):
- Cut Worms
- Sod Webworms
- Fire Ants/Army Ants

Fungicide (Group III):
- Leaf Spot Disease
- Patch Disease

Core Aerification

Spiking

Vertical Mowing

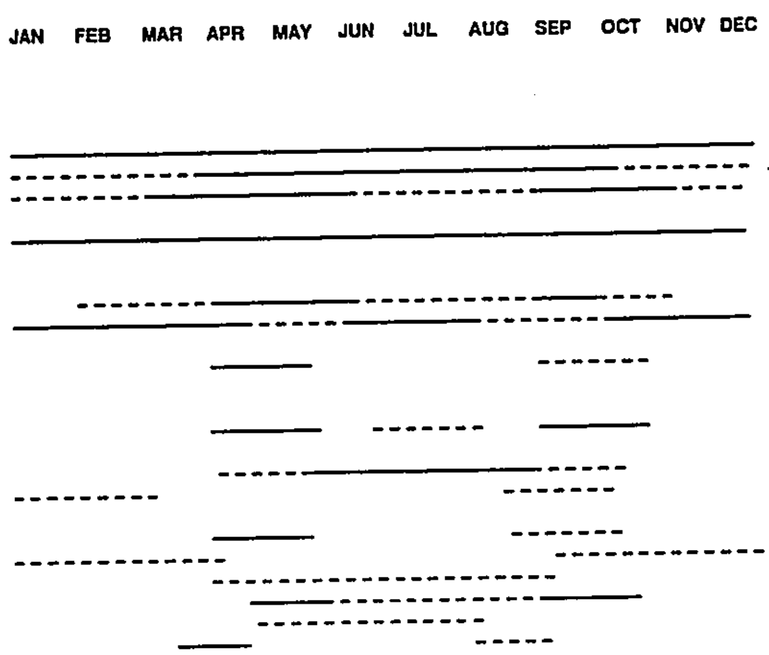
Code: ______ most likely time of occurrence
- - - - possible time of occurrence

TABLE: 9

IMPLEMENTATION SCHEDULES
FOR O'OMA II GOLF COURSE

LEVEL OF MANAGEMENT:

"Medium Maintenance"
FAIRWAYS and ROUGHS



Golf Course Growth and Use Period:
- use period
- leaf growth
- root growth

Irrigation Period:
- routine application (4-7 x's/wk)

Fertilizer:
- Water-Soluble
- Water Insoluble

Soil Amendments
- Liming/Gypsum

Herbicides (Group I):
- **Preemergent**
  - Poa Annua
- **Postemergent**
  - Monocotyledons
  - Dicotyledons

Insecticides (Group II):
- Cut Worms
- Sod Webworms
- Fire Ants/Army Ants

Aerification

Spiking

Vertical Mowing/Dethatching

Code: ______ most likely time of occurrence
- - - - possible time of occurrence

TABLE 10. PROBABLE BIOCIDES FOR USE ON O'OMA II GOLF COURSE PROJECT

GREENS/TEES

I. Herbicides * (Greens/Tees/Fairways/Roughs)

Common Name	Trade Name	Recomm Rate/App. lb/a.I./Ac.	Projected No. of Apps/Yr (Maximum)	Projected Maximum Annual Total/a.I. lb/a.I./Ac	Max. Acres Treated Per/Yr	Areas Treated
Imazaquin	Image	0.5	2 x's/yr	1.0	2.5	(T/R)
MSMA	Weedhoe, etc	2	2 x's/yr	4.0	5	(T/F/R)
Metribuzin	Sencor	.75	2 x's/yr	1.5	5	(T/F/R)
Glyphosate	Roundup	1.5	2 x's/yr	3.0	5	(F/R)
Fluazifop-P-butyl	Fusilade	0.30	2 x's/yr	0.6	1	Ornamental
2, 4-D/ Mecoprop/ Dicamba	Trimec	2.29	2 x's/yr	4.58	5	(R)
Oxadiazon[3]	Ronstar	4	3 x's/yr	12	35	(T/F/R)
Oryzalin	Surflan	3	2 x's/yr	6	3	(R)
Bensulide[2]	Betasan/ Betamec	12	2 x's/yr	24	8.5	(G/T)

II. Insecticides (Greens/Tees and spot treat Fairways/Roughs)

Common Name	Trade Name	Recomm Rate/App. lb/a.I./Ac.	Projected No. of Apps/Yr (Maximum)	Projected Maximum Annual Total/a.I. lb/a.I./Ac	Max. Acres Treated Per/Yr	Areas Treated
Chlorpyrifos	Dursban	.5	As Needed	2.0	12.5	(G/T/R)
Carbaryl	Sevin	1.5	As Needed	1.5	12.5	(G/T/R)
Trichlorfon	Proxol	6	As Needed	16	12.5	(G/T/R)
Fatty acid salts	Safer Soap				20.0	(R)

III. Fungicides (Greens/Tees only)

Common Name	Trade Name	Recomm Rate/App. lb/a.I./Ac.	Projected No. of Apps/Yr (Maximum)	Projected Maximum Annual Total/a.I. lb/a.I./Ac	Max. Acres Treated Per/Yr	Areas Treated
Mancozeb[1]	Fore	17	As Needed	68	8.5	(G/T)
Chlorothalonil	Daconil/2787	8	As Needed	24	8.5	(G/T)
Metalaxyl	Subdue	1.3	As Needed	2.5	3.5	(G)
Thiophanate-methyl	Cleary/3336	10.0	As Needed	20.0	8.5	(G/T)

* Low weed infestation is based on the assumption that the topsoil source will be derived from a yet undefined ration of cinder and ash rather than a conventional topsoil source.
1 Used more often because of the products ability to control algae.
2 Greens/Tees only.
3 Fairways only.

grasses containing residues), by insectivores consuming exposed surface insects or grubs. Once ingested, some pesticides, if not metabolized or excreted, may bioconcentrate to lethal levels in consumer body tissue. Since all pesticides volatilize to a certain extent, inhalation of air containing pesticides could potentially occur. However, the possibility of inhalation of a sufficient quantity for a sufficient length of time to induce mortality is essentially non-existent. Similarly, direct absorption through the skin requires exceedingly high concentrations for an extended period of time. Again, this is not a situation which would be encountered in well conceived and properly implemented pesticide control programs. The dose of a pesticide chemical or even a medical drug determines its effectiveness or detrimental effect. Salt, nicotine, aspirin, etc., ingested at too high a dosage can cause sickness or death. This is also true of pesticides. When one controls or eliminates exposure, one controls or eliminates the risk of injury.

Pesticide use

The following policy will be used when applying pesticides.

- Only after it has been determined by the golf course superintendent that a threshold limit of pest activity has been exceeded and there is no alternative measure for control will a pesticide application be made.

- The actual application of a pesticide will be made under the direction of a certified, licensed applicator.

- The golf course superintendent will be licensed in the following categories: Aquatic Weeds, Turf and Ornamental.

- The pest will be properly identified. The use of disease, insect, and weed identification guides will be used. Diagnostic aid kits will be used on pathogens for which they have been developed.

- Extension service and University lab assistance will be used to identify any unknown activity.

- All pesticide applications will be made in accordance with label specifications.

- In order to minimize drift from the target area, applications will not be made in winds in excess of 5 mph unless a spray shroud is used. Documentation will be verified by the Environmental Pestcaster.

- The applicator will adhere to all label specifications for loading, mixing, and applying the compound. All protective clothing as specified by the label will be worn by the applicator.

- Liquid application of a pesticide will be made using a low pressure boom type sprayer with the boom height no higher than 18" to further minimize drift.

- The use of low volume hollow cone nozzles and applicator spray shields will be installed on the spray boom.

- Notification of the application of a pesticide will be made in accordance with the law.

The golf course superintendent will be responsible for the administration of the above policies.

Handling and Mixing of Pesticides

The O'oma II Project will utilize a state-of-the-art boom sprayer (manufactured by the Hahn Corporation or similar manufacturer). Computerized flow meters, independent boom separation, ground tracking speeds and calibration for precise liquid applications and a sonar boom leveler are provided on this vehicle. The sprayer will be maintained to the highest standards and will immediately cease operation if any failure is noted by the golf course superintendent or operator. This vehicle is totally self-contained and will only be used to apply pesticides outside the drift barrier area. Within the drift zone a windfoil (hydrofoil) system with a shrouded spray boom should be used.

The spray equipment is filled with water from a back siphon protected hose outlet. The spray tank is filled up to 75% of its holding capacity. The compound chosen for use is added to the amount of water in the spray tank. All compound packaging is triple rinsed and poured into the spray tank. Packaging is placed inside the building in its original shipping cartons for disposal. Any pesticide chosen for use will remain at the loading area located adjacent to the pesticide storage building. This covered loading area has been excavated to a depth of one foot (1') with poured concrete as a retaining wall. Eight inches (8") below the surface lies an 18'x 18' piece of filter fabric on top of a 18'x 18' piece of black polyethylene. Approximately seven inches (7") of sand is compacted over the entire area. The purpose of this area is to guard against any form of rinsate that may accidentally be spilled. A hose outlet with a back siphon, protected by a concrete barrier is located at this site. In the center of the concrete wash pad, a drain and sump pump is to be installed to collect pump spillage or tank rinsate into one of two double-walled, above-ground 1000 gallon storage tanks. One is to be used to collect herbicides and the other insecticides or fungicides. A manual valve will direct the flow to the appropriate tank. These tanks are to be connected underground to the pesticide and fertilizer storage areas in the event of fire or storage area cleaning. These areas should be covered to eliminate rainfall collection.

Upon completion of the spray application, the equipment is returned to the rinsate area and filled within 50% of the tank holding capacity. The rinsate is then applied in the areas of rough, designated as perimeter rough, immediately adjacent to each hole where an application of a pesticide can be made. The rinsate is applied with the same ground speed as the actual application. It should be noted that no rinsate is applied in any areas deemed environmentally sensitive or having direct access to any areas with potential surface runoff. Secondary rinsate or spillage will be collected in the above ground tanks for later spray application into the safe rough areas.

Pesticide Spill and Response Plan

A written discharge response plan will be part of the training provided to each employee at O'oma II. The plan will conform to all applicable sections as defined by law. A copy of this plan will be readily available. The Police and Fire Department will be notified that this document has been completed. The Fire Department will be provided with a current copy of all chemicals and pesticides stored in the pesticide storage area. The Material Safety Data Sheets (MSDS) will be provided for each compound in the storage area. In the case of minimal discharge, employees will have the necessary protective equipment and clothing readily available. All materials will be disposed of through a licensed hazardous waste disposal firm. Discharge from dry bulk materials stored within the pesticide storage facility will be recovered by the use of a broom and dust pan used solely for the purpose of recovery of these materials. Any material that is not contaminated and suitable for use, will be repackaged with an original label affixed to the new packaging. It will be used when the appropriate

need arises and for its intended purpose and will not be disposed of unless contaminated.

As specified, only pesticides for use on the golf course will be stored in the building. All employees will receive training on the proper procedure to follow in the event of an accident or fire.

In the event of a fire, the following procedures take effect:

a. The person discovering a fire will notify the local fire department.

b. The person will notify the golf course superintendent as officer in charge. (The local fire department will be provided with the home number of the golf course superintendent).

c. The golf course superintendent will also be responsible for notifying all the appropriate state and local authorities as prescribed by law.

d. In the interest of safety all people will be evacuated from the area.

e. The fire will be directly supervised by the fire department. Other organizations will be notified if requested by the fire department.

f. Any other agency deemed necessary after consultation with the above agencies or under advice from the local government, police or fire departments will be notified.

g. Following a fire the area will be secured as recommended by the fire marshall or fire department.

h. Containment barriers will be installed as deemed appropriate to prevent further contamination of the surrounding area.

i. Upon approval from state and federal agencies and under the advice of approved consultants licensed in the removal of hazardous waste disposal, the clean up process will begin.

j. The above policy will serve as "all appropriate action" unless otherwise specified or clarified by regulation.

Pesticide Storage Facility

A structure of adequate size (approximately 200 ft^2) should be built at the furthermost end (away from offices or employee eating areas) of a single building. The entrance should provide ventilation that is actuated by a explosion proof light/fan switch. The room should have a cement containment floor and a wall of approximately six feet (6') or greater. The storage capacity of the containment floor must retain at least 20 minutes of continuous operation of the fire prevention sprinkler system. This capacity is independent of the outside storage tanks mentioned below. A floor drain connected to a sump pump and a line feeding two (2) 1000 gallon pesticide rinsate tanks should also be installed. A fire extinguisher should be located outside and inside the pesticide storage room. The facility should be designated as a pesticide storage area (as per law), with a copy of the chemicals contained in storage on file in the superintendent's office and one copy on file with the Fire Department.

Storage Facility Check List

The following operating procedure is recommended in regards to the pesticide storage facility at O'oma II golf course site:

a. The building is secured and locked at all times.

b. An additional key is placed in the office of the golf course superintendent in case of emergency.

c. Storage of materials are on shelves located high enough to permit cleaning of floor.

d. All materials have legible labels attached. Any materials whose packaging has been damaged are in containers clearly marked and labeled.

e. Plastic containers are used to store any containers in excess of 1 gallon or more for protection of spillage. A plastic trash barrel with lid is located inside the storage facility for cleanup.

f. The staff at O'oma II is trained in the operating procedures regarding this building.

g. All appropriate protective clothing and equipment is provided for use by those who handle pesticides.

h. Absorbent material designed to contain any accidental spill within the pesticide storage facility will be available at all times.

i. Disposal of pesticide containers shall comply with the instructions on the labeling and with other state and federal regulations. Empty containers will not be allowed to accumulate or be stored within this building.

j. The building is inspected monthly by the golf course superintendent and a record of each inspection is recorded in the records for pesticide use.

k. Obsolete, excess, and mixtures of pesticides shall be disposed of according to the statutes and regulations established by law.

l. Any pesticide accident will be reported immediately to the appropriate authority.

H. WATER REQUIREMENT AND REPLACEMENT

Water Requirement

The basis for determining the basic water requirement for the O'oma II golf course project was determined using Report R34 (DLNR/DOWALD, 1970) and R74 (Ekern and Chang, 1985). The rainfall data was collected at the Kona airport and is considered relevant to the project site. The pan evaporation (EV) data was collected at Hilo airport and adjusted for the project site using a 1.15 factor of increase. Local experience indicated that this adjustment is close to the reality of the actual water EV for the site.

The approximate water requirement was calculated by multiplying the pan evaporative rate EV by (crop factor for bermudagrass) minus 25% of mean rainfall (amount which is assumed effective for reducing irrigation requirement). This was the basis of the projected water replacement needs. No soil types, leaching factors, water application uniformity or convective airflow effects were considered in determining the ET (evapotranspiration) water replacement.

The annual water requirement will be approximately 730 acre-feet of water per year, assuming that the area of the golf course will be built using approximately 125 acres of turf. This is equivalent to 650,000 GPD.

Local wind conditions, soils and convective air flows over the adjoining lava fields may result in as much as an additional 200 acre-feet of water requirement per year.

Water Replacement Strategy

The project is dedicated to the efficient use of water. The project should therefore employ the services of a recognized golf course irrigation designer and a qualified installation contractor.

The system should be a state-of-the-art Rainbird Maxi V or Toro 8000 computerized irrigation system linked to a golf course weather station. These systems can sense the water usage for each day and correspondingly adjust each irrigation valve to the specific time of operation necessary to achieve efficient water replacement. Furthermore, these systems can help operate the pump systems at maximum power efficiency and help regulate hydraulic flows within the systems' hydraulic capabilities.

Water System Specification and Capabilities

The irrigation system designers should determine the particular materials specified in the irrigation design. It is suggested that heads be placed at 60 ft on center spacing using a triangular configuration. This will ensure efficient application of water. Field controls should be placed for user visibility. Valve-in-head sprinklers should be used with control wires for each head row from the individual heads to the field controllers. Heads on fairways and roughs can be paired on an average of two heads per station. Green and tee irrigation systems should be operated individually. Greens should be irrigated with full and part-circle sprinkler heads to allow the superintendent the ability to leach the salts from the greens without flooding the bunkers and aprons around the greens. The irrigation heads should be of the Toro 630 and 650 series or Rainbird 51 and 47 series. No low pressure heads should be used.

I. SUMMARY AND RECOMMENDATIONS

The O'oma II golf course project consists of 18 holes of golf situated on the Kona coast south of the Keahole Airport on the island of Hawaii. The project will be built on top of geologically recent lava flows using an imported topsoil source placed on several layers of "choaker" rock material. The topsoil material tentatively selected for modeling purposes is the Brewer Hilo soil. This soil is derived from sugar cane tailings originating from the

cleaning process of the cane. This soil appears to be structurally superior to other soils tested by the TPC but they are reported to be infested with noxious weeds and weed seeds. If this soil is utilized on this project it should be fumigated using methyl bromide in order to eliminate weed infestation.

The topsoil issue is one of the most significant and expensive elements of the construction of a golf course on the Kona coast. As an extension of ETS' scope of work ETS reviewed the potential topsoil materials which were known to be available. While it appears that the review was satisfactory for the purpose of reconnaissance, it is strongly recommended that a contract be issued for additional studies on this subject. It is necessary to determine if, in fact, the Hilo soil is the best choice when considering the elements of soil material cost, availability, performance, and the cost to control weeds and their seeds (e.g., fumigation with methyl bromide). This study should be conducted expeditiously so that if additional modeling is required for other topsoil materials it can be completed prior to your final project review.

Disease and insects are not a significant problem, based on site observations and interviews with the golf course superintendents of other golf course properties, (i.e., Mauna Kea, Mauna Lani, and Waikoloa). Chemical usage of fungicides and insecticides should therefore be light during normal golf course operation. In Table 10, note that the IGCM plan projected what appears to be high quantities of biocide materials. This was done to show the maximum amount of pesticides that would be required under heavy site specific pressure during unusual and detrimental weather conditions. Under normal conditions pesticide usage will be much lighter. As stated earlier in the body of this report, the use of Integrated Pest Management and good cultural practices are the methods that will be used to reduce the need of pesticides. Healthy turf has been shown to be an excellent filter and a good barrier to both insect, disease, and weed infestation or damage. It is the intention that the golf course superintendent would use the elements of "best management practices" to maintain healthy turf, therefore eliminating the need for significant pesticide usage.

The issue of herbicides, as mentioned earlier, is directly related to whatever imported topsoil is selected. No significant weed population is present at or near the project site. Weeds can be introduced by contaminated topsoil or from the grassing materials selected for use on the site. ETS strongly recommends that this be a significant consideration in the choice and treatment of the selected topsoil and grassing materials used for building the golf course and landscape areas.

As stated above, with the favorable climate of the Kona coast, the absence of existing disease and insect pressures, and with proper topsoil selection and treatment, pesticides will seldom be applied. Those pesticides which are required can be applied without any significant aerosol drift in areas of the golf course, especially in the sensitive areas adjoining the neighboring property. The use of a "windfoil" style shrouded spray applicator can be used which prevents the pesticide spray from entering the atmosphere. ETS recommends the utilization of this type of sprayer within 500' of the neighboring property. This sprayer can be safely used in wind conditions of zero (0) to twenty (20) mph. Under low wind conditions of less than five (5) mph, we feel that in all areas outside the 500' buffer that a normal boom sprayer such as the Hahn sprayer will be suitable and will pose no significant aerosol drift problem.

To further eliminate the concerns over aerosol drift, it is recommended that, as an element of the design of the golf holes adjoining the properties, a 100' buffer be established using lava and sand with isolated pockets of drip irrigated planting

materials. These planting materials should consist of varieties which have proven to require no pesticide treatment such as Fountain Grass and local palms which have a history of no significant disease or insect impact. In addition to the 100' buffer, ETS recommends that at least a 15' high, stacked lava berm be developed within this buffer area as an element of the golf course design which would further act as a physical barrier to the movement of aerosol sprays generated from normal pesticide usage or routine irrigation.

The berm being recommended for use to control irrigation aerosol could be an effective tool to intercept the aerosol drift when wind speeds are less than twenty miles per hour. During operation, if it is determined that the wind speed and direction of the wind would potentially cause aerosol drift from the irrigation system to move towards the neighboring property it is our recommendation that the central computer of the irrigation system be programmed to sense the wind speed direction via the on-site weather station and shut the irrigation system down in these areas until the winds diminish or change direction.

Concerning the issue of nitrogen fertilizer application and the potential of nitrate movement into the ground water, the use of "best management practices" and the use of organic based products or slow-release materials are the control methods planned. In the times when potential rainfall could occur and when the growth rate is slow these controlled relief products control excessive amounts of nitrogen build up or migration in the soil matrix at a time when the plants cannot utilize this material. Nitrogen applications will be kept below one pound of actual nitrogen per 1,000 square feet at any one time. The application of nitrogen and other nutrients applied to the greens will be kept at a rate of less than 0.75 pounds of actual nitrogen for use in those areas at any one time. Overall it is entirely possible to reduce the nitrogen movement though the soil matrix to nearly zero if proper management and selection of materials are utilized.

In summary, we have indicated that because of the low rainfall, good air circulation, and low humidity of the project site, the disease and insect problems associated with this golf course will not be of any significant concern. Pesticide use should be minimal. We further believe that if the topsoil is properly selected and treated for weeds that very few weed infestations will occur on this site, thus requiring low quantities of herbicides. Furthermore, with the use of good cultural practices in overall turf management program and in the selection and application of fertilizers there should not be a detrimental impact of nitrate migration into ground water. Overall, we feel that with the use of he berm and buffer zone concept, and an Integrated Golf Course Management Plan by a qualified golf course superintendent (outlined in this report) that the golf course could be operated in a safe and environmentally responsible way and pose no threat to the ground water or to the neighboring businesses adjacent to the property.

V. EVALUATION OF PESTICIDE MOBILITY, PERSISTENCE, HUMAN TOXICITY AND AQUATIC TOXICITY

This section contains descriptions and evaluations of the environmental chemistry and toxicity of the pesticides and fertilizers identified in Section IV (Management Plan) above. Key characteristics of all chemicals are listed. However, the discussion focuses on the 6 chemicals chosen for detailed modeling.

A. Definition of Terms

K_d- Soil/water distribution coefficient. The higher the K_d the more tightly bound the chemical is to soils. This varies for each pesticide from soil to soil. Pesticides with K_d values less than 1 are mobile in soils and can leach to ground water if it is persistent.

K_{oc}- The K_d divided by the organic carbon fraction of the soil. This, theoretically, should be calculated from the water solubility if experimental data are not available. The regression equation contained in the Kenaga and Goring reference (1980) is used below, when K_{oc} is calculated
($\log K_{oc}$) = 0.55 log WS + 3.64, where WS = water solubility in ppm).

LC_{50} - The lethal concentration calculated to kill 50% of the test organism population.

EC_{50}- The effective concentration calculated to affect the mobility, growth, or other nonlethal endpoint of 50% of the test organisms.

ADI - Acceptable Daily Intake for humans in milligrams/kilogram body weight/day, frequently referred to as the reference dose (RfD) when it represents an EPA-wide consensus.

Q* - Carcinogenic potency factor. This is multiplied times the dose, or intake, to produce the carcinogenic risk.

HAL - Health Advisory Level, an acceptable concentration level in drinking water based on the ADI and Q* described above. Standard assumptions for lifetime exposure: 70 kg person consuming 2 liters of water per day. Standard assumptions for childhood exposure to neurotoxins: 10 kg child consuming 1 liter of water per day.

Relative Aquatic Toxicity - Listed below are five toxicity classifications that EPA uses to qualitatively describe certain ranges of aquatic toxicity (Craven, Sept. 1990) based on the LC_{50} or EC_{50} of each pesticide. For example, a pesticide with an $LC_{50} < 0.1$ ppm is considered very highly toxic. These classifications are used in this report only to make generic assumptions about how these pesticides may impact organisms of concern in the ocean or NELHA/HOST Park.

Classification of Toxicity Categories based on Pesticide

Category	LC_{50} or EC50
Very highly toxic	= <0.1 ppm
Highly toxic	= 0.1 ppm to 1.0 ppm
Moderately toxic	= 1.0 ppm to 10.0 ppm
Slightly toxic	= 10.0 ppm to 100.0 ppm
Practically non toxic	= 100.0 ppm

Presumption of No Aquatic Risk - There is a presumption of no aquatic risk if the estimated environmental concentration (EEC) is less than 1/10th of the LC_{50} or EC_{50} of the most sensitive organisms (EPA-OPP/HED; 1986).

Availability and Significance of Aquatic Toxicity Data - The United States Environmental Protection Agency (EPA) and the United States Fish and Wildlife Service (FWS) have both compiled and published extensive data bases of acute toxicity of chemicals to aquatic organisms (Johnson and Finley, 1980; Mayer and Ellersieck, 1986; and Mayer 1987). As extensive as they are, there are many organisms and chemicals not evaluated. Indeed it would be an enormous and very expensive task to do so. The available data are generally provided for certain indicator species, as recommended by the EPA Office of Pesticides Programs guidance document: "Hazard Evaluation Division Standard Evaluation Procedure, Ecological Risk Assessment." These indicator species are selected based on criteria such as demonstrated sensitivities to toxic chemicals and ecological significance in widespread habitats (EPA/OPP/HED,1986). These data allow for assumptions and extrapolations to be made in assessing risk of chemicals to other organisms (Mayer, April 1987).

The aquaculture projects proposed for the HOST Park facilities involve or may involve crustacean and salmon rearing. Algae food cultures would include the chlorophyte, Dunaliella, and the cyanobacterium, Spirulina. Our literature search produced few data specific for the proposed aquaculture organisms. However, analyses of the acute toxicity data indicate that there are correlations for toxicity to aquatic organisms and that toxicity of chemical to one species could be predicted from toxicity to another species (Mayer and Ellersieck, 1986; Mayer et al., 1987). Correlations are best within the same families of fishes. Variations are expected to within an order of magnitude (Mayer, 1991). For example, interspecies correlation coefficients for acute static test values with Coho Salmon and rainbow trout, bluegill, and channel catfish are 0.96, 0.96, and 0.74, respectively. Interspecies correlations between chinooks salmon and rainbow trout, bluegill and channel catfish are 0.98, 0.99 and 0.79, respectively (Mayer et al., 1987).

There are also good correlations among invertebrates of the same families (Mayer et al., 1987). This is not to say that each species would be equally sensitive to a particular chemical, but a range of sensitivities can be determined and the estimated environmental concentrations can be compared to at least the low end of the sensitivities for species more taxonomically distant from the test species and more closely to the test values for species within the same family.

B. <u>Summary of Pesticide Chemistry & Toxicity</u>

The environmental fate, aquatic toxicity, and human toxicity of all 19 pesticides described in the Management Plan (Section IV) were evaluated. The principles for evaluation of environmental fate were described in part by Cohen, et al. (1984). The principles for aquatic and human toxicity evaluation were described in part in the "Definition of Terms" section above.

The following summarizes the evaluations. The dozens of references consulted are not listed. However, the reader is referred to the following key references for information on the chemicals.

- Davis, et al. (1990)
- EPA (1989)
- all EPA Chemical Fact Sheets listed
- EPA/OPP "One Liners" (Environmental Fate & Ground Water Branch 1-3 page review summaries)
- FCH (1991)
- Green and Karickhoff (1985)
- Jury, et al. (1987)
- Mayer (1987)
- Rao & Davidson (1980)
- SRC (data base)
- USDA, SCS (1988)
- WSSA (1989)

<u>Herbicides</u>

<u>2,4-D</u>

2,4-D dichlorophenoxyacetic acid is a post-emergent broadleaf herbicide. It is a chlorinated phenoxy acid, produced as a salt or an ester.

<u>Mobility.</u> 2,4-D is very mobile in most soils. Its water solubility is 900 ppm (WSSA, 1989) and its K_{oc} is probably 19.6 based on a literature review (Rao & Davidson, 1980).

<u>Persistence.</u> There is an extensive amount of information on degradation of 2,4-D in soils (e.g. Rao & Davidson, 1980; Smith, 1980; Rao, et al., 1985). A reasonable figure based on the literature is 8 days.

<u>Aquatic Toxicity.</u> According to information in EPA's database, 2,4-D and certain of the salts, esters, and amines can be considered moderately toxic to practically non-toxic to fish (EPA, September 1988). However, two 2,4-D esters were found highly toxic to juvenile chinook salmon and rainbow trout in a study by Finlayson and Verrue (1985). The 96 hr LC 50 ranged from 0.170 to 0.525 mg/L in continuous flow-through tests. Based on reduced survival and growth of alevins and fry, the authors recommend a maximum safe chronic exposure of 0.04 mg/l for the 2,4-D butoxy ethanol ester.

Toxicity data for estuarine fish is limited to certain of the esters. The range of LC50 values for the marine fish longnose killifish (<u>Fundulus similis</u>) was between 4.5 mg/l - 5.0 mg/l (Mayer 1987).

Certain 2,4-D esters' EC50 values for immobility in the brown shrimp ranges from 0.55 mg/l - 5.6mg/l (Mayer, 1987). Therefore, 2,4-D esters may be highly toxic to moderately toxic to organisms in the order of decapods. However, it is the free acid form that uis more likely to migrate in the aqueous phase.

The 96 - hour LC50s for the free acid form of 2,4-D range from 27,900 µg/l - 199,000 µg/l for five species of freshwater fish (cutthroat trout, rainbow trout, lake trout, fathead minnow, and bluegill) (Mayer and Ellersieck, 1986).

The 24-hour EC50 for cessation of growth in several marine/estuarine algae ranges between 50 mg/l - 150 mg/l (Mayer, 1987). 2,4-D may therefore be considered moderately to slightly toxic to aquatic algae. 2,4-D was slightly toxic to the alga dunaliella. The 240-hr EC50 for growth & 2 hr. EC50 for reduction in oxygen consumption for Dunaliella were 75 and 50 ppm respectively (Mayer, 1987).

A study was conducted by Glynn et al., (1984) using the coral species <u>Pocillopora damicornis</u> collected from Kaneohe Bay on Oahu. The coral was subjected to exposures of pure 2,4-D (sodium salt) up to 1.0 ppm. After seven days there were no apparent effects of the 2,4-D exposure on the coral. A later study by Glynn et al. (1986) demonstrated acute toxic effects (tissue sloughing and death) on the same coral species at a 2,4-D concentration of 0.02 ppm.

<u>Metribuzin</u>

Metribuzin is an herbicide of the triazine family that controls a large number of grass and broadleaf weeds (FCH, 1990).

<u>Mobility.</u> Its water solubility at 20°C is 1200 ppm (EPA, June 1985). The K_{oc} is 95 (Davis et al., 1990) indicating that this chemical is mobile in soil and may leach or runoff in the aqueous phase.

<u>Persistence.</u> The soil half life is 24 days (Davis, et al. 1990) indicating a low persistence.

<u>Aquatic Toxicity.</u> According to EPA's NPIRS database, metribuzin is characterized as slightly toxic to moderately toxic to aquatic organisms. Metribuzin's LC50 for rainbow trout and bluegill were 76.78 ppm and 75.96 ppm respectively. The LC50 for marine/estuarine shrimp was 48.3 ppm. It is somewhat more toxic to freshwater invertebrates with an LC50 value of 4.18 ppm (EPA, June 1985).

<u>Human Toxicity.</u> The EPA Office of Drinking Water has established an HAL of 200 ppb based on the RFD of 0.025 mg/kg/day (EPA, 1989).

<u>Bensulide</u>

Bensulide is a preemergent herbicide that controls grassy weeds. It is a sulfonamide linked to phosphorodithioate group.

<u>Mobility.</u> Its water solubility is 25 ppm (WSSA, 1989) and its K_{oc} is calculated to be 743. Therefore it is predicted to have very limited mobility in soils and is not likely to leach or runoff in the aqueous phase to a significant extent.

<u>Persistence.</u> Its half life at 70°-80°F in moist loam is 4 months and in moist loamy sand it is 6 (WSSA, 1989). Extrapolation of information about residual activity yields a soil half life of 2.3 months (based on Rao, et al., 1985).

<u>Aquatic Toxicity.</u> The 48-hour EC50 for loss of equilibrium or death in the juvenile brown shrimp (<u>Penaeus aztecus</u>) is greater than 1 ppm (the highest dose tested) in saltwater (Mayer, 1987). The 96-hour LC50 for the freshwater invertebrate <u>G. fasciatus</u> ranged between 0.4 - 5.1 ppm (Johnson & Finley, 1980). These values suggest that bensulide is highly toxic to moderately toxic to aquatic invertebrates, including marine species.

The acute toxicity for the juvenile estuarine fish 'spot' (Leiostomus xanthurus) is 0.32 ppm (Mayer, 1987). The 96-hour LC50 for goldfish (freshwater) is between 1-2 ppm (FCH, 1990). Based on these values, bensulide may considered to be highly toxic to moderately toxic to fish as well, including marine species.

Human Toxicity. The ADI in EPA's Office of Pesticide Program files is 0.0066, mg/kg/day, which yields a HAL of 231 ppb for lifetime exposure and 66 ppb for long-term exposure to young children.

Chlorpyrifos

Chlorpyrifos is an organophosphorous insecticide.

Mobility. Its water solubility is 2 ppm at 25°C and its K_{oc} is 9,000. Therefore it is not mobile and probably not likely to leach or runoff into the aqueous phase.

Persistence. Its soil half life was determined to be 36 days indicating that it is not persistent.

Aquatic Toxicity.

96-hour EC50 values for the Brown shrimp and Pink shrimp (both Penaeid shrimp) resulting in immobility are 0.20 µg/l and 2.4 µg/l respectively. The 48-hour EC50 for the Blue crab is . 5.2 µg/l (Mayer, 1987). These values would indicate that chlorpyrifos is very highly toxic to these particular marine and estuarine invertebrates.

The 96-hour LC50 values for marine/estuarine fish range from 240 µg/l - 300 µg/l for the Sheepshead minnow and from 2.6 µg/l - 6.9 µg/l for the longnose killifish. The 48-hour LC50 for the saltwater fish Spot is 7.0 µg/l (Mayer, 1987). These values

indicate that chlorpyrifos is also very highly toxic to marine and estuarine fish.

96-hour EC50 values resulting in reduced growth for three saltwater algae species range from 120 µg/l - 340 µg/l. These species are not in the same division as the proposed aquaculture species, it is not unreasonable to consider that chlorpyrifos may be highly toxic to most of the marine algae.

The U.S. EPA has established an ambient water quality criteria standard (WQC) for chlorpyrifos in both freshwater and marine environments. The WQC recommendation is considered to be protective of 95% of the aquatic organisms. For marine environment, the chronic WQC is 0.0056 µg/l. This is the average 96-hour concentration that should not be exceeded more than once every three years. The acute WQC is 0.011 µg/l representing the average 1 hour concentration not to be exceeded once every three years (Sabock, 1990).

Human Toxicity. Its RfD is $3x10^{3}$ mg/kg/day, which yields a HAL of 105 ppb.

Trichlorfon

Trichlorfon is an organophosphate insecticide.

Mobility. Its water solubility is 15,400 ppm (Davis, et al., 1990) and its calculated K_{oc} is 45 according to information in the SRC, Chemfate data bases. Therefore it is mobile in soils and may leach or runoff in the aqueous phase.

Persistence. Its soil half-life is approximately 5.3 days.

Aquatic Toxicity

48-hour EC50 values resulting in immobility for the pink shrimp (Penaeid shrimp (Penaeid shrimp) is .36 mg/l (Mayer, 1987). The

96-hour LC50 for the freshwater decapod *Procambarus* spp. (crayfish) ranges from 6,500 µg/l - 9,300 µg/l (Johnson and Finley, 1980). These values suggest that trichlorfon is highly to moderately toxic to decapods including marine species.

Little data are available for marine/estuarine species of fish. The 48-hour LC50 for the saltwater Spot is > 1 mg/l (Mayer, 1987). 96-hour LC50 values for several warm freshwater fish including bluegill, channel catfish, largemouth bass, and fathead minnow ranged from 645 µg/l - 9,260 µg/l (Johnson and Finley, 1980). Based on these studies, trichlorfon may be considered highly to moderately toxic to warm water fish including certain marine species.

It is interesting to note that, although organophosphate insecticides can be toxic to aquatic organisms, some of them, including trichlorfon, are actually used in salmon aquaculture to treat salmon lice (Pike, 1989; Ross, 1989). Incidents of high Atlantic salmon mortality have been noted following trichlorfon lice treatments (Horsberg, et al., 1989).

The 48-hour and 72-hour EC50 for some marine algae species resulting in reduced growth are > 50 mg/l (Mayer, 1987).

Human Toxicity. Its ADI is 0.125 mg/kg/day (EPA, June 1984), which yields a HAL of 4000 ppb.

Metalaxyl

Metalaxyl is soil or foliar applied systemic action fungicide.

Mobility. Its water solubility is 7,100 ppm (EPA One Liner) and its K_{oc} is 35 (Davis, et al., 1990). Therefore it is predicted to be mobile in soils with the likelihood that it may leach or runoff in the aqueous phase.

Persistence. Its soil half life is 25 days (Davis, et al., 1990) indicating that it is not very persistent in soils.

Aquatic Toxicity.

96 hour LC50 values for rainbow trout and bluegill are 132 ppm and 139 ppm respectively. The LC50s for catfish, carp, and guppy are all > 100 ppm. The 96 hour LC50 for the daphnia was 300 ppm and other freshwater invertebrates 12.5 ppm. A 1989 study of the saltwater invertebrate, mysid shrimp, provided a 96 hour LC50 of 25 ppm (Balcomb, 1990). These values suggest that metalaxyl is practically non-toxic to fish and perhaps only slightly toxic to aquatic invertebrates including marine species.

Human Toxicity. According to information in the IRIS data base, the RFD for metalaxyl is $6x10^{-2}$ mg/kg/day, which yields a HAL of 420 ppb.

C. Selection of Pesticides for Modeling

It would be very time consuming and costly to conduct detailed modeling for all 19 of the pesticides listed in the IGCMP (section IV). It is also not necessary. The mobility and persistence criteria described above and in Table 11, combined with human and aquatic toxicity characteristics, make it possible to qualitatively evaluate the pesticides to determine which ones would be most appropriate for modeling.

The six pesticides selected -- bensulide. chlorpyrifos, 2,4-D, metalaxyl, metribuzin, and trichlorfon -- exhibit the combined properties of high mobility and/or persistence and/or high human toxicity and/or high aquatic toxicity. They also represent all three classes of pesticides in this study--herbicides, insecticides and fungicides. The six pesticides have the greatest chance to pose a threat to the sensitive receptors identified in section III.

Table 11. Summary of Environmental Fate and Toxicity of 18 Pesticides.

Pesticide	Projected Use - Annual - (lb ai/Ac)	Use Area (Acre)	Mobility: Water Sol'y (ppm)	Mobility: K_{oc}	Persistence: T1/2 (Days)	Toxicity: Human HAL (ppb)	Toxicity: Aquatic* Fish	Toxicity: Aquatic* Invert
Imazaquin	1.0	2.5	60	460	60	8,750	pn	pn
MSMA	4.0	5	57,000	300,000	10		s/m	m
Metribuzin	1.5	5	1,200	95	24	200	s	s/m
Glyphosate	0.23	5	12,000	10,000	30	350	pn/s	
Fluazifop-P butyl	0.6	1	2		7	350	m	--
2,4-D	2.80	5	900	20	8	70	pn/h	m/vh
Dicamba	0.29	5	4,500	8	7-14	200	pn/s	pn
MCPP	1.49	5	620	130	12	105	pn	--
Oxadiazon	12.0	35	0.7	5,300		18	TOXI	TOXI
Oryzalin	6.0	3	2.5	138	70		--	h
Bensulide	24.0	8.5	25	740	70	66 c 231 a	m/h	m/h
Chlorpyrifos	2.0	12.5	2	9,000	12	105	h/vh	vh
Carbaryl	1.5	12.5	40	229	30	700	pn/m	vh
Trichlorfon	16.0	12.5	15,400	45	1-27	4,000	m/h	m/h
Mancozeb	68.0	8.5	0.5	1,000	1-2	0.2	m/h	h
Thiophanate-methyl	20.0	8.5	slight		<1	560	m/vh	m
Metalaxyl	2.6	3.5	7,100	35	25	420	pn	s
Chlorothalonil	24.0	8.5	0.6	5,800	40	2	vh	h/vh

* Additional data on toxicity to algae are available for fluazifop-P butyl, trichlorfon, and chlorpyrifos indicating s, s, and h toxicity ratings respectively.
c = children a = adult

VI. MODELING PESTICIDE & NUTRIENT TRANSPORT IN GROUND WATER

A. Pesticide Transport Modeling

In order to attempt to assess the risk of potential contamination of ground water from the use of turf chemicals on the proposed O'oma II golf course, it is essential to try to forecast the migration of those chemicals from the area(s) of application. This is the most scientific and logical approach that can be taken for a proposed development project such as the O'oma II golf course since monitoring for potential environmental contamination is not possible. Our approach to making conservative predictions of expected environmental concentrations of turf chemicals is to employ the use of sophisticated computer models that incorporate site-specific data and chemical-specific data to simulate the transport of chemicals overland in runoff and through the soil in leaching water.

Model Selection

The discussion in section III above shows that one of the most significant pathways for contamination to sensitive receptors is through the leaching of chemicals vertically through the turf application area down to ground water and then horizontal translocation of the leached chemicals to the ocean and to brackish water wells on the neighboring NELHA facilities. Because ground water is the primary route of exposure, we have selected an EPA model that links the Pesticide Root Zone Model (PRZM) (Carsel et al., 1984) with an unsaturated zone flow and transport model called VADOFT. This model link is a recent accomplishment of the EPA's Center for Exposure Assessment Modeling (CEAM) in Athens, Georgia and is referred to as PRZM2 (representing PRZM version 2). It was developed within the scope of a project referred to as RUSTIC -- Risk of Unsaturated/Saturated Transport and Transformation of Chemical Concentrations (Dean, et al., 1989; Dean, et al., 1989b).

Model Description

The following descriptions of PRZM and VADOFT are adapted from Dean, et al. (1989) and Dean, et al. (1989b).

PRZM

The Pesticide Root Zone Model (PRZM) is a one dimensional, compartmental, numerical solution model that performs computations to simulate the fate and transport of pesticides within and just below the root zone. It also provides for calculation of erosion loss in surface runoff. The PRZM model has two major components: hydrology and chemical transport. These components will be described in some detail in the following paragraphs. Two input files are required to run PRZM, a meteorological file and the PRZM parameter file. Information on both of these files are found below in the Input Parameters description.

The hydrology component considers both horizontal movement across the soil surface and vertical movement of water into the soil. The hydrologic component for calculating surface runoff and erosion is based on the Soil Conservation Service curve number technique (USDA, SCS, 1986) and the Universal Soil Loss Equation (Williams, 1975). Vertical water movement through the root zone is simulated using general soil characteristics. These include field capacity, wilting point, and saturation water content. Irrigation may also be simulated. Water is "applied" when soil moisture falls below specified conditions. This application scheme is comparable to the state of the art irrigation systems introduced above in the Integrated Golf Course Management Plan.

The pesticide transport component takes into account the location of application (i.e. foliar, incorporated). Pesticide concentrations are estimated for the dissolved, adsorbed, and vapor phases. These concentrations are simulated simultaneously considering the processes of plant uptake, surface runoff and erosion, decay, volatilization, foliar washoff, advection, dispersion, and retardation. The output can be specified for a daily, monthly, or annual time step. The water flux and chemical concentrations are passed along daily to the Vadose Zone Flow and Transport Model (VADOFT).

VADOFT

The Vadose Zone Flow and Transport Model (VADOFT) is a one dimensional, single phase, finite-element model that simulates movement of water and transport of chemicals through the unsaturated zone (also referred to as the vadose zone). The Galerkin finite-element technique is used for the flow and transport equations. Water flow is governed by Darcy's law and dispersive/diffusive chemical transport is governed by Fick's law. Transport processes taken into account in the VADOFT model include hydrodynamic dispersion, advection, linear equilibrium sorption, and first order decay. Recharge and pesticide mass are output on the same time step selected for the PRZM model.

Input Parameters

PRZM

The first file contains meteorological data for the simulation. Weather data required are daily precipitation and mean daily temperature. Evaporation data can be input into this file or simulated by the model based on the daily temperature data. Daily wind speed and daily solar radiation data are required if volatilization simulation is desired.

For many locations throughout the United States, the meteorological file which consists of daily precipitation, evaporation, temperature, wind speed, and solar radiation data can be input easily from an extensive EPA database of weather information from hundreds of first order weather stations. This however is not the case for modeling scenarios in Hawaii. The meteorological file was constructed from historical climatological data obtained from the NOAA National Climatic Data Center in Asheville, North Carolina. Five years of daily precipitation and mean temperature were randomly chosen from the twenty wettest years of a forty year period of record. This was done to achieve a relative worst case weather scenario for this modeling exercise. The climatic data were obtained for the Kona Airport station #68.3 located near the O'oma II site. The Kona airport station area is somewhat drier than the project site based on isopleth maps of average annual precipitation found in the University of Hawaii -

Water Resources Research Center 1986 report R76, "Rainfall Atlas of Hawaii" (Giambelluca, et al., 1986). A correction factor of 1.144 was used to correct the precipitation record to reflect the somewhat wetter conditions relative to the Kona Airport. There are no evaporation data for any significant period of record for any location along the Kona coast. Evaporation data were chosen from the Hilo Airport which is at a similar latitude. A correction factor of 1.15 was used to adjust the evaporation data to reflect the drier, less humid conditions of the Kona coast area with respect to the Hilo coast. This number was chosen based on isopleth maps found in the State of Hawaii Department of Land and Natural Resources/Division of Water and Land Development report R74, "Pan Evaporation: State of Hawaii, 1894-1983" (Ekern and Chang, 1985). Daily wind speed and solar radiation were not input into this scenario. The net effect of this is that the volatilization of the pesticides simulated would be underestimated.

The second file contains PRZM model parameters. These parameters describe the site specific hydrology, soil, crop (turf in this case), and pesticides. Two scenarios were modeled for the proposed O'oma II golf course. Certain soil and pesticide specific parameters differed between the two scenarios. One scenario was set up to simulate pesticide applications to the golf greens. The selection of soil parameters for this scenario was based in part on the assumption that the greens would be constructed according to the plan outlined in the above IGCHP. Figure 3 is a conceptual model that illustrates that infiltrating water will pass through the thatch layer, the root zone of the green, the soil underlying the root zone, and then be collected in a gravel/drainage system and diverted through the drain outfall to the surface of an adjacent grassed rough. From this point it will once again infiltrate through the thatch layer and root zone of the rough and the soil layer below the root zone before it passes into the vadose zone and ultimately to ground water. This obviously is a simplified illustrative description of the flow and does not describe the many different processes that are simulated in the PRZM model. The gravel/drainage layer and grassed rough thatch layer were not modeled with PRZM in order to simplify the input sequence. The second scenario was set up to simulate the application of pesticides to the fairways. Figure 4 shows the

conceptual model of the flow of water through the thatch layer, the root zone of the fairway and the soil underlying the root zone before it passes to the vadose zone. The soil parameters for this scenario were based on the assumption that topsoil brought to the site would be sugar cane wash soils from Hilo Coast Processing. These two scenarios represent the most vulnerable areas on the golf course to leaching of pesticides from the area of application. The tee areas would be similar to the fairways except that an additional four inches of greensmix soil would be in place on top of the topsoil. The roughs are not intensively maintained with turf chemicals like the other areas of the golf course. A detailed listing of the important PRZM parameters is provided in the tables 12 and 13.

Figure 3 - Conceptual Model of the Greens Scenario

Conceptual Model of the Greens Scenario

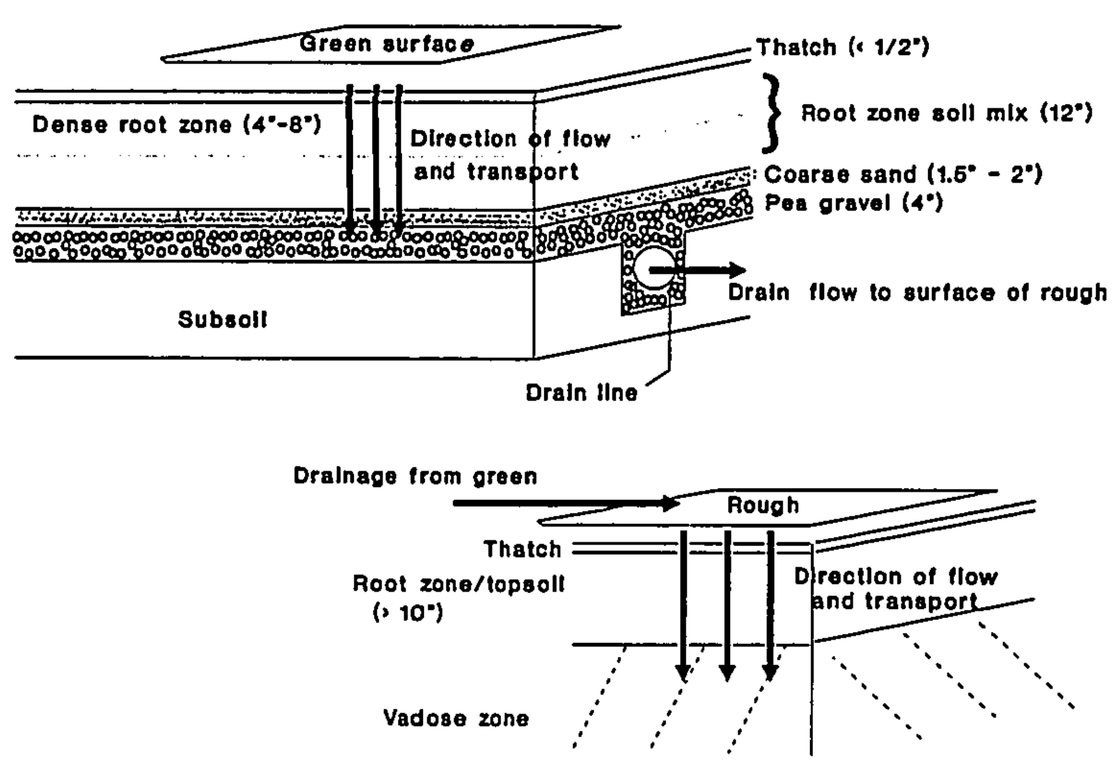


Figure 4 - Conceptual Model of the Fairways Scenario

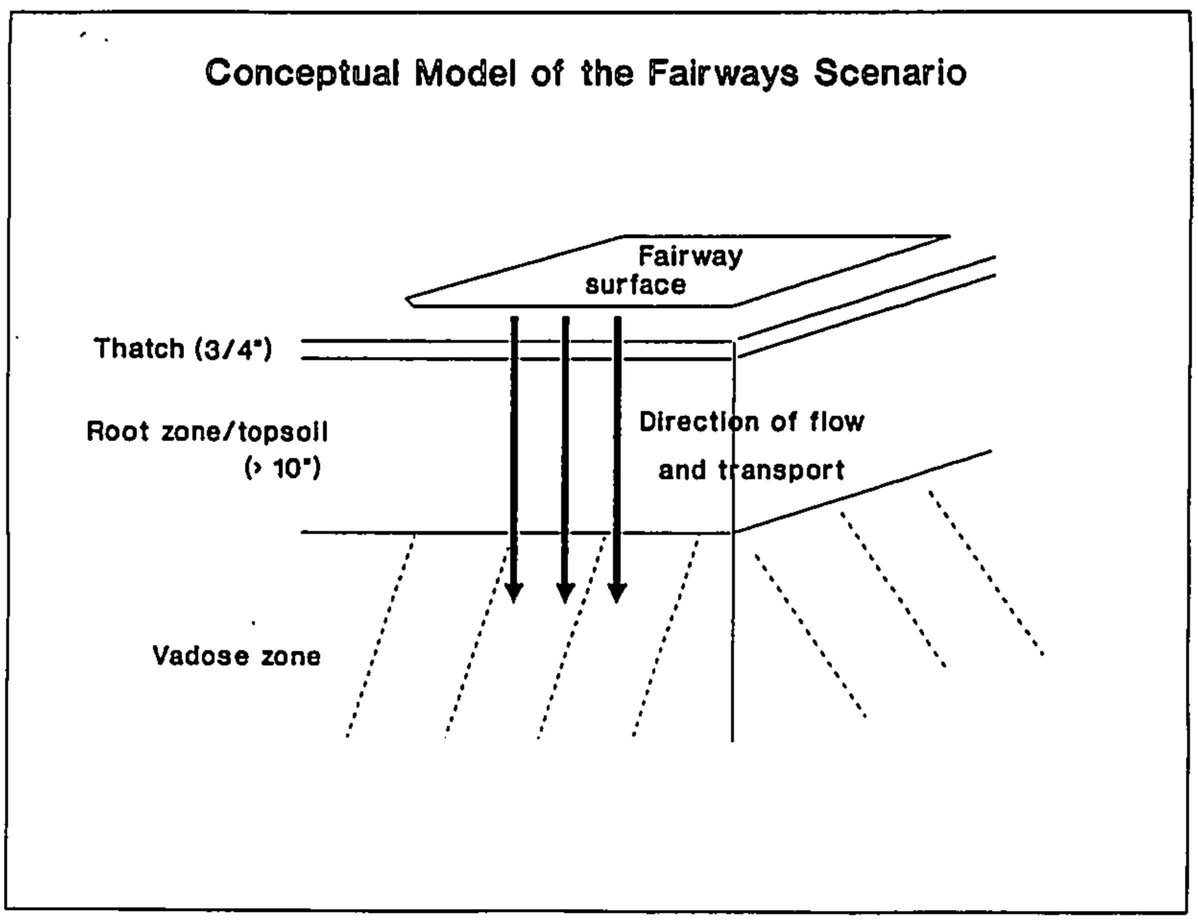


Table 12 PRZM Input Parameters for O'oma II Greens Scenario*

<u>Control Parameters</u>

Modeling period	5 years
Time series	daily
Number of chemicals	6
Metabolites	none

<u>Hydrology Parameters</u>

Pan Factor (estimates ET)	1.08
Min. depth to extract evap.	20.0 cm
Ave. dly hrs of daylight (per month)	11.4 10.8 12.4 12.6 13.6 13.3 13.7 13.3 12.2 12.0 11.2 11.3
USLE erodibility factor (K)	0.08
USLE topographic factor (LS)	0.28
USLE support prac. fctr (P)	1.0
USLE cover mgmt. factor (C)	0.01
Runoff curve no.	39 (hyd grp A soil-good cond) (USDA, SCS, 1986)
Area of plot	3.8 hectares
Ave. dur'n of runoff prod'g storm	6.0 hours
Active rooting depth	30.5 cm (incl 2 root zones)
Coverage of plant canopy	100%

<u>Pesticide Parameters</u>

No. of applications	60 (6 chmcls * 2 appl * 5 yrs)
No. of diff. chemicals	6
Pesticide names/applications:	
bensulide	2 appls @ 13.45 kg/ha/appl
chlorpyrifos	2 appls @ 0.56 kg/ha/appl
2,4-D	2 appls @ 1.25 kg/ha/appl
metalaxyl	2 appls @ 1.46 kg/ha/appl
metribuzin	2 appls @ 0.67 kg/ha/appl
trichlorfon	2 appls @ 7.15 kg/ha/appl
Depth of incorporation	0.0 cm
Pesticide washoff/cm of prcp	0.10 for all pesticides (Smith and Carsel, 1984)
Foliar decay rate	0.07-0.35
Vapor-phase decay rate	0.0
Dissolved-phase decay rate	0.002-.100
K_{oc}	see table 11
Diffusion in air coeff.	4300 cm^2 day^{-1}

Table 12 (cont'd) PRZM Input Parameters for O'oma II Greens Scenario*

<u>Absorbed-Phase Decay Rate</u> (Day^{-1})

	Hrzn 1	Hrzn 2	Hrzn 3	Hrzn 4
bensulide	0.010	0.010	0.003	0.010
chlorpyrifos	0.019	0.019	0.006	0.019
2,4-D	0.087	0.087	0.029	0.087
metalaxyl	0.035	0.035	0.011	0.035
metribuzin	0.023	0.023	0.040	0.023
trichlorfon	0.130	0.130	0.007	0.130

<u>Soil Parameters</u>**

Total depth of core 56.0 cm (incl two root zones)
Number of horizons 4

	Thickness (cm)	Bulk density (g/cm^3)	Field Cap (cm^3/cm^3)	Wilting Pt (cm^3/cm^3)
Hrzn 1 (thatch)	1	0.224	0.250	0.030
Hrzn 2 (root zn1)	15	1.400	0.091	0.033
Hrzn 3 (below rz1)	15	1.400	0.091	0.033
Hrzn 4 (root zn2)	25	1.100	0.125	0.055

* Unless otherwise noted, parameters estimated from information provided in Dean, et al. (1986b).

** Soil parameters estimated based on Dean, et al. (1986b) and Dixon (1991).

Table 13

PRZM Input Parameters for O'oma II Fairways Scenario*

Control Parameters

Modeling period	5 years
Time series	daily
Number of chemicals	5
Metabolites	none

Hydrology Parameters

Pan Factor (estimates ET)	1.08
Min. depth to extract evap.	10.0 cm
Ave. dly hrs of daylight (per month)	11.4 10.8 12.4 12.6 13.6 13.3 13.7 13.3 12.2 12.0 11.2 11.3
USLE erodibility factor (K)	0.27
USLE topographic factor (LS)	0.28
USLE support prac. fctr (P)	1.0
USLE cover mgmt. factor (C)	0.01
Runoff curve no.	39 (hyd grp A soil-good cond) (USDA, SCS, 1986)
Area of plot	28.3 hectares
Ave. dur'n of runoff prod'g storm	6.0 hours
Active rooting depth	15.24 cm
Coverage of plant canopy	100%

Pesticide Parameters

No. of applications	50 (5 chmcls * 2 appl * 5 yrs)
No. of diff. chemicals	5
Pesticide names/applications:	
bensulide	2 appls @ 13.45 kg/ha/appl
chlorpyrifos	2 appls @ 0.56 kg/ha/appl
2,4-D	2 appls @ 1.25 kg/ha/appl
metribuzin	2 appls @ 0.67 kg/ha/appl
trichlorfon	2 appls @ 7.15 kg/ha/appl
Depth of incorporation	0.0 cm
Pesticide washoff/cm of prcp	0.10 for all pesticides (Smith and Carsel, 1984)
Foliar decay rate	0.10-0.35
Vapor-phase decay rate	0.0
Dissolved-phase decay rate	0.002-0.100
K_{oc}	see table 11
Diffusion in air coeff.	4300 cm^2 day^{-1}

Table 13 (cont'd)

PRZM Input Parameters for O'oma II Fairways Scenario*

Absorbed-Phase Decay Rate (Day^{-1})

	Hrzn 1	Hrzn 2
bensulide	0.010	0.010
chlorpyrifos	0.019	0.019
2,4-D	0.087	0.087
metribuzin	0.023	0.023
trichlorfon	0.130	0.130

Soil Parameters**

Total depth of core: 27.5 cm
Number of horizons: 2

	Thickness (cm)	Bulk density (g/cm^3)	Field Cap (cm^3/cm^3)	Wilting Pt (cm^3/cm^3)
Hrzn 1 (thatch)	1.5	0.224	0.250	0.030
Hrzn 2 (root zn)	15	1.100	0.125	0.055

* Unless otherwise noted, parameters estimated from information provided in Dean, et al. (1986b).

** Soil parameters estimated based on Dean, et al. (1986b) and Dixon (1991).

VADOFT

The vadose zone is assumed to be relatively consistent across the project site with one exception. The depth of the vadose zone between the topsoil and the saturated zone varies from sea level to about 110 feet. at the mauka portion of the site at Queen Kaahumanu Highway. A conservative depth of 10 feet was chosen for these simulations and only one set of VADOFT parameters was used in conjunction with both the PRZM greens and PRZM fairways scenarios. Figure 5 illustrates the conceptual model of the vadose zone across the O'oma II project site. Basically, three horizontal layers of different sized materials will make up the unsaturated zone. The top layer (bordering the bottom layer of topsoil) will be roughly 4 inches deep consisting of finely crushed lava material. This will prevent the topsoil from filtering down through the voids in the deeper material and creating depressions in the surface grade. The second layer will be about 15 inches deep and will consist of larger crushed lava material resulting from the site grading process. These top two layers are referred to in previous sections as the choaker layer. The third layer is the moderately to highly porous basaltic lava bed that extends to ground water. This layer is assumed to be highly fractured and may possibly contain fumaroles or lava tubes that will greatly increase the movement of water through the vadose zone. The PRZM and VADOFT models are linked together such that the water and chemical flux from PRZM will be read into VADOFT on a daily time step. The input parameters generally define the geometry of the flow region, the soil moisture properties of the different materials simulated (including Darcy's velocity, longitudinal dispersivity, and values for solving the van Genuchten model which specifies the relationship of relative permeability versus water saturation), and solute transport parameters (namely the decay coefficient for the simulated chemicals in water). Table 14 lists the important VADOFT input parameters for the O'oma II modeling exercise. The data for Darcy's velocity, effective porosity, saturated water content, and hydrodynamic dispersivity were obtained from the following sources: Egan, (1991); Freeze and Cherry, (1979); Driscoll, (1986).

Figure 5 - Conceptual Model of the Vadose Zone

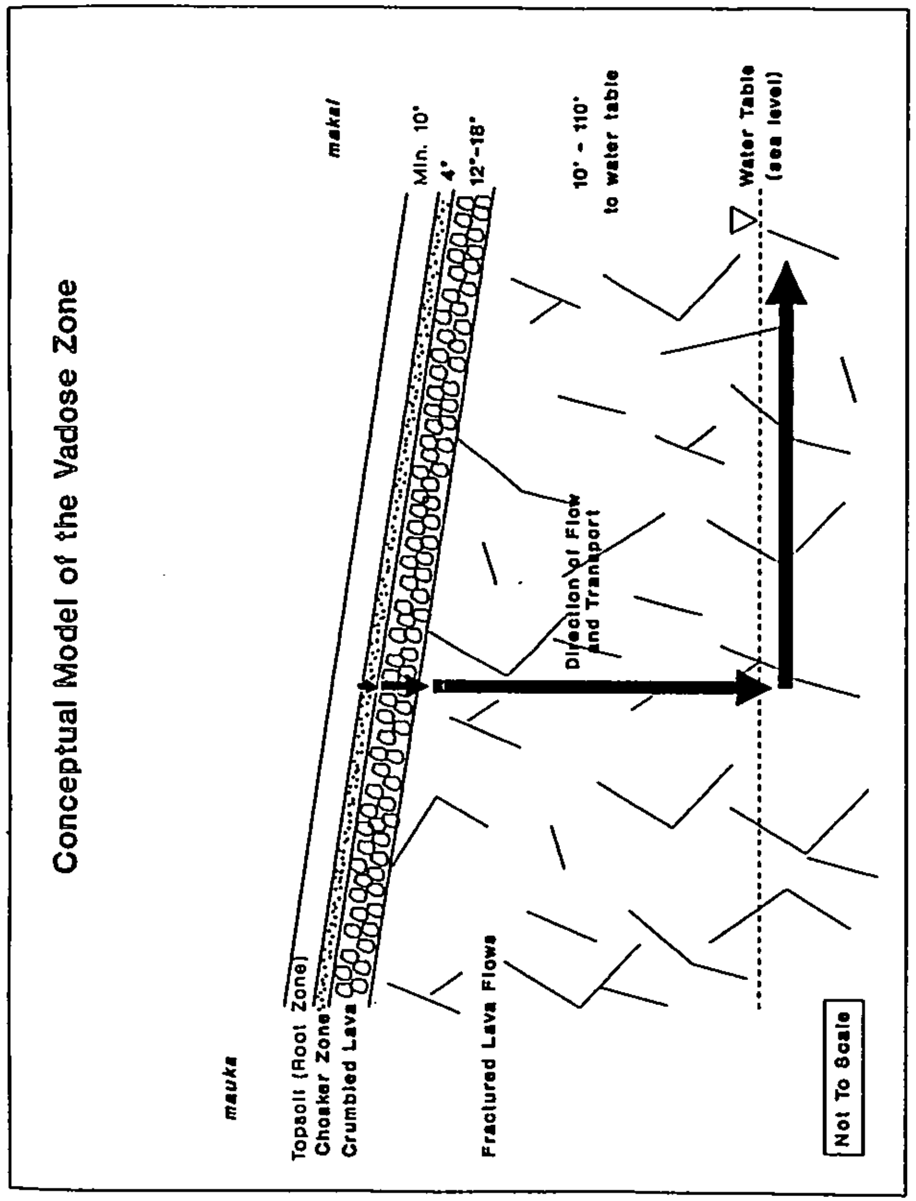


Table 14 VADOFT Input Parameters for O'oma II

Number of nodal points	85
Number of diff. porous materials	3
Type of nonlinear iteration proc.	modified Newton-Raphson
Head tolerance	1.0
Number of layers (horizons)	3

	Layer 1	Layer 2	Layer 3
# Finite elements	10	13	61
Material #	1	2	3
Thickness (cm)	10	39	305
Satur'd hydr. cond. (cm/day)	8,600	86,400	30,500
Effective porosity	.25	.280	.15
Longitudinal dispers. (cm)	1.0	3.8	16C.0
Retardation coeff.	1.0	1.0	1.0
Molecular diff.	0.0	0.0	0.0
(values for ret.coef. and mol.diff. are for all chemicals simul'd)			
Residual water content (%)	0.10	0.20	0.30
van Genuchten (n)*	-1.0	-1.0	-1.0
van Genuchten (α)*	.174	.174	.174
van Genuchten (β)*	2.97	2.97	2.97
van Genuchten (γ)*	.66	.66	.66
Default Darcy velocity	8,640	86,400	30,500
Default water saturation (%)	.25	.20	.15
Decay coeff. (day^{-1})	.002	.002	.002
(for all chemicals simul'd, very conservative)			

* van Genuchten equation values selected for sand (most porous available material in reference (Dean, et al., 1989b)).

B. Quality Assurance

The information gained from modeling can only be as good as the data that are used to define the model. The accuracy and suitability of the data for each of the modeling scenarios for the proposed golf course at O'oma II were reviewed by several individuals with varied expertise. The hydrology and hydrogeology related parameters were reviewed by three hydrogeologists (N.L. Barnes, ETS; Dave Egan, Apex Environmental, Inc., Rockville ; Jan Kool, Hydrogeologic, Inc. Herdon, VA). Alan Schildknecht of Irrigation Hawaii verified that the irrigation scenario employed in the PRZM model (apply water at 1/2 field capacity up to field capacity plus an additional 20%) would be optimum and that standard practice with the use of brackish water is to apply up to 20% additional water to leach salts. Finally, the Study Director, S. Cohen, verified two randomly chosen sets of parameters from beginning to end as a QC check. Those parameters were saturated hydraulic conductivity, and degradation rate constants and Koc for the herbicide metribuzin.

In addition to verifying the input, an exercise was conducted to check that the output are reasonable. Water is the driving factor for the whole modeling effort. The water flux values provided by the PRZM output represent the total percolate water lost from the root zone. In order to determine if those values are reasonable for a golf course at the proposed site, the water flux values were verified by manual calculations. Data for the manual calculations were obtained from literature for certain hydrologic variables. The variables include daily water use rates (Beard, 1982), pan evaporation and a pan factor (Ekern and Chang, 1985), and the acreage for the golf course.

The calculations involve simple mathematics to convert the daily water use rate into yearly water use rates for a particular climate type. The product of pan evaporation, pan factor, and the acreage determines the potential evapotranspiration for the site. The potential evapotranspiration is subtracted from the yearly water use rate to yield the water flux. The water flux calculated for the O'oma II site ($2.27*10^8$ l/yr) was only slightly higher

(8.8%) than the PRZM output (ave. $2.07*10^8$ l/yr). Therefore the computer simulation generated reasonable values for water flux.

C. Conservative Assumptions

Water is the driving factor for PRZM and VADOFT. Initially, the most important input into the modeling scenario is the daily precipitation data record. The basis of the selection of daily rainfall from the upper 50% of 40 years of recorded climatological data for use in the simulation was to provide a conservative modeling of the hydrology of the O'oma II project site.

The conceptual model for the greens scenario shows the flow path of water as it passes through the soil profile of the green, through the drainage system, and then through the soil profile of the grassed rough. To simplify the modeling, the drainage system was not modeled (including the sand and gravel interface), nor was the grass/thatch complex of the rough. We would expect that silt and organic material would accumulate in the sand/gravel interface of the drainage system which would further attenuate chemical transport through the model.

Only 10 inches of topsoil was modeled for the fairways scenario. This should be considered the absolute minimum depth for topsoil to provide for proper rooting depth. This relatively shallow soil profile for this scenario would represent the worst case for the site.

The thickness of the vadose zone (between the root zone and ground water) varies from 0 feet at sea level to approximately 110 feet at the Queen Kaahumanu Highway. The vadose zone was modeled to a depth of 10 feet which represents the portion of the fraction one hole is proposed to be this close to the ocean. Seventeen of the eighteen holes would be at least 35 feet above sea level (HHK Master Plan, 1990) and, likewise, ground water. The greater depth of the vadose zone allows for more attenuation of pesticide and nutrient contamination.

Simulation of all of the volatilization processes was not conducted in this modeling exercise. Daily wind speed and solar radiation data would be required to run this simulation. These data are not readily available for the project site. The net result of this would be to underestimate volatilization loss of the pesticides.

A backwards-difference scheme was employed to solve the transport equations. This results in a "pulse" transport scenario between soil compartments which may tend to over predict chemical transport through the root zone. This scheme was chosen however to simulate the artificial perched water table that occurs in a golf green as a result of the difference in water tension between the soil and gravel at the interface. The infiltrating water accumulates at the interface until gravity forces overcome the greater capillary tension forces in the soil horizon. The water is then released in a pulse to the gravel drainage system.

2,4-D was modeled using a soil decay rate constant based on a half-life of 8 days. This value is most likely too long for Hawaiian soils. A more realistic half-life is in the range of 4-5 days based on several of the references listed above in Section V(B). The result of this is that 2,4-D would persist longer in the environment described by the modeling scenario than what would probably be reality. Chlorpyrifos was modeled using a water decay rate constant based on a hydrolysis half-life of about 16.5 weeks. Studies show a hydrolysis half-life more likely to be about 4 weeks.

D. Modeling Results

The PRZM-VADOFT model was run for six pesticides and two different environmental setting. Each simulation comprised a five year period and output was interpreted from yearly summaries of water outflow and pesticide mass outflow from the vadose zone. Tables 15 and 16 summarize the average daily pesticide losses in terms of mass and concentration respectively.

The tee and practice areas were figured into the calculations for the greens scenarios and the rough were included in the fairways scenarios' calculations. Greens, Tees, and practice area applications account for approximately 3.8 hectares (9.4 acres).

Applications on fairways and roughs could account for up to 28.3 hectares (70 acres) of the golf course. The understanding is that pesticides are going to be applied conservatively (i.e. spot treatments) according to the management plan described in section IV of this report.

The VADOFT pesticide output is presented in kilograms per hectare (kg/ha) whereas water outflow is presented in centimeters (cm). The acreage of the green, tees, practice areas, fairways, and roughs were used to calculate pesticide mass losses, percolate water volume, and then pesticide leachate concentrations. For example, the average daily loss of 2,4-D for the five year simulation from greens, tees, and practice areas was $7.78 * 10^{-6}$ kg/ha, and from fairways and roughs, $4.92 * 10^{-5}$ kg/ha. The average daily water outflow from the vadose zone was 0.300 cm for the greens and tees simulations and 0.237 cm for the fairways and roughs simulations. Assuming the above acreage yields an average 2,4-D mass loss of 1.42 * 15 kg for the entire golf course ($2.96 * 10^{-5}$ kg - greens/tees/practice + $1.39 * 10^{-3}$ kg - fairways/roughs), and a percolate water volume of $6.70 * 10^5$ liters. The leachate concentration equals the pesticide mass outflow divided by the water outflow: $142 * 10^3$ kg + $6.70 * 10^5$ l = $2.12 * 10^{-9}$ kg/l ($12.12 * 10^{-3}$ mg/l).

TABLE 15 PRZM-VADOFT Modeling Results
Average Daily Pesticide Mass Loss (kg)

Pesticide	Greens, Tees, Practice	Fairways/Roughs	Total
Bensulide	$1.23 * 10^{-11}$	$1.70 = 10^{-7}$	$1.70 + 10^{-7}$
Chlorpyrifos	0.0	0.0	0.0
2,4-D	$2.96 * 10^{-5}$	$1.39 * 10^{-3}$	$1.42 * 10^{-3}$
Metalaxyl	$1.99 * 10^{-4}$	not applied	$1.99 * 10^{-4}$
Metribuzin	$2.66 * 10^{-6}$	$1.05 * 10^{-4}$	$1.08 * 10^{-4}$
Trichlorfon	$8.76 * 10^{-7}$	$7.75 * 10^{-4}$	$7.76 * 10^{-4}$

Table 16
Average Daily Leachate Concentrations

Pesticide	µg/L	µM
Bensulide	$2.54 *10^{-4}$	$6.16 * 10^{-7}$
Chlorpyrifos	0.0	0.0
2,4-D	2.12	$9.57 * 10^{-3}$
Metalaxyl	$2.90 * 10^{-1}$	$1.04 * 10^{-3}$
Metribuzin	$1.62 * 10^{-1}$	$7.53 * 10^{-4}$
Trichlorfon	1.17	$4.51 * 10^{-3}$

E. Uncertainty Analysis of the Pesticide Modeling Results

1. Background

Modeling the environmental fate of organic compounds is a complicated process that must consider the uncertainties in the modeled system. There are three types of uncertainties: model uncertainty, pesticide parameter uncertainty, and environmental parameter uncertainty. Hopefully, model uncertainty is not an issue in this case due to the fact that a widely used EPA-supported and validated modeling system is being used. For example see the discussion in Section VI(A) above, as well as Lorber and Offutt (1986).)

Past experience indicates that the degradation rate constant(s) (k) is the most critical pesticide chemistry parameter for leaching assessments. This is because it occurs as an exponential function in the model algorithms. It also has a tendency to vary significantly depending on site conditions. Similarly, the soil-water distribution coefficient (K_d) or its soil organic carbon analog (K_{oc}) can significantly impact pesticide leaching assessments as well. For example, Loague, et al. (1990) recently demonstrated that uncertainties in K_{oc} and k can introduce significant uncertainties in the application of the Attenuation Factor (AF) model to Hawaii soils. Boesten and van der Linden (1991) found that changing Kom (K_d divided by the organic matter fraction) by a factor of 2 changed the predicted mass of pesticide leachate by about a factor of 10. They also found that their model was sensitive to k (rate constant) at high values of Kom.

Spatial variability can be large or small depending on the environmental parameters. For example, Jury (1986) found little variability for bulk density but significant variance in saturated soil hydraulic conductivity (K_s) for specific field sites. The latter environmental parameter is important for modeling water flow through soils.

Therefore it was decided to conduct an uncertainty analysis based on variance in the most critical input parameters: k, K_{oc}, and Ks.

2. Application to O'oma II

Research was conducted to determine expected standard deviations in the three critical parameters described above. A reference by Rao and Davidson (1980) is an excellent source of information for this issue. They critically reviewed the literature and obtained coefficients of variation (CV; [std. dev./mean] x 100) of rate constant (k) and K_{oc} values for 31 and 42 pesticides, respectively. These CVs were combined and it was found that the average CV for k was 73% and for K_{oc} it was 62%. Therefore these CVs were used for all soil degradation rate constants for all pesticides except 2,4-D, which has an extensive data base of its own. The CV for 2,4-D's k was taken to be 60%. The hydrolysis k CV was assumed to be 20%, based on the personal experience of one of the authors (SC).

The CV of the saturated hydraulic conductivity (Ks) of the volcanic mater was estimated to be 200%. This value is the average of the CV's for all materials presented in Dean, et al. (1989b). This is more conservative than the average Ks that can be calculated from the data in Jury (1986)--119%.

This information was used to calculate 95% confidence limits as follows the uncertainty analysis as follows. The CVs were used to compute the standard deviation for each parameter, based on the mean values used in the modeling assessment above. The PRZM-VADOFT input parameters were then recomputed for the best case and the worst case scenarios by adding or subtracting one standard deviation (SD) to each parameter as appropriate. Thus the best case scenario was represented by k + SD, K_{oc} + SD, and K_s^- SD, and the worst case scenario was represented by k^-SD, K_{oc} $^-$SD, and K_s + SD. Worst case/best case variance in a single parameter would normally be represented by two SDs (approximating the 95% confidence limit). But it was felt that there would be a very low probability that all three parameters would trend toward an extreme simultaneously. Thus the O'oma II PRZM-VADOFT scenario was completely rerun to generate a range of results that span the best case and the worst case.

The minimum predicted pesticide leachate mass was subtracted from the maximum mass to calculate the expected range of results

for each pesticide. Then this range was divided by 4 to approximate the standard deviation in each pesticide leachate calculation. (It is a general rule of thumb that one can divide the expected range of results by 4 to 6 to obtain an approximation of the standard deviation (Parrish, 1991). The divisor 4 was used to be more conservative and to account for the fact that the parameter means plus or minus one SD was used as input rather than two SDs.) The final calculation was to add and subtract two standard deviations to the predicted mean pesticide leaching results -- this constitutes an approximation of the 95% confidence interval of each leaching estimate.

The results follow.

3. Uncertainty Analysis Results

Table 17 presents the 95% confidence intervals for all six pesticide calculations in both fairways/roughs and greens/tees scenarios.

These leachate masses are used to estimate off-site concentrations in ground water in section VII (D) below. The health and aquatic toxicity implications of these concentrations are also discussed.

Table 17. Uncertainty Analysis Results - Pesticide Leachate Concentrations

Pesticide	Ave Daily Mass Loss (kg)		Range	Standard Deviation	95% Confidence Int. Upper Limit	
	Best Case	Worst Case			(kg)	(ppb)
Bensulide	***	$3.66*10^{-2}$	$3.66*10^{-2}$	$9.15*10^{-3}$	$1.83*10^{-2}$	27.3
Chlorpyrifos	***	$3.03*10^{-9}$	$3.03*10^{-9}$	$7.58*10^{-10}$	$1.52*10^{-9}$	$2.26*10^{-6}$
2,4-D	***	$2.23*10^{-2}$	$2.23*10^{-2}$	$5.58*10^{-3}$	$1.26*10^{-2}$	18.8
Metalaxyl	***	$6.10*10^{-3}$	$6.10*10^{-3}$	$1.52*10^{-3}$	$3.24*10^{-3}$	4.8
Metribuzin	***	$5.84*10^{-3}$	$5.84*10^{-3}$	$1.46*10^{-3}$	$3.03*10^{-3}$	4.5
Trichlorfon	***	$3.47*10^{-2}$	$3.47*10^{-2}$	$8.68*10^{-3}$	$1.81*10^{-2}$	27.0

*** The best case results were all less than the mean values by at least two orders of magnitude. This results in the range being equal to the worst case mass values.

F. Nitrogen Leachate and Off-Site Migration

The prime nutrient of concern for ground water contamination potential is nitrogen. Phosphorus tends to form insoluble complexes under certain conditions, and also binds to clays and organic matter. Therefore it is not a threat to leach to ground water under normal turf management conditions. Potassium is mobile but non-toxic. It is not usually a nutrient of concern in ecological assessments, including sensitive wetlands sites. Further, it is a significant food ingredient in electrolyte products such as Gatorade® and salt substitutes.

Nitrogen, however, can cause excessive topgrowth of vegetation, algal blooms, etc. Therefore it is necessary to predict nitrogen losses to the environment. However, there are no readily available, validated leaching models that can simulate the transformation and transport of nitrogen fertilizers. Therefore an approach was used in this assessment that differs from the approach used above for pesticides: average nitrogen (N) loss rates from the soil profile were estimated from test plot data published in the scientific literature; the leached mass was mixed into ground water; and a ground water model was used to estimate N concentrations that might migrate to the ocean.

1. Literature Review

Petrovic (1990) recently reviewed the literature on nitrogen losses from turf. He evaluated N uptake by turf and loss in runoff, leachate, and volatilization. Data from approximately 40 papers were reviewed. He concluded that N leaching losses "... generally were far less than 10%."

Two of the papers cited by Petrovic were good multiple test plot studies of the fate of N in bermudagrass turf over permeable soils. This scenario is relevant to O'oma II, which would have bermudagrass turf over permeable soil (see section V "Integrated Golf Course Management Plan" (IGCMP)). Synder, et al. (1981) studied turfgrass color, growth and N leaching in established plots of Tifgreen bermudagrass over Pompano sand (96% sand). The turf plots were in Florida and were irrigated daily, except during rainy periods. Suction lysimeters were installed to sample leachate, and eight different kinds of quick-release and slow-release N fertilizers were applied. Application rates were 20% below and 60% above normal. Average bi-monthly leachate was 31 cm (1.2 in), indicating a significant amount of rain plus irrigation. The nitrate-N concentration in the leachate averaged less than 5 ppm, and was typically less than 2 ppm. (The drinking water Maximum Contaminant Level is 10 ppm.) More importantly for this assessment, the average loss of N in the leachate at the highest application rate was 2.6%.

Brown, et al. (1982) studied the fate of five different quick-release and slow-release forms of N in Tifdwarf bermudagrass greens. The soils consisted of different types of greens mixes, but generally had greater than 80% sand. The greens were located in Texas and were irrigated 1 cm/day (0.4 in/day), which was greater than evapotranspiration. N fertilizers were applied at 3-4 times normal rates, and up to 33 times the rates specified in Table 7 of the IGCMP. Therefore the percent N-loss calculations would be less relevant since the turfgrass system could be overloaded causing greater leaching, particularly for water soluble N. For example, 70%-80% of the N-fertilizer recommended in the IGCMP (section IV (F)) is in the slow release form, which significantly reduces ground water contamination potential relative to quick release forms of N.

With these reservations, it is still possible to obtain some limited results relevant to O'oma II. IBDU is the N-source of more than half of the water insoluble (slow release) N-fertilizers listed in Table 7. It was applied by Brown, et al. (1982) at the equivalent rate of 3 lb N/1000 ft^2, 1.5-3 times the recommended rates in Table 7. Total N loss in leachate averaged 0.9% (0.2% - 1.4% range) across the three test plots.

Thus a good conservative N loss rate to assume for O'oma II would be 2.6%. This value is somewhat conservative because the application rate was very high and the water flux was high as well in the Synder et al. study.

In a different approach to calculate N-leaching rates, Dollar and Atkinson (in review) have evaluated nutrient input from golf

courses to Big Island nearshore coastal waters. Their focus was on two golf courses on the Kona Coast -- Waikoloa Beach and Keauhou. Based on nitrate concentrations in ground water and surface water, it appeared that 10% of the applied N had leached below the root zone. However, the ratio of slow release to quick release fertilizer products at both sites is unknown. It is known that the Keauhou site uses a significant amount of reclaimed sewage effluent for irrigation. The Waikoloa Beach golf course uses greater than 1,000,000 GPD of irrigation, probably due to a thin soil base which is permeable cinder soil (Mallory, 1991). Thus a heavy water flux through a permeable soil may be increasing the chances for nitrate to leach to ground water. Based on these differences, the relevance of these sites to O'oma II is unclear.

Therefore it was decided to use two N-leach rate values in our risk assessment: 2.6% as the average expectation value, 10% as a worst case value.

2. <u>Nitrogen Concentrations Leaching to Ground Water</u>

The calculations below were performed using the two N-leaching rates described above. Thus the N mass in the 2.6% table was determined simply by multiplying 0.026 times the estimated total N likely to be applied (19,000 kg over the whole golf course annually). The water flux was obtained from the PRZM output summarized in section VI below, and "reality" checked against standard water use tables for turfgrass (Beard, 1982).

Table 18

Predicted N Concentrations Assuming a 10% Leach Rate (Worst Case)

Year	N Mass (annual)	N conc.	Water flux (annual)
1	1900 kg	570 μM	2.37×10^8 l
2	1900 kg	830 μM	1.63×10^8 l
3	1900 kg	890 μM	1.54×10^8 l
4	1900 kg	600 μM	2.28×10^8 l
5	1900 kg	520 μM	2.59×10^8 l
Ave.	1900 kg	680 ± 150 μM	$(2.07 \pm 0.43) \times 10^8$ l

Table 19

Predicted N Concentrations Assuming a 2.6% Leach Rate

Year	N Mass (annual)	N conc.	Water flux
1	494 kg	149 μM	2.37×10^8 l
2	494 kg	216 μM	1.63×10^8 l
3	494 kg	232 μM	1.54×10^8 l
4	494 kg	157 μM	2.28×10^8 l
5	494 kg	136 μM	2.59×10^8 l
Ave.	494 kg	178 ± 38 μM	$(2.07 \pm 0.43) \times 10^8$ l

3. Estimated Nitrogen Concentrations Reaching the Shoreline

Nance (1991) modeled nitrogen loading to the shoreline using the numbers presented above. They determined that the effects of the 2.6% N leaching rate would be fully diluted before reaching the shoreline. At the worst case, 10% leaching rate, an N increase of 20-40 μM would occur in ground water reaching the shoreline.

Water quality analysis (Marine Research Consultants, 1990b) indicates that natural ground water input is rapidly mixed to background coastal oceanic levels within 10 M of the shoreline. This is consistent with observations of a strong, narrow, mixing zone described in Section VII (A) immediately following this section. Dollar and Atkinson (in review) also indicates that no impacts of golf course nutrients have been detected in near-shore coastal waters of the Big Island, even in areas with larger, calmer mixing zones. Thus it is highly unlikely that nitrate impacts would be detected offshore of the O'oma site.

VII. POTENTIAL FOR DISCHARGE OF CONTAMINATED GROUND WATER TO THE OCEAN AND HOST PARK

Turf chemical leachate concentrations were projected in the previous section. The purpose of this section is to discuss the potential for contamination and off-site migration of ground water.

A. Site Hydrogeology

The project site has an elevation range of 0-110 feet and is located on the western flank of Hualalai Dome; its most recent volcanic activity was around the year 1801 (Geolabs-Hawaii, 1988). The site lies to the south and west of the main northwest-southeast trending rift zone of Hualalai. This rift zone forms a structural and hydrological boundary (Geolabs-Hawaii, 1988).

A series of dunes which separates the less than 40 yard (36.6m) of beach is underlain by a covering of pahoehoe lava with small amounts of aa lava typical of the Hualalai Volcanic series. The strong mixing effects is due to the rocky shoreline, strong currents and close breakers. Due to the above mentioned physical hazards, swimming or snorkeling to is very difficult, though not impossible. There is a live coral reef immediately offshore.

In 1988, Geolabs-Hawaii installed 16 monitoring wells at 6 sites on the NELHA complex. Two of the wells (W-1 and W-2) are in the immediate vicinity of the O'oma II site. These are the only soil boring logs in the project vicinity that are readily available.

W-1 was drilled along the NELHA access road at elevation 102 feet near the intersection with Queen Kaahumanu Hwy. W-2 was installed approximately 4800 feet (1463m) west southwest of W-1, 75 feet south of the NELHA/O'oma boundary line at an elevation of six feet. Ground water was encountered in W-1 at approximately 102 feet below land surface (BLS) and 5.8 feet BLS in W-2 producing a ground water gradient and flow from W-1 to W-2. Thus the basal lens is very thin at well W-2. The surficial geology in both boreholes is characterized by vesicular basalt moderate to high

porosity. The soil boring logs from these wells are attached to this report as Appendix D.

B. Ground Water Quality

Salinity, nutrients, and silica gradients in the NELHA monitoring well network generally follow the vertical and lateral trends expected in coastal ground water systems.

Subsequent to the initial monitoring well installation at the NELHA property, cluster 10 wells were installed at various depths adjacent to the initial boreholes except for W-1 which was*. Thus W-2 was completed to 53.5 feet, W-2A was completed to 24.5 feet and W-2B was completed to 14.5 feet in order to eliminate cross-contamination between discrete flow tubes within the aquifer (Geolabs-Hawaii, 1988).

The pH of water from all NELHA monitoring wells at all depths was slightly alkaline, in the pH range 7.7-8.6. Gradients for other parameters are quite pronounced, as indicated below.

The trends evident in these data are typical for what is expected in coastal volcanic hydrogeology. Silicate and nutrient concentrations decrease as ground water flows downward and toward the coast. Salinity increases with increasing depth and proximity to the coastline. The data indicate the freshwater/saltwater transition point is 25 feet below the water table near the highway and 10-15 feet below the water table near the shoreline (Nance, 1991). This observation has some relevance to the ground water flow/mixing scenario presented in section D below.

*completed to 135 feet BLS, approximately 30-35 feet into the basal aquifer.

Site/Depth	P*	N**	Salinity†	Si††
W-1/135	3.26-3.81	49.50-91.50	6.04-7.46	713-775
W-2/53.5	0.61-1.34	14.20-35.40	26.95-28.72	268-315
W-2A/24.5	2.05-3.25	44.00-64.80	14.62-18.47	491-571
W-2B/14.5	2.46-3.65	50.60-86.40	6.35-8.82	651-734

All data are taken from NELHA (1990).

C. Potential Ground Water Flow Pathways

Ground water in this type of environment generally flows from mauka to makai, as noted above. Significant lateral flow is generally not encountered. Lava tubes will generally follow the laydown sequence, and not flow from one lava tube laterally to the next. Also, aquifer permeability in the direction of lava flow is approximately one to two orders of magnitude greater than in the perpendicular direction. Finally, lateral components of cones of depression are generally not significant in this type of system. Thus, as a general rule, ground water flow from underneath the proposed golf course to the NELHA property should not be significant (Nance, 1991).

However, a lagoon has been proposed for the O'oma II complex that would create a hydraulic barrier, diverting the normal ground water flow paths (Nance, 1991). A 7-acre unlined lagoon with a wave machine is proposed (Fig. 2). An unlined lagoon is preferred to a lined lagoon for several reasons, including esthetics and the fact that there would be no need for algaecides. Porous basalt with no lining means that a significant flux of water would be expected to pass through the bottom of the pond to ground water.

*P = Phosphate in μM.
**N = Nitrate in μM.
†Salinity in parts per thousand (ppth)
††Si = Silicate in μM.

Nance (1991) anticipates a 25,000 GPM (36MGD) well system on the inland side of the lagoon. The plan is to install five to eight wells which would yield 3,000 to 5,000 GPM per well.* Water would be pumped from the wells into the higher ponds and flow by gravity to the lowest 7-acre pond. This high volume discharge would create a hydraulic barrier (a mound in which seeping water moves away from the pond in all directions diverting natural flow of brackish ground water north and south of the "mounding" effect of pond seepage. It would then percolate through the porous bottom and sides and work its way back to the shoreline.

D. Estimation of Off-Site Pesticide Concentrations

Projected turf chemical leachate concentrations were generated using PRZM-VADOFT in section VI above. The next task is to model horizontal transport of this leachate in the saturated zone (aquifer system).

Estimation of pesticide concentrations in ground water was based on the nitrate modeling by Nance (1991). Nance (1991) estimated 25,000 GPM seepage from the 7-acre water recreation park and near shore permeability. Given the conservative 10 percent leaching effect, the dilution factor in ground water reaching the shoreline is 0.031 for nitrogen.

This same dilution factor was used to estimate the leaching of pesticides applied to the golf course. Concentration levels from the PRZM/VADOFT Model for proposed pesticides reaching the nearshore environment are shown in Table 20. These levels are compared with Human Health Advisory Levels (HAL) and to Aquatic Toxicity concentrations of concern. As can be seen from Table 20,

*The wells are to be screened (or open hole) well below the brackish ground water lens to produce water of seawater salinity to avoid discharging nutrient rich brackish ground water into the ponds.

the nearshore concentrations for all pesticides are well below any health hazards for humans or marine life which might be present. The Kohanaiki Anchialine Ponds are also within the dilution factor range and will not be adversely affected by properly applied pesticides.

With concentrations this low in the ground water, it is unnecessary to attempt to determine concentrations that might occur in the ocean as a result of ground water extrusion to the open coastline. The additional dilution would further reduce the pesticide concentrations to infinitesimal values.

The assessment of nutrient contamination potential was completely addressed in Section VI(F) above. The Kohanaiki Anchialine Ponds lie along the coast south according to GW flow path.

Table 20. Predicted Nearshore Pesticide Concentrations

Pesticide	Leachate Connectraction (ppb)	Nearshore Concentration		HAL (ppb)	Aquatic Toxicity (ppb)*
		Mean Values (ppb)	Upper 95% C.I. (ppb)		
Bensulide	$2.54 * 10^{-4}$	$7.88 * 10^{-6}$	$8.47 * 10^{-1}$	231	320
Chlorphyrifos	0.0	0.0	$6.99 * 10^{-8}$	105	0.0056**
2,4-D	2.12	$6.58 * 10^{-2}$	$5.79 * 10^{-1}$	70	20***
Metalaxyl	$2.90 * 10^{-1}$	$9.00 * 10^{-3}$	$1.50 * 10^{-1}$	420	25,000
Metribuzin	$1.61 * 10^{-1}$	$4.98 * 10^{-3}$	$1.40 * 10^{-1}$	200	48,300
Trichlorfon	1.16	$3.60 * 10^{-2}$	$8.41 * 10^{-1}$	4000	360

*Most sensitive LC_{50} for salt water species.

**EPA ambient water quality criteria standard for salt water.

***The aquatic toxicity value of 20 µg/l for 2,4-D was for a species of coral (P. damicornis) in a study by Glynn, et al. (1986). The 96 hour LC_{50} range for the free acid form of 2,4-D for fish is three order of magnitude higher (27,900 µg/l-199,000 µg/l) (Mayer and Ellersieck, 1986).

VIII. USE OF EFFLUENT WATER FOR IRRIGATION

Kahala Capital Corp. is planning to use sewage effluent to meet the partial irrigation needs of the O'oma II golf course. The effluent would be produced by an on-site sewage treatment plan producing approximately 500,000 GPD. This use of sewage effluent has several advantages:

- It conserves potable water.
- It recharges the aquifer.
- It is an environmentally sound way to reuse wastewater that would be considered an undesirable waste to many.
- It can be cheaper than municipal water.
- It is a source of nitrogen and other turfgrass nutrients.

In Arizona, this practice will soon be required by law (Mancino, et al., 1990). It is widespread elsewhere as well (Wastewater Conf., 1978).

The issue has also been studied extensively in Hawaii. Lau (1981; 1990) and Lau et al. (1991) have demonstrated that secondary and primary effluent can be used successfully for irrigation and concurrently for aquifer recharge. This is an important area of research because water reuse is a state policy, but it is relatively limited (Lau et al., 1991). Lau's work has demonstrated that natural grassed systems (Californiagrass and Bermudagrass) act as a surface living filter and a subsurface trickling filter, surpassing secondary treatment in improving water quality under certain conditions.

However, although the recharge water quality is acceptable, the applied effluent often contains human enteric viruses, even after chlorination (B. Anderson, 1991; Lau, 1981). Therefore it might be appropriate to model the extent to which effluent irrigation spray water might drift off-site. Unfortunately, the

current state-of-the-art can not support such modeling with a high degree of certainty. Thus, the most appropriate, albeit expensive, solution would be to increase the treatment standards significantly to minimize or eliminate the presence of viable microbes. If this approach is adopted, it is recommended that California's regulations and guidance in this area be seriously considered. Specifically, Title 22, Cal. Code Regns., Chapter 3, Section 60301, describes the requirements. Guidance for complying with these regulations can be found in "Policy Statement for Wastewater Reclamation Plants with Direct Filtration" (Cal. Dept. Health Services, Sacramento, June 10, 1988).

Basically, the regulations require the clarity of the sewage effluent to be lowered to 2 NTU prior to chlorination (Johnson, 1991). ("NTU", nominal turbidity unit, is a measure of the turbidity or cloudiness of the solution.) This would allow "unrestricted use" of the water, i.e. direct human contact with no buffer areas. Other guidance documents are also available for complying with these regulations (Johnson, 1991).

IX. MODELING PESTICIDE DRIFT

One of the potential pathways of exposure to sensitive organisms is pesticide drift during application as noted in Section III of this report. This concern also was expressed by NELHA management. Thus, a state-of-the-art drift modeling assessment was conducted for pesticide use at the proposed O'oma II golf course.

The drift assessment was performed by Honeycutt & Tolle (1991; Appendix C). The model used was AGDISP (Bilanir, et al., 1989). AGDISP was developed by Continuum Dynamics of Princeton, New Jersey under the sponsorship of NASA, USDA-Forest Service and the U.S. Army Dugway Proving Grounds. It was originally developed to model aerial application, but appears to be a model preferred by many in EPA and the pesticide industry for use on ground application. A lagrangian approach is used to set up and solve a series of differential equations for material motion. Conditions of speed of cross winds, turbulence, plant canopy, tractor speed, droplet size, evaporation fraction, humidity, spray boom height, etc. are all considered on a site-specific basis.

Input parameters for this assessment were taken from the O'oma II Integrated Golf Course Management Plan (section IV of this report) and other sources cited in Appendix C. A combination of reasonable and conservative assumptions were used, not best case assumptions.

Honeycutt & Tolle not only provided an estimate of spray drift as a function of cross wind speed, but performed a sensitivity analysis as well for the effects of boom height, terrain angle, and horizontal spray velocity.

The results can be summarized as follows: pesticide spray drift is not expected beyond 45 feet when crosswinds are 5 mph or less; significant drift past 50 feet could occur with crosswinds

of 10 mph; however, winds at the project site can be expected to be below 12 knots (~14 mph) about 95% of the time (Lindner, 1991). Thus, a feasible restriction would be to limit spraying to times when cross winds are below 5 mph and in an area with a 50 feet spray buffer. In addition, wind foils can be used with the tractor boom to further limit drift (Section IV). Note, also, recommendations in Section XIII regarding physical and vegetative buffer.

The sensitivity analysis results show a modest effect by increasing spray boom height, however, changes in terrain angle and horizontal spray velocity show no discernible impacts.

X. Ciguatera Toxin

Ciguatera poisoning can arise when people consume reef fish contaminated by ciguatoxins. The toxins are produced by microscopic marine organisms called dinoflagellates (Gambierdiscus toxicus; G. toxicus) that attach to the surface of red and brown macroalgae. Toxins are concentrated in the gut, liver, roe, and muscle tissue after ingestion of the algae by herbivorous fish. Carnivorous reef fish such as snapper and eel that prey on the herbivores can accumulate the toxin, as can surgeon and parrot fish that feed directly on the algae or the coral reef that supports the algae. Reports of illness and deaths from ciguatera have increased in recent years. West Hawaii had the highest number of reported incidents (11) in 1989. (For a good general discussion of the problem, the reader should consult the DOH pamphlet, "Fish Poisoning in Hawaii"(1988).)

The cause of ciguatera outbreaks is unknown. However, significant habitat alteration, e.g. coral destruction through storms or dredging, can create ideal habitats for macroalgae. There is, also, speculation that such habitat alteration(s) may cause the proliferation of G. toxicus; however, there is no proof for this theory (DOH, 1990). Specific factors have not been demonstrated to cause dinoflagellate blooms, including alterations of coral reef systems.

Two studies on this subject have recently been completed. Marine Research Consultants (MRC) (1991; Appendix E) reviewed the literature in response to concerns that coastal development may be implicated in ciguatoxin outbreaks. The first reported ciguatera poisoning incident was 1602, showing that this is not a recent phenomenon. There have also been recent outbreaks in New Caledonia, Fiji, Okinawa, Guam, Japan, and in the Atlantic throughout the Caribbean and Florida. It is important to note that the presence of the dinoflagellate does not guarantee toxic

conditions; i.e. G. toxicus can exist and grow in the wild in a non-ciguatoxic state.

The most important observations and conclusions of the MRC (1991) report are as follows:

- G. toxicus is more likely to occur in sheltered areas where land runoff and turbulence is minimal.
- Increases in G. toxicus cells were not caused by increases in nitrate and phosphate, forms of commonly-used golf course fertilizers, in the only two studies where this relationship was evaluated.
- Ciguatera outbreaks often appear to follow disturbance of coral reefs by manmade or natural causes, such as storms; however, these relationships are implied rather than proven.
- The areas of highest number of toxic incidences on West Hawaii are far removed from any development, but are associated with locations of the greatest fishing effort.

A recent preliminary study of West Hawaii by the State Department of Health also attempted to identify relationships that might explain ciguatera outbreaks. The Clean Water Branch of the DOH collaborated with the Natural Energy Laboratory of Hawaii (Kona) and the Department of Pathology, U.H.-Manoa to sample and analyze reef fish, substrates (coral, sand), and near-shore sea water (DOH, 1990). Approximately half of the fish sampled were found to be either positive or borderline for ciguatoxin. The most prominent nutrients in near-shore waters were dissolved silica and nitrates. However, there is a general absence of marine macroalgae that could support G. toxicus. G. toxicus was not confirmed in algae, coral, or sand.

One final important observation can be made based on an appendix to the DOH report. Locations and types of ciguatera fish poisoning incidents is plotted for Oahu, The Big Island, Kauai, and Maui for the 1984-1988 period. It is clear from the patterns of these plots that there are no obvious on-shore land-use causes of the outbreaks -- golf courses, hotels, cities, etc.

Therefore causes of ciguatera outbreaks remain unexplained with no plausible hypothesis for the reported incidents in this area.

XI. Termiticides

There are no requirements for subterranean termite control on the Big Island. However, chemical treatment of soil is standard industry practice, even in arid areas with minimal soil such as the proposed O'oma II site.

The pesticides permethrin, cypermethrin, chlorpyrifos, and isofenphos could be used safely and effectively if handled properly. However, all of these pesticides are highly toxic to fish and aquatic invertebrates. Given the sensitivities of neighbors to potential pesticide accidents or misuse, it is recommended that a new, alternative termite control agent be evaluated. This agent is a basaltic sand barrier. It functions by creating a physical barrier with spaces too small for the termites to crawl through and too large for the termites to move. (Lum, 1987).

Minoru Tamashiro, Ph.D., Professor, Department of Entomology, University of Hawaii, and a research team developed the basaltic sand barrier as a permanent, environmentally acceptable barrier to prevent the attack of subterranean termites on building structures. A minimum 4"-6" compacted layer of the material is placed directly under the slab of the structure. The areas around the perimeter of the slab where the material contacts the surface need to be sealed (i.e. 2" concrete). Constructed and maintained properly, this will form an effective barrier to termite attack that will significantly outlast any of the registered chemical controls (Lum, 1987).

There is no performance warranty, however, its efficacy has been demonstrated both in the laboratory and in the field. Six years of field data from use on Oahu have been obtained showing that there have been no occurrences of penetration by termites. Because of the nature of the material, the location and climatic conditions will not change the characteristics or performance of the basaltic sand. Thus the demonstrated efficacy on Oahu should carry over the use on the Big Island (Tamashiro, 1991).

A rough estimate is that the cost may be in the $200,000 - $500,000 price range for O'oma II.

XII. CONCLUSIONS

The O'oma II golf course is planned for an area that is likely to require minimal pesticide use relative to golf courses in many other areas of the country, including the windward side of Hawaii and Oahu.

Average concentrations of pesticides in ground water reaching the shoreline, anchialine ponds, and NELHA property are estimated to be between four and ten orders of magnitude (powers of ten (i.e. 1/10,000th - 1/10,000,000,000th)) below human Health Advisory Levels (HALs). Likewise, average values are estimated to be two to seven orders of magnitude below levels of concern for marine organisms (1/10th the LC_{50} of the most sensitive species tested). At the upper 95% confidence limits, predicted concentrations are generally orders of magnitude lower than 1/100th of the HAL and 1/10th of aquatic levels of concern. Therefore there is no concern for pesticides migrating off-site in toxicologically significant concentrations. However, it is recommended that leachate (drainage) from greens be diverted to surface areas where it can undergo further attenuation. (Greens are the most heavily managed parts of the golf course.)

A realistic expectation is that 2.6% of the fertilizer nitrogen (N) that is applied to the golf course may leach to ground water. A worst case expectation is for 10% of the N to leach. In neither case is there expected to be an impact on off-site water quality. However, it is still recommended that the superintendent follow the guidance in this document, which primarily recommends use of slow-release nitrogen fertilizers. These are less likely to leach to ground water.

Pesticide spray drift can be readily controlled by a series of physical and vegetative buffer areas. Common sense and federal law would also limit spraying during times of high cross winds. A spray shroud can be used for pesticide applications in winds between 5 mph and 20 mph. Higher cross winds are unlikely since wind speeds are less than 12 knots (14 mph) 95% of the time.

Use of secondary effluent water for golf course irrigation could benefit the golf course and the sewage treatment plant. However, drift of live microbes to adjacent properties could be a small but finite probability. Therefore a higher treatment standard based on California regulations would be required to reduce concerns for off-site drift of irrigation effluent spray.

There is no linkage between ciguatera toxin outbreaks and turf chemical applications. There is no valid hypothesis that has been advanced by competent scientists to suggest this linkage. Ciguatoxin outbreaks usually occur where there are no golf courses.

XIII. RECOMMENDATIONS

Effluent

Extensive spray drift precautions are recommended below. However, possibilities of even small amounts of microbial drift into nearby aquaculture facilities should not be taken lightly. Therefore it is recommended that Kahala Capital adopt California's treatment standards for use of effluent water in turf irrigation (Title 22, Cal. Code Regns., Chapter 3, Sect. 60301). These standards include a requirement that the turbidity be lowered to 2 NTU prior to chlorination. Adoption of this strict pre-chlorination clarity standard would mean that O'oma II's wastewater would be classified as class B--unrestricted use, suitable for human contact. It also means that clarification, flocculation, and coagulation processes may be necessary in the sewage treatment plant, in addition to oxidation and filtration.

Spray Drift

Pesticides should not be applied if cross wind speeds exceed 5 mph and no windfoil-style shrouded spray applicator is used. Applications in winds up to 20 mph could be made if such an applicator is used. In any case, legally enforceable statements on the label that forbid spray drift should be obeyed.

A lava rock or similar berm should be constructed that is at least 15 feet high along the O'oma II property boundary line near sensitive areas.

A vegetative buffer should be planted on the downslope on-property side of the berm. The complete buffer should be 100 ft wide. Vegetation planted in this buffer should be watered with drip irrigation. Local palm trees should be planted that have a history of no significant insect or disease problems. If necessary, insecticides should only be applied through direct or deep root injection. Otherwise, no pesticides should be applied in the 100 feet buffer strip.

Drainage

Drainage from greens should be 'daylighted' onto turf, other vegetation, or into a lined pond. This would further reduce turf chemical leachate concentrations through dissipative processes.

Soils

Sugar cane refuse soils from Hilo seem appropriate for this site, but off-site fumigation with methyl bromide may be required. The issue of appropriate soil selection should be studied further.

Pesticide Storage Facility

A pesticide storage facility (PSF) is an integral part of any golf course. ETS recommends for safety and environmental concerns that the following guideline be incorporated into the design and operation of the pesticide storage facility at the O'oma II site.

- The PSF must be of adequate size for proper chemical storage and personnel/equipment mobility (approx. 200 ft^2).
- The PSF should be built at an isolated location away from eating areas, offices, residences, etc.
- There should be adequate ventilation for worker health and safety.
- An emergency eye wash and shower station should be available for personnel, particularly in areas where pesticides are likely to be mixed or loaded.
- The PSF should be constructed with a cement floor and a drain equipped with a sump pump connected to (2) 1000 gallon pesticide rinsate storage tanks.
- Local fire codes must be met and fire extinguishers should be place both inside and outside the PSF.

- The PSF must be properly identified as a "Pesticide Storage Area" with a sign(s) placed at a visible location(s) and "Danger-Pesticides Keep-out" posted on the doors.
- Complete record keeping should be maintained that will include the availability of Material Safety Data Sheets for all stored chemicals.

Turfgrass Species

The following bermudagrass turfgrass species should be used due to disease resistance, salt tolerance, low water usage, pest resistance, and other factors:

- Tidwarf on greens;
- Tifgreen 328 on tees; and
- Tifway II on fairways, roughs, aprons, and for sod stabilization.

Termiticides

The pesticides permethrin, cypermethrin, chlorpyrifos, and isofenphos could be used safely and effectively for termite control. However, it is recommended that an alternative control agent, a basaltic sand barrier, be evaluated for the feasibility of its use on the O'oma II project. A rough estimate for the cost of this effective control is in the $200,000 to $500,000 range.

REFERENCES

Anderson, B. May 6, 1991 Personal communication. State of Hawaii, Department of Health , Honolulu, Hawaii.

Anderson, M. May 14 and June 20, 1991. Personal communications. NELH, North Kona, Hawaii.

Balcomb, R. September, 1990. Personal communication. Biologist, Aquatic Effects Branch, Ciba-Geigy Corporation.

Beard, J.B. 1982. Turf Management for Golf Courses. United States Golf Association, Macmillan Publishing Company, pp. 341-347.

Bilanin, A., M. Teske, J. Barry, and R. Ekbald. 1989. "AGDISP: The Aircraft Spray Dispersion Model, Code Development and Experimental Validation." Transaction of the ASAE, 32(1):327-334.

Boesten, J.J.T.I. and A.M.A. van der Linden. 1991. "Modeling the Influence of Sorption and Transformation on Pesticide Leaching and Persistence." J. Environ Qual., 20(2):425.

Brandenburg, R.L. 1989. "Improved Turfgrass Insect Management, Part 3." North Carolina Turfgrass News, 7(2):11,13.

Brown, K.W., J.C. Thomas, and R.L. Duble. 1982. "Nitrogen Source Effect on Nitrate and Ammonium Leaching and Runoff Losses from Greens." Agron. J., 74:947-950.

Chapman, R.A. and C.M. Cole. 1982. "Observations on the Influence of Water and Soil pH on the Persistence of Insecticides." J. Environ. Sci. Health, B17(5): 487-504.

Cohen S.Z., S. Nickerson, R. Maxey, A. Dupuy, Jr., and J. Senita. 1990. "A Ground Water Monitoring Study for Pesticides and Nitrates Associated with Golf Courses on Cape Cod." Ground Water Mon. Rev., 10:160-173.

Craven, H. September, 1990. Personal communication. Office of Pesticide Programs, Aquatic Effects Branch, EPA, Washington, D.C.

Daar, S. 1982. "Managing Vegetation: Using IPM Principals to Manage Turf Without Herbicides." IPM Practitioner, 4(9):3, 11.

Davis, F.M., R.A. Leonard, and W.G. Knisel. 1990. "GLEAMS User's Manual, Version 1.8.55." 39 pp.

Dean, J.D., P.S. Huyakorn, A.S. Donigian, Jr., K.A. Voos, R.W. Schanz, Y.J. Meeks, and R.F.Carsel. July, 1989. "Risk of Unsaturated/Saturated Transport and Transformation of Chemical Concentrations (RUSTIC) Volume I: Theory and Code Verification." EPA/600/3-89/048a, Contract No. 68-03-6304 for the Environmental Research Laboratory, EPA, Athens, Georgia.

Dean, J.D., P.S. Huyakorn, A.S. Donigian, Jr., K.A. Voos, R.W. Schanz, and R.F.Carsel. July 1989b. "Risk of Unsaturated/ Saturated Transport and Transformation of Chemical Concentrations (RUSTIC) Volume II: User's Guide." EPA/600/3-89/048b, Contract No. 68-03-6304 for the Environmental Research Laboratory, EPA, Athens, Georgia.

Dixon, C. May-August, 1991. Personal communications. Soil scientist, Turf Diagnostics and Design, Olathe, Kansas.

DNLR/DOWALD. 1970. "An Inventory of Basic Resources Data, Island of Hawaii." Report R34. State of Hawaii, DLNR, DOWALD, Honolulu, HI.

DOH (State of Hawaii, Department of Health, Clean Water Branch). 1990. Interim Report on Coastal Water Quality and Ciguatoxin Fish Survey in West Hawaii. Honolulu, HI.

Dollar, S. and M. Atkinson. In review. "Effects of Nutrient Subsidies from Ground Water Nearshore Marine Ecosystems off the Island of Hawaii." Estuarine Coastal and Shelf Science.

Driscoll, F.G.,(Ed.). 1986. Groundwater and Wells. St. Paul, Minnesota.

Egan, D. June, 1991. Personal communications. Hydrogeologist, Apex Environmental, Inc., Rockville, MD.

Ekern, P.C. and J. Chang. August, 1985. "Pan Evaporation: State of Hawaii, 1894-1983." Report R74. State of Hawaii, DLNR, DOWALD, Honolulu, HI; Water Resources Research Center, University of Hawaii at Manoa, Honolulu, HI; in cooperation with the Hawaiian Sugar Planters Association, Aiea, HI.

Eyre, P. May, 1991. Personal communications. Hydrogeologist, U.S. Geological Survey, Honolulu, HI.

EPA. October, 1983. "Pesticide Fact Sheet Number 8: Dicamba." NTIS #PB87-111944;

EPA. June, 1984. Chemical Fact Sheet #30 for Trichlorfon.

EPA. September, 1984. Chemical Fact Sheet #37 for Chlorpyrifos.

EPA. September, 1984b. Chemical Fact Sheet #36 for Chlorothalonil.

EPA. June, 1985. Chemical Fact Sheet #53 for Metribuzin.

EPA. 1986. Chemical Fact Sheet #83 for Imazaquin.

EPA. 1987. "Handbook: Ground Water, EPA, Office of Research and Development." Center for Environmental Research Information, Cincinnati, Ohio and Robert S. Kerr Environmental Research Laboratory, Ada, Oklahoma.

EPA. November, 1987. Pesticide Tolerance for Fluazifop-Butyl. Federal Register, 52(21):42651-52. November 6, 1987.

EPA. June, 1987. Chemical Fact Sheet #195 for Bendiocarb.

EPA. March, 1988. Chemical Fact Sheet #155.1 for Metalaxyl.

EPA. September, 1988. Chemical Fact Sheet #94.2 for 2,4-Dichlorophenoxyacetic acid (2,4-D).

EPA. December, 1988. Chemical Fact Sheet #192 for Mecopprop (MCPP).

EPA. January, 1989. "Drinking Water Regulations and Health Advisories," Office of Drinking Water, EPA, Washington, D.C.

EPA/EAB (Environmental Protection Agency/Exposure Assessment Branch). "One Liner" fact sheet summaries of various pesticides. Office of Pesticide Programs, EPA, Washington, D.C.

EPA/OPP/HED (Environmental Protection Agency/Office of Pesticide Programs/Hazard Evaluation Division). June, 1986. "Hazard Evaluation Division Standard Evaluation Procedure, Ecological Risk Assessment." NTIS #PB86-247657, Office of Pesticide Programs, EPA, Washington, D.C.

FCH. 1991. Farm Chemicals Handbook. Meister Publising Company, Willoughby, Ohio.

Finlayson, B.J. and K.M. Verrue. 1985. "Toxicities of Butoxyethanol Ester and Propylene Glycol Butyl Ether Ester Formulations of 2,4-Dichlorophenoxyacetic Acid (2,4-D) to Juvenile Salmonids." Arch. Environ. Cont. Toxicol., 14(2):153-160.

Foy, J.H. 1988. "Integrated Pest Management - A Different Approach to the Same Old Problems." USGA Greens Section Record, 26(5):9-11, September/October, 1988.

Freeze, R.A. and J.A. Cherry. 1979. Groundwater. Prentice-Hall, Inc., Englewood Cliffs, N.J.

Geolabs-Hawaii, C.W. Associates. December 22, 1988. "Installation Report Water Quality Monitoring Wells Natural Energy Laboratory of Hawaii (NELH) and Hawaii Ocean Science and Technology Park, Keahole, North Kona, Hawaii." W.O. 1846-10; for R. M. Towill Corporation.

Giambelluca, T.W., M.A. Nullet, and T.A. Schroeder. June, 1986. "Rainfall Atlas of Hawaii." Report R76. State of Hawaii, DLNR, DOWALD, Honolulu, HI; Water Resources Research Center, University of Hawaii at Manoa, Honolulu, HI; in cooperation with the Department of Meteorology, University of Hawaii at Manoa, Honolulu, HI.

Glynn, P.W., L.S. Howard, E. Corcoran, and A.D. Freay. 1984. "The Occurrence and Toxicity of Herbicides in Reef Building Corals," in Marine Pollution Bulletin, 15:370-374.

Glynn, P.W., L.S. Howard, E. Corcoran, and A.D. Freay. 1986. Coral Reef Population Biology. Sea Grant Coop. Rep., University of Hawaii, pp. 473-485.

Green, R.E. and S.W. Karickhoff. "Estimating Pesticide Sorption Coefficients for Soils and Sediments." in Small Watershed Model (SWAM) for Water, Sediment, and Chemical Movement, Supporting Documentation. United States Department of Agriculture, Agricultural Research Service, ARS-80, pp. 1-18.

Hachmuth, C. June 19, 1991. Personal communication. NELHA, North Kona, Hawaii.

Harrison S.A. August, 1989. "Effects of Turfgrass Establishment Method and Management on the Quantity and Nutrient and Pesticide Content of Runoff and Leachate." Master of Science Thesis in Agronomy, College of Agriculture, Pennsylvania State University.

Horsberg, T.E., T. Hoey, and I. Nafstad. 1989. "Organophosphate Poisoning of Atlantic Salmon in Connection with Treatment Against Salmon Lice." Acta Vet. Scand., 30(4):385-390.

IRIS (Integrated Risk Information System) data base, maintained by the Environmental Protection Agency.

Johnson, L. September 11, 1991. Personal communication; Chief, Office of Water Recycling, State Water Resources Control Board, Sacramento, California.

Johnson, W.W. and M.T. Finley. 1980. "Handbook of Acute Toxicity of Chemicals to Fish and Aquatic Invertebrates." Resource Publication 137. U.S. Dept. of the Interior, Fish and Wildlife Service, Washington, D.C.

Jury. W.A. 1986 "Spatial Variability of Soil Properties." in Vadose Zone Modeling of Organic Pollutants, S.C. Hern and S.M. Melancon, [Ed.], Lewis Publishers, Inc., Chelsea, Michigan, pp. 245-269.

Jury, W.A., D.D. Focht, and W.J. Farmer. 1987. "Evaluation of Pesticide Ground Water Pollution Potential from Standard Indices of Soil-Chemical Adsorption and Biodegradation." J. Environ. Qual., 16:422-428.

Kearney, T. May 19, 1991. Personal communication. Wastewater Branch, State of Hawaii, Department of Health, Honolulu, HI.

Lau, S.L. 1990. "A Water Reclamation Facility for Ewa: Recycling Effluent into Assets and Benefits." presented to Hawaii Water Pollution Control Association, 12th Annual Conference, Sheraton Waikiki Hotel, Honolulu, HI. February 8, 1990.

Lau, S.L. 1981. "Wastewater Use for Irrigation: A Case History in Hawaii." Water Reuse Symposium II Proceedings, Volume 2, August, 1981, pp. 935-945.

Lau, S.L., I. Wu, and H.K. Gee. 1991. "A New Drip-Irrigation Technology For Wastewater Reuse." presented to Hawaii Water Pollution Control Association, 13th Annual Conference, Sheraton Waikiki Hotel, Honolulu, HI. February 7-8, 1991.

Lorber, M.N. and C.K. Offutt. 1986. "A Method for the Assessment of Ground Water Contamination Potential." in Evaluation of Pesticides in Ground Water, W.Y. Garner, R.C. Honeycutt, and H.N. Nigg, [Eds.], pp. 342-365. American Chemical Society, Washington, D.C.

Loague, K.M., R.E. Green, T.W. Giambelluca, T.C. Liang, and R.S. Yost. 1990. "Impact of Uncertainty in Soil, Climatic and Chemical Information in a Pesticide Leaching Assessment." J. Contam. Hydrol., 5:171-194.

Lucas, L.T. 1984. "Turf Diseases and Problems in 1984." North Carolina Turfgrass News, 2(2):17.

Lum. 1987. "Report to Ameron HC&D on Basaltic Termite Barrier for Residential Construction." Walter Lum Associates, Inc., December 4, 1987.

Mallory, S. July 24 and August 15, 1991. Personal communications. Superintendent, Waikoloa Village Golf Course, Waikoloa, HI.

Mancino, C. F., A. Hayes, D. M. Kopec, and I. Pepper. August 1990. "The Use of Secondarily Treated Wastewater in Turfgrass Irrigation." Golf Course Management, 58(8):72-78.

Marine Research Consultants (S. Dollar). 1990. "An Assessment of Nearshore Marine Community Structure at O'oma, North Kona, Hawaii." prepared for Helber Hastert & Kimura, Planners Honolulu, HI and Kahala Capital Corp., Kailua-Kona, HI.

Marine Research Consultants. 1990b. "Effects of Golf Course Irrigation and Fertilization on Nearshore Marine Waters Off the West Coast of the Island of Hawaii." prepared for Helber Hastert & Kimura, Planners Honolulu, HI and Kahala Capital Corp., Kailua-Kona, HI.

Mayer, F.L. 1991. Personal communication. Environmental Research Laboratory, EPA, Gulf Breeze, Florida.

Mayer, F.L. April, 1987. "Acute Toxicity of Chemicals to Estuarine Organisms." EPA/600 8-87/017, EPA, ERL, Gulf Breeze, FL.

Mayer, F.L., Deans, C.H., and A.G. Smith. September, 1987. "Inter-Taxa Correlations for Toxicity to Aquatic Organisms." EPA/600/X-87/332, EPA, ERL, Gulf Breeze, FL; prepared for the Ecological Risk Assessment Program, Office of Pesticides and Toxic Substances, EPA, Washington, D.C.

Mayer, F.L. and M.R. Ellersieck. 1986. "Manual of Acute Toxicity; Interpretation and Data Base for 410 Chemicals and 66 Species of Freshwater Animals." Resource Publication 160. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C.

Morton, T.G., A.J. Gold, and W.M. Sullivan. 1988. "Influence of Overwatering and Fertilization on Nitrogen Losses From Home Lawns." J. Environ. Qual. 17:124-130.

Nance, T. May 10, June 12, and June 14, 1991. Personal communications. Tom Nance & Assoc. Water Resources Engineers, Honolulu, HI.

Nance, T. (Tom Nance Water Resources Engineering, Honolulu, HI). August, 1991. "Saltwater Ponds of the O'oma II Project: Recommended Circulation System and Analysis of Environmental Effects." prepared for Kahala Capital Corp., Kailua-Kona, HI.

NELHA (Natural Energy Laboratory of Hawaii Authority). October, 1990. "Annual Report for the Comprehensive Environmental Monitoring Program Covering the Period: July 1989 through June 1990." NELHA Water Quality Lab Staff, North Kona, Hawaii.

NPIRS (National Pesticide Information Retrieval System) database, maintained by Purdue University and EPA.

Orus, M.I., E. Marco, and F. Martinez. 1990. "Effect of Trichlorfon on N^2-Fixing Cyanobacterium Anabaena PCC 7119." Arch. Environ. Contam. Toxicol., 19(3):297-301.

Parrish, R. August 21 and September 4, 1991. Personal communications. Statistician, Computer Sciences Corporation, Environmental Research Laboratory, Athens, Georgia.

Petrovic, A.M. September, 1989. "Golf Course Management and Nitrates in Ground Water." Golf Course Management, pp. 54-64.

Petrovic, A.M. 1990 "The Fate of Nitrogenous Fertilizer Applied to Turfgrass." J. Environ. Qual., 19:1-14.

Pike, A.W. 1989. "Sea Lice--Major Pathogens of Farmed Atlantic Salmon." Parasitol. Today, 5(9):291-297.

Rao, P.S.C. and J.M. Davidson. 1980. "Estimation of Pesticide Retention and Transformation Parameters Required in Nonpoint Source Pollution Models." in Environmental Impact of Nonpoint Source Pollution, M.R. Overcash and J.M. Davidson, (Eds.), Ann Arbor Science Publishers, Ann Arbor, MI, pp. 23-66.

Rao, P.S.C., A.G. Hornsby, and R.E. Jessup. 1985. "Indices for Ranking the Potential for Pesticide Contamination of Ground Water." Soil and Crop Sci. Soc. Florida Proc., 44:1-8.

Ross, A. 1989. "Nuvan Use in Salmon Farming: The Antithesis of the Precautionary Principle." Marine Pollution Bulletin, 20(8): 372-374.

Sabock, D. September, 1990. Personal communication. Office of Water Regulations and Standards, EPA, Washington, D.C.

Schildknecht, A. July 24, 1991. Personal communication. Irrigation Hawaii, Honolulu, HI.

Smith, A.E. 1980. "Persistence Studies with [^{14}C] 2,4-D in Soils Previously Treated with Herbicides and Pesticides." Weed Research, 20:355-359.

SRC (Syracuse Research corporation), CHEMFATE Data Bases (peer reviewed), Syracuse, New York.

Sportsturf. 1988. Anonymous. "Aeration and Cultivation, Making Sure the Cure is Better than the Disease." Sportsturf, May, 4(5):21-26.

Synder, G.H., E.O. Burt, and J.M. Davidson. 1981. "Nitrogen Leaching in Bermudagrass Turf: Effects of Nitrogen, Sources, and Rates." in Proc. 4th Int. Turfgrass Res. Conf., U.Guelph, Ont., 19-23 July, R. W. Shead (Ed.), U. Guelph, Guelph, Canada.

Tamashiro, M. September 11, 1991, Personal Communication. Professor, Department of Entomology, University of Hawaii.

USDA, SCS. November, 1988. "I-5 Pesticide Data Base." in Water Quality Workshop: Integrating Water Quality and Quantity into Conservation Planning, U.S. Department of Agriculture, Soil Conservation Service, Washington, D.C.

USDA, SCS. 1986. "Urban Hydroglogy for Small Watersheds, 2nd Edition." Technical Release No. 55. Washington, D.C., 162 pp.

U. S. Department of Commerce. 1989. "U.S. Fish and Wildlife Service Biological opinion on Selected Pesticides: June 1989." NTIS PB90-12/266/4.

U. S. Department of Commerce. 1962. "Rainfall Frequency Atlas of the Hawaiian Islands." Technical Paper No. 43, 60 pp.

U.S. Department of Interior, Fish and Wildlife Service. 1980. "Handbook of Acute Toxicity of Chemicals to Fish and Aquatic Invertebrates." Resource Publication 137, 98 pp.

Vittum, P.J. November, 1986. "Secret of Controlling White Grubs." Association of Landscape Architects, 7(11):34-38.

Wastewater Conference. November, 1978. Proceedings of Wastewater Conference. Chicago, Illinois. Sponsered by the American Society of Golf Course Architects Foundation, USGA Greens Section, National Golf Foundation, and Golf Course Superintendents Association of America.

Williams, J.R. 1975. "Sediment Yield Prediction With Universal Equation Using Runoff Energy Factor." in Present and Prospective Technology for Predicting Sediment Yields and Sources, U.S. Department of Agriculture, Agricultural Research Service, Southern Region, ARS-5-40, pp. 244-252.

WSSA (Weed Science Society of America). 1989. Herbicide Handbook of the Weed Science Society of America, Sixth Edition, Champaign, Illinois.

Willis, G.H. and L.L. McDowell. 1987. "Pesticide Persistence on Foliage." Rev. Environ. Contam. Toxicol., 6(100):23-73.

Appendix A. Letter Requesting Research on Organic Turf Chemicals on Hawaii

ENVIRONMENTAL & TURF SERVICES, INC.

"Addressing Golf's Environmental Concerns"

CORPORATE HEADQUARTERS
11141 GEORGIA AVE., SUITE 208
WHEATON, MD 20902
(301) 933-4700
FAX (301) 933-4701

REGIONAL OFFICE
3525 WELLSTON COURT
SIMI VALLEY, CA 93063
(805) 527-9147
FAX (805) 527-1247

May 22, 1991

Vonnie Estes, Plant Pathologist
Ringer Corporation
9959 Valley View Road
Minneapolis, MN 55344

re: Use of Ringer Products in Hawaii

Dear Vonnie:

Thanks for your time on the phone this week.

As I mentioned, there could be several potential applications for Ringer products in Hawaii. Unfortunately, as you noted, there are no field data supporting use of these products on turf in Hawaii. Therefore I am pleased to hear that you will consider field trials of your turf chemicals in Hawaii as a result of our conversation. I would suggest doing studies at windward and leeward sites, due to significant differences in rainfall.

The turf and agrichemical markets could always use more environmentally sound products such as those offered by Ringer.

Please call if we can help set up those field trials. Please also keep us informed of your progress in this area.

Sincerely,

/s/

Stuart Z. Cohen, Ph.D
President

cc: W.K. Alkire II, California
Michael O'Connor, Vermont

Printed on recycled paper

Greens Scenario -- 1st Three Pesticides
(chlorpyrifos, bensulide, metalaxyl)

Flow simulation from 1 Jan 5 to 31 Jan 5
Transport simulation from 1 Jan 5 to 31 Jan 5
Transport simulation from 1 Jan 5 to 31 Jan 5
Transport simulation from 1 Jan 5 to 31 Jan 5
Flow simulation from 1 Feb 5 to 28 Feb 5
Transport simulation from 1 Feb 5 to 28 Feb 5
Transport simulation from 1 Feb 5 to 28 Feb 5
Transport simulation from 1 Feb 5 to 28 Feb 5
Flow simulation from 1 Mar 5 to 31 Mar 5
Transport simulation from 1 Mar 5 to 31 Mar 5
Transport simulation from 1 Mar 5 to 31 Mar 5
Transport simulation from 1 Mar 5 to 31 Mar 5
Flow simulation from 1 Apr 5 to 30 Apr 5
Transport simulation from 1 Apr 5 to 30 Apr 5
Transport simulation from 1 Apr 5 to 30 Apr 5
Transport simulation from 1 Apr 5 to 30 Apr 5
Flow simulation from 1 May 5 to 31 May 5

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****************************************************************************
Transport simulation from  1 Sep  5 to 30 Sep  5
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****************************************************************************
Flow simulation from  1 Oct  5 to 31 Oct  5
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Transport simulation from  1 Oct  5 to 31 Oct  5
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****************************************************************************
Transport simulation from  1 Oct  5 to 31 Oct  5
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****************************************************************************
Transport simulation from  1 Oct  5 to 31 Oct  5
****************************************************************************
****************************************************************************
Flow simulation from  1 Nov  5 to 30 Nov  5
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****************************************************************************
Transport simulation from  1 Nov  5 to 30 Nov  5
****************************************************************************
****************************************************************************
Transport simulation from  1 Nov  5 to 30 Nov  5
****************************************************************************
****************************************************************************
Transport simulation from  1 Nov  5 to 30 Nov  5
****************************************************************************
****************************************************************************
Flow simulation from  1 Dec  5 to 31 Dec  5
****************************************************************************

        SUMMARY OF VOLUMETRIC FLOW BALANCE OUTPUT
        -----------------------------------------

        Elapsed simulation time =   0.3100E+02
        Current value of time increment =   0.1000E+01

        Fluid flux value at first node =  0.1513E-12
        Fluid flux value at last node = -0.1069E-09

        NOTE: These "net" values are only for last day of time step
        Net value of fluid flux = -0.1068E-09
        Net rate of volumetric storage = -0.1158E-09
        FLOW BALANCE ERROR =  0.9050E-11
        NORMALIZED BALANCE ERROR =  0.4060E-01

        NOTE: These "cumulative" values are for the entire time step
        Cumulative volumetric storage = -0.1252E-02
        Cumulative inflow volume =  0.5497E+03
        Cumulative outflow volume = -0.5486E+03



Transport simulation from  1 May  5 to 31 May  5
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****************************************************************************
Transport simulation from  1 May  5 to 31 May  5
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****************************************************************************
Transport simulation from  1 May  5 to 31 May  5
****************************************************************************
****************************************************************************
Flow simulation from  1 Jun  5 to 30 Jun  5
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Transport simulation from  1 Jun  5 to 30 Jun  5
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Transport simulation from  1 Jun  5 to 30 Jun  5
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Transport simulation from  1 Jun  5 to 30 Jun  5
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Flow simulation from  1 Jul  5 to 31 Jul  5
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Transport simulation from  1 Jul  5 to 31 Jul  5
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Transport simulation from  1 Jul  5 to 31 Jul  5
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Transport simulation from  1 Jul  5 to 31 Jul  5
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Flow simulation from  1 Aug  5 to 31 Aug  5
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****************************************************************************
Transport simulation from  1 Aug  5 to 31 Aug  5
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****************************************************************************
Transport simulation from  1 Aug  5 to 31 Aug  5
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****************************************************************************
Transport simulation from  1 Aug  5 to 31 Aug  5
****************************************************************************
****************************************************************************
Flow simulation from  1 Sep  5 to 30 Sep  5
****************************************************************************
****************************************************************************
Transport simulation from  1 Sep  5 to 30 Sep  5
****************************************************************************
****************************************************************************
Transport simulation from  1 Sep  5 to 30 Sep  5
```

TIME VS HEAD AT NODE NUMBER 1

0.1000E+01	-0.3446E+03	0.2000E+01	-0.3540E+03	0.3000E+01	-0.3540E+03	0.4000E+01	-0.3446E+03
0.5000E+01	-0.3446E+03	0.6000E+01	-0.3540E+03	0.7000E+01	-0.3540E+03	0.8000E+01	-0.3446E+03
0.9000E+01	-0.3446E+03	0.1000E+02	-0.3540E+03	0.1100E+02	-0.3540E+03	0.1200E+02	-0.3446E+03
0.1300E+02	-0.3446E+03	0.1400E+02	-0.3540E+03	0.1500E+02	-0.3540E+03	0.1600E+02	-0.3446E+03
0.1700E+02	-0.3446E+03	0.1800E+02	-0.3540E+03	0.1900E+02	-0.3540E+03	0.2000E+02	-0.3446E+03
0.2100E+02	-0.3446E+03	0.2200E+02	-0.3540E+03	0.2300E+02	-0.3540E+03	0.2400E+02	-0.3446E+03
0.2500E+02	-0.3540E+03	0.2600E+02	-0.3540E+03	0.2700E+02	-0.3446E+03	0.2800E+02	-0.3446E+03
0.2900E+02	-0.3540E+03	0.3000E+02	-0.3540E+03	0.3100E+02	-0.3540E+03		

TIME VS HEAD AT NODE NUMBER 11

0.1000E+01	-0.3372E+03	0.2000E+01	-0.3440E+03	0.3000E+01	-0.3440E+03	0.4000E+01	-0.3372E+03
0.5000E+01	-0.3372E+03	0.6000E+01	-0.3440E+03	0.7000E+01	-0.3440E+03	0.8000E+01	-0.3372E+03
0.9000E+01	-0.3372E+03	0.1000E+02	-0.3440E+03	0.1100E+02	-0.3440E+03	0.1200E+02	-0.3372E+03
0.1300E+02	-0.3372E+03	0.1400E+02	-0.3440E+03	0.1500E+02	-0.3440E+03	0.1600E+02	-0.3372E+03
0.1700E+02	-0.3372E+03	0.1800E+02	-0.3440E+03	0.1900E+02	-0.3440E+03	0.2000E+02	-0.3372E+03
0.2100E+02	-0.3372E+03	0.2200E+02	-0.3440E+03	0.2300E+02	-0.3440E+03	0.2400E+02	-0.3372E+03
0.2500E+02	-0.3440E+03	0.2600E+02	-0.3440E+03	0.2700E+02	-0.3372E+03	0.2800E+02	-0.3372E+03
0.2900E+02	-0.3440E+03	0.3000E+02	-0.3440E+03	0.3100E+02	-0.3440E+03		

TIME VS HEAD AT NODE NUMBER 26

0.1000E+01	-0.2991E+03	0.2000E+01	-0.3050E+03	0.3000E+01	-0.3050E+03	0.4000E+01	-0.2991E+03
0.5000E+01	-0.2991E+03	0.6000E+01	-0.3050E+03	0.7000E+01	-0.3050E+03	0.8000E+01	-0.2991E+03
0.9000E+01	-0.2991E+03	0.1000E+02	-0.3050E+03	0.1100E+02	-0.3050E+03	0.1200E+02	-0.2991E+03
0.1300E+02	-0.2991E+03	0.1400E+02	-0.3050E+03	0.1500E+02	-0.3050E+03	0.1600E+02	-0.2991E+03
0.1700E+02	-0.2991E+03	0.1800E+02	-0.3050E+03	0.1900E+02	-0.3050E+03	0.2000E+02	-0.2991E+03
0.2100E+02	-0.2991E+03	0.2200E+02	-0.3050E+03	0.2300E+02	-0.3050E+03	0.2400E+02	-0.2991E+03
0.2500E+02	-0.3050E+03	0.2600E+02	-0.3050E+03	0.2700E+02	-0.2991E+03	0.2800E+02	-0.2991E+03
0.2900E+02	-0.3050E+03	0.3000E+02	-0.3050E+03	0.3100E+02	-0.3050E+03		

TIME VS HEAD AT NODE NUMBER 85

0.1000E+01	0.0000E+00	0.2000E+01	0.0000E+00	0.3000E+01	0.0000E+00	0.4000E+01	0.0000E+00
0.5000E+01	0.0000E+00	0.6000E+01	0.0000E+00	0.7000E+01	0.0000E+00	0.8000E+01	0.0000E+00
0.9000E+01	0.0000E+00	0.1000E+02	0.0000E+00	0.1100E+02	0.0000E+00	0.1200E+02	0.0000E+00
0.1300E+02	0.0000E+00	0.1400E+02	0.0000E+00	0.1500E+02	0.0000E+00	0.1600E+02	0.0000E+00
0.1700E+02	0.0000E+00	0.1800E+02	0.0000E+00	0.1900E+02	0.0000E+00	0.2000E+02	0.0000E+00
0.2100E+02	0.0000E+00	0.2200E+02	0.0000E+00	0.2300E+02	0.0000E+00	0.2400E+02	0.0000E+00
0.2500E+02	0.0000E+00	0.2600E+02	0.0000E+00	0.2700E+02	0.0000E+00	0.2800E+02	0.0000E+00
0.2900E+02	0.0000E+00	0.3000E+02	0.0000E+00	0.3100E+02	0.0000E+00		

****
Transport simulation from 1 Dec 5 to 31 Dec 5
****

MASS TRANSPORT BALANCE, CHEMICAL 1
---- --------- -------- -------- --

NOTE: These "net" values are only for last day of time step
Net dispersive flux = 0.0000E+00
Net advective flux = 0.0000E+00
Net rate of mass accumulation = 0.0000E+00
Net rate of formation = 0.0000E+00
Net rate of mass decay = 0.0000E+00
MASS BALANCE ERROR = 0.0000E+00
NORMALIZED MASS BALANCE ERROR = 0.0000E+00

NOTE: These "cumulative" values are for the entire time step
Cumulative mass storage = 0.0000E+00
Cumulative mass decay = 0.0000E+00
Cumulative inflow mass = 0.0000E+00
Cumulative outflow mass = 0.0000E+00

ANNUAL SUMMARY OF CUMULATIVE CONCENTRATIONS
------ ------- -- ---------- --------------

NOTE: These "cumulative" values are yearly summaries
Annual cumulative mass storage = 0.0000E+00
Annual cumulative mass decay = 0.0000E+00
Annual cumulative inflow mass = 0.0000E+00
Annual cumulative outflow mass = 0.0000E+00

TIME VS CONCENTRATION AT NODE NUMBER 1

0.1000E+01	0.0000E+00	0.2000E+01	0.0000E+00	0.3000E+01	0.0000E+00	0.4000E+01	0.0000E+00
0.5000E+01	0.0000E+00	0.6000E+01	0.0000E+00	0.7000E+01	0.0000E+00	0.8000E+01	0.0000E+00
0.9000E+01	0.0000E+00	0.1000E+02	0.0000E+00	0.1100E+02	0.0000E+00	0.1200E+02	0.0000E+00
0.1300E+02	0.0000E+00	0.1400E+02	0.0000E+00	0.1500E+02	0.0000E+00	0.1600E+02	0.0000E+00
0.1700E+02	0.0000E+00	0.1800E+02	0.0000E+00	0.1900E+02	0.0000E+00	0.2000E+02	0.0000E+00
0.2100E+02	0.0000E+00	0.2200E+02	0.0000E+00	0.2300E+02	0.0000E+00	0.2400E+02	0.0000E+00
0.2500E+02	0.0000E+00	0.2600E+02	0.0000E+00	0.2700E+02	0.0000E+00	0.2800E+02	0.0000E+00
0.2900E+02	0.0000E+00	0.3000E+02	0.0000E+00	0.3100E+02	0.0000E+00		

TIME VS CONCENTRATION AT NODE NUMBER 11

0.1000E+01	0.0000E+00	0.2000E+01	0.0000E+00	0.3000E+01	0.0000E+00	0.4000E+01	0.0000E+00
0.5000E+01	0.0000E+00	0.6000E+01	0.0000E+00	0.7000E+01	0.0000E+00	0.8000E+01	0.0000E+00
0.9000E+01	0.0000E+00	0.1000E+02	0.0000E+00	0.1100E+02	0.0000E+00	0.1200E+02	0.0000E+00
0.1300E+02	0.0000E+00	0.1400E+02	0.0000E+00	0.1500E+02	0.0000E+00	0.1600E+02	0.0000E+00
0.1700E+02	0.0000E+00	0.1800E+02	0.0000E+00	0.1900E+02	0.0000E+00	0.2000E+02	0.0000E+00
0.2100E+02	0.0000E+00	0.2200E+02	0.0000E+00	0.2300E+02	0.0000E+00	0.2400E+02	0.0000E+00
0.2500E+02	0.0000E+00	0.2600E+02	0.0000E+00	0.2700E+02	0.0000E+00	0.2800E+02	0.0000E+00
0.2900E+02	0.0000E+00	0.3000E+02	0.0000E+00	0.3100E+02	0.0000E+00		

TIME VS CONCENTRATION AT NODE NUMBER 24

0.1000E+01	0.0000E+00	0.2000E+01	0.0000E+00	0.3000E+01	0.0000E+00	0.4000E+01	0.0000E+00
0.5000E+01	0.0000E+00	0.6000E+01	0.0000E+00	0.7000E+01	0.0000E+00	0.8000E+01	0.0000E+00
0.9000E+01	0.0000E+00	0.1000E+02	0.0000E+00	0.1100E+02	0.0000E+00	0.1200E+02	0.0000E+00
0.1300E+02	0.0000E+00	0.1400E+02	0.0000E+00	0.1500E+02	0.0000E+00	0.1600E+02	0.0000E+00
0.1700E+02	0.0000E+00	0.1800E+02	0.0000E+00	0.1900E+02	0.0000E+00	0.2000E+02	0.0000E+00
0.2100E+02	0.0000E+00	0.2200E+02	0.0000E+00	0.2300E+02	0.0000E+00	0.2400E+02	0.0000E+00
0.2500E+02	0.0000E+00	0.2600E+02	0.0000E+00	0.2700E+02	0.0000E+00	0.2800E+02	0.0000E+00
0.2900E+02	0.0000E+00	0.3000E+02	0.0000E+00	0.3100E+02	0.0000E+00		

TIME VS CONCENTRATION AT NODE NUMBER 85

0.1000E+01	0.0000E+00	0.2000E+01	0.0000E+00	0.3000E+01	0.0000E+00	0.4000E+01	0.0000E+00
0.5000E+01	0.0000E+00	0.6000E+01	0.0000E+00	0.7000E+01	0.0000E+00	0.8000E+01	0.0000E+00
0.9000E+01	0.0000E+00	0.1000E+02	0.0000E+00	0.1100E+02	0.0000E+00	0.1200E+02	0.0000E+00
0.1300E+02	0.0000E+00	0.1400E+02	0.0000E+00	0.1500E+02	0.0000E+00	0.1600E+02	0.0000E+00
0.1700E+02	0.0000E+00	0.1800E+02	0.0000E+00	0.1900E+02	0.0000E+00	0.2000E+02	0.0000E+00
0.2100E+02	0.0000E+00	0.2200E+02	0.0000E+00	0.2300E+02	0.0000E+00	0.2400E+02	0.0000E+00
0.2500E+02	0.0000E+00	0.2600E+02	0.0000E+00	0.2700E+02	0.0000E+00	0.2800E+02	0.0000E+00
0.2900E+02	0.0000E+00	0.3000E+02	0.0000E+00	0.3100E+02	0.0000E+00		

Transport simulation from 1 Dec 5 to 31 Dec 5

MASS TRANSPORT BALANCE, CHEMICAL 2

NOTE: These "net" values are only for last day of time step
Net dispersive flux = -0.1622E-26
Net advective flux = 0.1579E-17
Net rate of mass accumulation = -0.2487E-10
Net rate of formation = 0.0000E+00
Net rate of mass decay = 0.2447E-10
MASS BALANCE ERROR = 0.3951E-12
NORMALIZED MASS BALANCE ERROR = 0.8008E-02

NOTE: These "cumulative" values are for the entire time step
Cumulative mass storage = 0.5299E-08
Cumulative mass decay = 0.7096E-09
Cumulative inflow mass = 0.7879E-08
Cumulative outflow mass = 0.1246E-07

ANNUAL SUMMARY OF CUMULATIVE CONCENTRATIONS

NOTE: These "cumulative" values are yearly summaries
Annual cumulative mass storage = 0.2304E-07
Annual cumulative mass decay = 0.3114E-08
Annual cumulative inflow mass = 0.3830E-07
Annual cumulative outflow mass = 0.5818E-07

TIME VS CONCENTRATION AT NODE NUMBER 1

0.1000E+01	0.6964E-09	0.2000E+01	0.6948E-09	0.3000E+01	0.6934E-09	0.4000E+01	0.6991E-09
0.5000E+01	0.7147E-09	0.6000E+01	0.7130E-09	0.7000E+01	0.7116E-09	0.8000E+01	0.7173E-09
0.9000E+01	0.7332E-09	0.1000E+02	0.7315E-09	0.1100E+02	0.7300E-09	0.1200E+02	0.7358E-09
0.1300E+02	0.7519E-09	0.1400E+02	0.7502E-09	0.1500E+02	0.7487E-09	0.1600E+02	0.7544E-09
0.1700E+02	0.7709E-09	0.1800E+02	0.7691E-09	0.1900E+02	0.7676E-09	0.2000E+02	0.7734E-09
0.2100E+02	0.7901E-09	0.2200E+02	0.7883E-09	0.2300E+02	0.7867E-09	0.2400E+02	0.7926E-09
0.2500E+02	0.7909E-09	0.2600E+02	0.7893E-09	0.2700E+02	0.7944E-09	0.2800E+02	0.8114E-09
0.2900E+02	0.8095E-09	0.3000E+02	0.8079E-09	0.3100E+02	0.8063E-09		

TIME VS CONCENTRATION AT NODE NUMBER 11

0.1000E+01	0.6850E-09	0.2000E+01	0.6837E-09	0.3000E+01	0.6824E-09	0.4000E+01	0.6912E-09
0.5000E+01	0.7029E-09	0.6000E+01	0.7017E-09	0.7000E+01	0.7003E-09	0.8000E+01	0.7093E-09
0.9000E+01	0.7212E-09	0.1000E+02	0.7199E-09	0.1100E+02	0.7184E-09	0.1200E+02	0.7276E-09
0.1300E+02	0.7397E-09	0.1400E+02	0.7384E-09	0.1500E+02	0.7369E-09	0.1600E+02	0.7462E-09
0.1700E+02	0.7585E-09	0.1800E+02	0.7571E-09	0.1900E+02	0.7556E-09	0.2000E+02	0.7650E-09
0.2100E+02	0.7775E-09	0.2200E+02	0.7761E-09	0.2300E+02	0.7745E-09	0.2400E+02	0.7840E-09
0.2500E+02	0.7826E-09	0.2600E+02	0.7810E-09	0.2700E+02	0.7878E-09	0.2800E+02	0.7993E-09
0.2900E+02	0.7978E-09	0.3000E+02	0.7962E-09	0.3100E+02	0.7946E-09		

TIME VS CONCENTRATION AT NODE NUMBER 24

0.1000E+01	0.5756E-09	0.2000E+01	0.5745E-09	0.3000E+01	0.5734E-09	0.4000E+01	0.5803E-09
0.5000E+01	0.5876E-09	0.6000E+01	0.5865E-09	0.7000E+01	0.5853E-09	0.8000E+01	0.5930E-09
0.9000E+01	0.6010E-09	0.1000E+02	0.5999E-09	0.1100E+02	0.5987E-09	0.1200E+02	0.6068E-09
0.1300E+02	0.6153E-09	0.1400E+02	0.6142E-09	0.1500E+02	0.6129E-09	0.1600E+02	0.6215E-09
0.1700E+02	0.6303E-09	0.1800E+02	0.6291E-09	0.1900E+02	0.6279E-09	0.2000E+02	0.6367E-09
0.2100E+02	0.6458E-09	0.2200E+02	0.6446E-09	0.2300E+02	0.6433E-09	0.2400E+02	0.6524E-09
0.2500E+02	0.6512E-09	0.2600E+02	0.6499E-09	0.2700E+02	0.6589E-09	0.2800E+02	0.6679E-09
0.2900E+02	0.6667E-09	0.3000E+02	0.6654E-09	0.3100E+02	0.6641E-09		

TIME VS CONCENTRATION AT NODE NUMBER 85

0.1000E+01	0.4669E-09	0.2000E+01	0.4661E-09	0.3000E+01	0.4652E-09	0.4000E+01	0.4726E-09
0.5000E+01	0.4799E-09	0.6000E+01	0.4791E-09	0.7000E+01	0.4781E-09	0.8000E+01	0.4853E-09
0.9000E+01	0.4925E-09	0.1000E+02	0.4916E-09	0.1100E+02	0.4906E-09	0.1200E+02	0.4977E-09
0.1300E+02	0.5049E-09	0.1400E+02	0.5039E-09	0.1500E+02	0.5029E-09	0.1600E+02	0.5100E-09
0.1700E+02	0.5172E-09	0.1800E+02	0.5163E-09	0.1900E+02	0.5152E-09	0.2000E+02	0.5224E-09
0.2100E+02	0.5297E-09	0.2200E+02	0.5288E-09	0.2300E+02	0.5277E-09	0.2400E+02	0.5350E-09
0.2500E+02	0.5340E-09	0.2600E+02	0.5330E-09	0.2700E+02	0.5404E-09	0.2800E+02	0.5479E-09
0.2900E+02	0.5469E-09	0.3000E+02	0.5458E-09	0.3100E+02	0.5448E-09		

Transport simulation from 1 Dec 5 to 31 Dec 5

MASS TRANSPORT BALANCE, CHEMICAL 3

NOTE: These "net" values are only for last day of time step
Net dispersive flux = -0.2737E-19
Net advective flux = 0.1256E-10
Net rate of mass accumulation = -0.2065E-03
Net rate of formation = 0.0000E+00
Net rate of mass decay = 0.2034E-03
MASS BALANCE ERROR = 0.3143E-05
NORMALIZED MASS BALANCE ERROR = 0.7667E-02

NOTE: These "cumulative" values are for the entire time step
Cumulative mass storage = 0.3830E-01
Cumulative mass decay = 0.5692E-02
Cumulative inflow mass = 0.7092E-01
Cumulative outflow mass = 0.1034

ANNUAL SUMMARY OF CUMULATIVE CONCENTRATIONS

NOTE: These "cumulative" values are yearly summaries
Annual cumulative mass storage = 0.1937
Annual cumulative mass decay = 0.2446E-01
Annual cumulative inflow mass = 0.2439
Annual cumulative outflow mass = 0.4127

TIME VS CONCENTRATION AT NODE NUMBER 1

0.1000E+01	0.6487E-02	0.2000E+01	0.6470E-02	0.3000E+01	0.6457E-02	0.4000E+01	0.6457E-02
0.5000E+01	0.6779E-02	0.6000E+01	0.6761E-02	0.7000E+01	0.6748E-02	0.8000E+01	0.6704E-02
0.9000E+01	0.6992E-02	0.1000E+02	0.6974E-02	0.1100E+02	0.6960E-02	0.1200E+02	0.6866E-02
0.1300E+02	0.7108E-02	0.1400E+02	0.7091E-02	0.1500E+02	0.7076E-02	0.1600E+02	0.6928E-02
0.1700E+02	0.7115E-02	0.1800E+02	0.7099E-02	0.1900E+02	0.7085E-02	0.2000E+02	0.6879E-02
0.2100E+02	0.7008E-02	0.2200E+02	0.6993E-02	0.2300E+02	0.6979E-02	0.2400E+02	0.6720E-02
0.2500E+02	0.6710E-02	0.2600E+02	0.6696E-02	0.2700E+02	0.6400E-02	0.2800E+02	0.6436E-02
0.2900E+02	0.6423E-02	0.3000E+02	0.6410E-02	0.3100E+02	0.6397E-02		

TIME VS CONCENTRATION AT NODE NUMBER 11

0.1000E+01	0.6264E-02	0.2000E+01	0.6254E-02	0.3000E+01	0.6242E-02	0.4000E+01	0.6367E-02
0.5000E+01	0.6573E-02	0.6000E+01	0.6562E-02	0.7000E+01	0.6549E-02	0.8000E+01	0.6643E-02
0.9000E+01	0.6814E-02	0.1000E+02	0.6803E-02	0.1100E+02	0.6789E-02	0.1200E+02	0.6842E-02
0.1300E+02	0.6968E-02	0.1400E+02	0.6956E-02	0.1500E+02	0.6942E-02	0.1600E+02	0.6945E-02
0.1700E+02	0.7020E-02	0.1800E+02	0.7006E-02	0.1900E+02	0.6992E-02	0.2000E+02	0.6942E-02
0.2100E+02	0.6960E-02	0.2200E+02	0.6947E-02	0.2300E+02	0.6933E-02	0.2400E+02	0.6829E-02
0.2500E+02	0.6814E-02	0.2600E+02	0.6800E-02	0.2700E+02	0.6588E-02	0.2800E+02	0.6483E-02
0.2900E+02	0.6469E-02	0.3000E+02	0.6456E-02	0.3100E+02	0.6443E-02		

TIME VS CONCENTRATION AT NODE NUMBER 24

0.1000E+01	0.4606E-02	0.2000E+01	0.4598E-02	0.3000E+01	0.4589E-02	0.4000E+01	0.4697E-02
0.5000E+01	0.4815E-02	0.6000E+01	0.4807E-02	0.7000E+01	0.4797E-02	0.8000E+01	0.4920E-02
0.9000E+01	0.5046E-02	0.1000E+02	0.5037E-02	0.1100E+02	0.5027E-02	0.1200E+02	0.5151E-02
0.1300E+02	0.5274E-02	0.1400E+02	0.5265E-02	0.1500E+02	0.5254E-02	0.1600E+02	0.5370E-02
0.1700E+02	0.5479E-02	0.1800E+02	0.5469E-02	0.1900E+02	0.5458E-02	0.2000E+02	0.5556E-02
0.2100E+02	0.5644E-02	0.2200E+02	0.5634E-02	0.2300E+02	0.5623E-02	0.2400E+02	0.5697E-02
0.2500E+02	0.5686E-02	0.2600E+02	0.5675E-02	0.2700E+02	0.5730E-02	0.2800E+02	0.5764E-02
0.2900E+02	0.5753E-02	0.3000E+02	0.5742E-02	0.3100E+02	0.5730E-02		

TIME VS CONCENTRATION AT NODE NUMBER 85

0.1000E+01	0.2943E-02	0.2000E+01	0.2939E-02	0.3000E+01	0.2933E-02	0.4000E+01	0.3057E-02
0.5000E+01	0.3179E-02	0.6000E+01	0.3174E-02	0.7000E+01	0.3168E-02	0.8000E+01	0.3287E-02
0.9000E+01	0.3405E-02	0.1000E+02	0.3400E-02	0.1100E+02	0.3393E-02	0.1200E+02	0.3509E-02
0.1300E+02	0.3625E-02	0.1400E+02	0.3619E-02	0.1500E+02	0.3612E-02	0.1600E+02	0.3727E-02
0.1700E+02	0.3843E-02	0.1800E+02	0.3836E-02	0.1900E+02	0.3829E-02	0.2000E+02	0.3942E-02
0.2100E+02	0.4057E-02	0.2200E+02	0.4050E-02	0.2300E+02	0.4042E-02	0.2400E+02	0.4154E-02
0.2500E+02	0.4147E-02	0.2600E+02	0.4139E-02	0.2700E+02	0.4249E-02	0.2800E+02	0.4357E-02
0.2900E+02	0.4350E-02	0.3000E+02	0.4341E-02	0.3100E+02	0.4333E-02		

Greens Scenario -- 2nd Three Pesticides
(2,4-D, trichlorfon, metribuzin)

```
Flow simulation from  1 Jan  5 to 31 Jan  5
Transport simulation from  1 Jan  5 to 31 Jan  5
Transport simulation from  1 Jan  5 to 31 Jan  5
Transport simulation from  1 Jan  5 to 31 Jan  5
Flow simulation from  1 Feb  5 to 28 Feb  5
Transport simulation from  1 Feb  5 to 28 Feb  5
Transport simulation from  1 Feb  5 to 28 Feb  5
Transport simulation from  1 Feb  5 to 28 Feb  5
Flow simulation from  1 Mar  5 to 31 Mar  5
Transport simulation from  1 Mar  5 to 31 Mar  5
Transport simulation from  1 Mar  5 to 31 Mar  5
Transport simulation from  1 Mar  5 to 31 Mar  5
Flow simulation from  1 Apr  5 to 30 Apr  5
Transport simulation from  1 Apr  5 to 30 Apr  5
Transport simulation from  1 Apr  5 to 30 Apr  5
Transport simulation from  1 Apr  5 to 30 Apr  5
Flow simulation from  1 May  5 to 31 May  5

Transport simulation from  1 May  5 to 31 May  5
Transport simulation from  1 May  5 to 31 May  5
Transport simulation from  1 May  5 to 31 May  5
Flow simulation from  1 Jun  5 to 30 Jun  5
Transport simulation from  1 Jun  5 to 30 Jun  5
Transport simulation from  1 Jun  5 to 30 Jun  5
Transport simulation from  1 Jun  5 to 30 Jun  5
Flow simulation from  1 Jul  5 to 31 Jul  5
Transport simulation from  1 Jul  5 to 31 Jul  5
Transport simulation from  1 Jul  5 to 31 Jul  5
Transport simulation from  1 Jul  5 to 31 Jul  5
Flow simulation from  1 Aug  5 to 31 Aug  5
Transport simulation from  1 Aug  5 to 31 Aug  5
Transport simulation from  1 Aug  5 to 31 Aug  5
Transport simulation from  1 Aug  5 to 31 Aug  5
Flow simulation from  1 Sep  5 to 30 Sep  5
Transport simulation from  1 Sep  5 to 30 Sep  5
Transport simulation from  1 Sep  5 to 30 Sep  5
```

```
*****************************************************************************
*****************************************************************************
Transport simulation from  1 Sep  5 to 30 Sep  5
*****************************************************************************
*****************************************************************************
Flow simulation from  1 Oct  5 to 31 Oct  5
*****************************************************************************
*****************************************************************************
Transport simulation from  1 Oct  5 to 31 Oct  5
*****************************************************************************
*****************************************************************************
Transport simulation from  1 Oct  5 to 31 Oct  5
*****************************************************************************
*****************************************************************************
Transport simulation from  1 Oct  5 to 31 Oct  5
*****************************************************************************
*****************************************************************************
Flow simulation from  1 Nov  5 to 30 Nov  5
*****************************************************************************
*****************************************************************************
Transport simulation from  1 Nov  5 to 30 Nov  5
*****************************************************************************
*****************************************************************************
Transport simulation from  1 Nov  5 to 30 Nov  5
*****************************************************************************
*****************************************************************************
Transport simulation from  1 Nov  5 to 30 Nov  5
*****************************************************************************
*****************************************************************************
Flow simulation from  1 Dec  5 to 31 Dec  5
*****************************************************************************
```

SUMMARY OF VOLUMETRIC FLOW BALANCE OUTPUT

Elapsed simulation time = 0.3100E+02
Current value of time increment = 0.1000E+01

Fluid flux value at first node = 0.1513E-12
Fluid flux value at last node = -0.1069E-09

NOTE: These "net" values are only for last day of time step
Net value of fluid flux = -0.1068E-09
Net rate of volumetric storage = -0.1158E-09
FLOW BALANCE ERROR = 0.9050E-11
NORMALIZED BALANCE ERROR = 0.4060E-01

NOTE: These "cumulative" values are for the entire time step
Cumulative volumetric storage = -0.1252E-02
Cumulative inflow volume = 0.5497E+03
Cumulative outflow volume = -0.5486E+03

TIME VS HEAD AT NODE NUMBER 1

0.1000E+01	-0.3446E+03	0.2000E+01	-0.3540E+03	0.3000E+01	-0.3540E+03	0.4000E+01	-0.3446E+03
0.5000E+01	-0.3446E+03	0.6000E+01	-0.3540E+03	0.7000E+01	-0.3540E+03	0.8000E+01	-0.3446E+03
0.9000E+01	-0.3446E+03	0.1000E+02	-0.3540E+03	0.1100E+02	-0.3540E+03	0.1200E+02	-0.3446E+03
0.1300E+02	-0.3446E+03	0.1400E+02	-0.3540E+03	0.1500E+02	-0.3540E+03	0.1600E+02	-0.3446E+03
0.1700E+02	-0.3446E+03	0.1800E+02	-0.3540E+03	0.1900E+02	-0.3540E+03	0.2000E+02	-0.3446E+03
0.2100E+02	-0.3446E+03	0.2200E+02	-0.3540E+03	0.2300E+02	-0.3540E+03	0.2400E+02	-0.3446E+03
0.2500E+02	-0.3540E+03	0.2600E+02	-0.3540E+03	0.2700E+02	-0.3446E+03	0.2800E+02	-0.3446E+03
0.2900E+02	-0.3540E+03	0.3000E+02	-0.3540E+03	0.3100E+02	-0.3540E+03		

TIME VS HEAD AT NODE NUMBER 11

0.1000E+01	-0.3372E+03	0.2000E+01	-0.3440E+03	0.3000E+01	-0.3440E+03	0.4000E+01	-0.3372E+03
0.5000E+01	-0.3372E+03	0.6000E+01	-0.3440E+03	0.7000E+01	-0.3440E+03	0.8000E+01	-0.3372E+03
0.9000E+01	-0.3372E+03	0.1000E+02	-0.3440E+03	0.1100E+02	-0.3440E+03	0.1200E+02	-0.3372E+03
0.1300E+02	-0.3372E+03	0.1400E+02	-0.3440E+03	0.1500E+02	-0.3440E+03	0.1600E+02	-0.3372E+03
0.1700E+02	-0.3372E+03	0.1800E+02	-0.3440E+03	0.1900E+02	-0.3440E+03	0.2000E+02	-0.3372E+03
0.2100E+02	-0.3372E+03	0.2200E+02	-0.3440E+03	0.2300E+02	-0.3440E+03	0.2400E+02	-0.3372E+03
0.2500E+02	-0.3440E+03	0.2600E+02	-0.3440E+03	0.2700E+02	-0.3372E+03	0.2800E+02	-0.3372E+03
0.2900E+02	-0.3440E+03	0.3000E+02	-0.3440E+03	0.3100E+02	-0.3440E+03		

TIME VS HEAD AT NODE NUMBER 24

0.1000E+01	-0.2991E+03	0.2000E+01	-0.3050E+03	0.3000E+01	-0.3050E+03	0.4000E+01	-0.2991E+03
0.5000E+01	-0.2991E+03	0.6000E+01	-0.3050E+03	0.7000E+01	-0.3050E+03	0.8000E+01	-0.2991E+03
0.9000E+01	-0.2991E+03	0.1000E+02	-0.3050E+03	0.1100E+02	-0.3050E+03	0.1200E+02	-0.2991E+03
0.1300E+02	-0.2991E+03	0.1400E+02	-0.3050E+03	0.1500E+02	-0.3050E+03	0.1600E+02	-0.2991E+03
0.1700E+02	-0.2991E+03	0.1800E+02	-0.3050E+03	0.1900E+02	-0.3050E+03	0.2000E+02	-0.2991E+03
0.2100E+02	-0.2991E+03	0.2200E+02	-0.3050E+03	0.2300E+02	-0.3050E+03	0.2400E+02	-0.2991E+03
0.2500E+02	-0.3050E+03	0.2600E+02	-0.3050E+03	0.2700E+02	-0.2991E+03	0.2800E+02	-0.2991E+03
0.2900E+02	-0.3050E+03	0.3000E+02	-0.3050E+03	0.3100E+02	-0.3050E+03		

TIME VS HEAD AT NODE NUMBER 85

0.1000E+01	0.0000E+00	0.2000E+01	0.0000E+00	0.3000E+01	0.0000E+00	0.4000E+01	0.0000E+00
0.5000E+01	0.0000E+00	0.6000E+01	0.0000E+00	0.7000E+01	0.0000E+00	0.8000E+01	0.0000E+00
0.9000E+01	0.0000E+00	0.1000E+02	0.0000E+00	0.1100E+02	0.0000E+00	0.1200E+02	0.0000E+00
0.1300E+02	0.0000E+00	0.1400E+02	0.0000E+00	0.1500E+02	0.0000E+00	0.1600E+02	0.0000E+00
0.1700E+02	0.0000E+00	0.1800E+02	0.0000E+00	0.1900E+02	0.0000E+00	0.2000E+02	0.0000E+00
0.2100E+02	0.0000E+00	0.2200E+02	0.0000E+00	0.2300E+02	0.0000E+00	0.2400E+02	0.0000E+00
0.2500E+02	0.0000E+00	0.2600E+02	0.0000E+00	0.2700E+02	0.0000E+00	0.2800E+02	0.0000E+00
0.2900E+02	0.0000E+00	0.3000E+02	0.0000E+00	0.3100E+02	0.0000E+00		

```
******************************************************************************
Transport simulation from  1 Dec  5 to 31 Dec  5
******************************************************************************
```

MASS TRANSPORT BALANCE, CHEMICAL 1

```
NOTE: These "net" values are only for last day of time step
Net dispersive flux =              -0.1291E-21
Net advective  flux =               0.3931E-12
Net rate of mass accumulation =    -0.3664E-05
Net rate of formation =             0.0000E+00
Net rate of mass decay =            0.3565E-05
MASS BALANCE ERROR =                0.9885E-07
NORMALIZED MASS BALANCE ERROR =     0.1368E-01

NOTE: These "cumulative" values are for the entire time step
Cumulative mass storage =           0.2118E-02
Cumulative mass decay =             0.1634E-03
Cumulative inflow mass =            0.3914E-05
Cumulative outflow mass =           0.1954E-02
```

ANNUAL SUMMARY OF CUMULATIVE CONCENTRATIONS

```
NOTE: These "cumulative" values are yearly summaries
Annual cumulative mass storage =        0.1990E-01
Annual cumulative mass decay =          0.2072E-02
Annual cumulative inflow mass =         0.2116E-01
Annual cumulative outflow mass =        0.3894E-01
```

TIME VS CONCENTRATION AT NODE NUMBER 1

0.1000E+01	0.1407E-05	0.2000E+01	0.1409E-05	0.3000E+01	0.1406E-05	0.4000E+01	0.9962E-06
0.5000E+01	0.8016E-06	0.6000E+01	0.8029E-06	0.7000E+01	0.8013E-06	0.8000E+01	0.5623E-06
0.9000E+01	0.4482E-06	0.1000E+02	0.4490E-06	0.1100E+02	0.4481E-06	0.1200E+02	0.3115E-06
0.1300E+02	0.2461E-06	0.1400E+02	0.2466E-06	0.1500E+02	0.2461E-06	0.1600E+02	0.1696E-06
0.1700E+02	0.1328E-06	0.1800E+02	0.1331E-06	0.1900E+02	0.1328E-06	0.2000E+02	0.9072E-07
0.2100E+02	0.7044E-07	0.2200E+02	0.7060E-07	0.2300E+02	0.7046E-07	0.2400E+02	0.4774E-07
0.2500E+02	0.4795E-07	0.2600E+02	0.4786E-07	0.2700E+02	0.3195E-07	0.2800E+02	0.2449E-07
0.2900E+02	0.2455E-07	0.3000E+02	0.2450E-07	0.3100E+02	0.2445E-07		

TIME VS CONCENTRATION AT NODE NUMBER 11

0.1000E+01	0.1818E-05	0.2000E+01	0.1809E-05	0.3000E+01	0.1806E-05	0.4000E+01	0.1361E-05
0.5000E+01	0.1043E-05	0.6000E+01	0.1038E-05	0.7000E+01	0.1036E-05	0.8000E+01	0.7758E-06
0.9000E+01	0.5898E-06	0.1000E+02	0.5868E-06	0.1100E+02	0.5856E-06	0.1200E+02	0.4353E-06
0.1300E+02	0.3282E-06	0.1400E+02	0.3265E-06	0.1500E+02	0.3258E-06	0.1600E+02	0.2403E-06
0.1700E+02	0.1797E-06	0.1800E+02	0.1788E-06	0.1900E+02	0.1784E-06	0.2000E+02	0.1306E-06
0.2100E+02	0.9701E-07	0.2200E+02	0.9648E-07	0.2300E+02	0.9629E-07	0.2400E+02	0.7009E-07
0.2500E+02	0.6968E-07	0.2600E+02	0.6954E-07	0.2700E+02	0.4923E-07	0.2800E+02	0.3564E-07
0.2900E+02	0.3543E-07	0.3000E+02	0.3536E-07	0.3100E+02	0.3529E-07		

TIME VS CONCENTRATION AT NODE NUMBER 24

0.1000E+01	0.1198E-03	0.2000E+01	0.1195E-03	0.3000E+01	0.1192E-03	0.4000E+01	0.1119E-03
0.5000E+01	0.1051E-03	0.6000E+01	0.1049E-03	0.7000E+01	0.1047E-03	0.8000E+01	0.9846E-04
0.9000E+01	0.9268E-04	0.1000E+02	0.9244E-04	0.1100E+02	0.9225E-04	0.1200E+02	0.8692E-04
0.1300E+02	0.8193E-04	0.1400E+02	0.8171E-04	0.1500E+02	0.8155E-04	0.1600E+02	0.7693E-04
0.1700E+02	0.7257E-04	0.1800E+02	0.7239E-04	0.1900E+02	0.7224E-04	0.2000E+02	0.6820E-04
0.2100E+02	0.6439E-04	0.2200E+02	0.6422E-04	0.2300E+02	0.6409E-04	0.2400E+02	0.6054E-04
0.2500E+02	0.6039E-04	0.2600E+02	0.6027E-04	0.2700E+02	0.5694E-04	0.2800E+02	0.5379E-04
0.2900E+02	0.5366E-04	0.3000E+02	0.5355E-04	0.3100E+02	0.5344E-04		

TIME VS CONCENTRATION AT NODE NUMBER 85

0.1000E+01	0.2817E-03	0.2000E+01	0.2810E-03	0.3000E+01	0.2805E-03	0.4000E+01	0.2671E-03
0.5000E+01	0.2539E-03	0.6000E+01	0.2533E-03	0.7000E+01	0.2528E-03	0.8000E+01	0.2403E-03
0.9000E+01	0.2281E-03	0.1000E+02	0.2275E-03	0.1100E+02	0.2270E-03	0.1200E+02	0.2155E-03
0.1300E+02	0.2043E-03	0.1400E+02	0.2038E-03	0.1500E+02	0.2034E-03	0.1600E+02	0.1929E-03
0.1700E+02	0.1828E-03	0.1800E+02	0.1823E-03	0.1900E+02	0.1819E-03	0.2000E+02	0.1724E-03
0.2100E+02	0.1632E-03	0.2200E+02	0.1628E-03	0.2300E+02	0.1625E-03	0.2400E+02	0.1539E-03
0.2500E+02	0.1535E-03	0.2600E+02	0.1532E-03	0.2700E+02	0.1450E-03	0.2800E+02	0.1372E-03
0.2900E+02	0.1369E-03	0.3000E+02	0.1366E-03	0.3100E+02	0.1363E-03		

```
******************************************************************************
Transport simulation from  1 Dec  5 to 31 Dec  5
******************************************************************************
```

MASS TRANSPORT BALANCE, CHEMICAL 2

```
NOTE: These "net" values are only for last day of time step
Net dispersive flux =               0.3552E-23
Net advective  flux =               0.6398E-15
Net rate of mass accumulation =    -0.7878E-08
Net rate of formation =             0.0000E+00
Net rate of mass decay =            0.7717E-08
MASS BALANCE ERROR =                0.1605E-09
NORMALIZED MASS BALANCE ERROR =     0.1029E-01
```

NOTE: These "cumulative" values are for the entire time step
Cumulative mass storage = 0.2637E-05
Cumulative mass decay = 0.2758E-06
Cumulative inflow mass = 0.1476E-05
Cumulative outflow mass = 0.3832E-05

ANNUAL SUMMARY OF CUMULATIVE CONCENTRATIONS

NOTE: These "cumulative" values are yearly summaries
Annual cumulative mass storage = 0.2659E-04
Annual cumulative mass decay = 0.3650E-05
Annual cumulative inflow mass = 0.3149E-04
Annual cumulative outflow mass = 0.5438E-04

TIME VS CONCENTRATION AT NODE NUMBER 1

0.1000E+01	0.1515E-06	0.2000E+01	0.1510E-06	0.3000E+01	0.1507E-06	0.4000E+01	0.1343E-06
0.5000E+01	0.1481E-06	0.6000E+01	0.1476E-06	0.7000E+01	0.1473E-06	0.8000E+01	0.1319E-06
0.9000E+01	0.1462E-06	0.1000E+02	0.1458E-06	0.1100E+02	0.1455E-06	0.1200E+02	0.1311E-06
0.1300E+02	0.1464E-06	0.1400E+02	0.1459E-06	0.1500E+02	0.1456E-06	0.1600E+02	0.1322E-06
0.1700E+02	0.1488E-06	0.1800E+02	0.1483E-06	0.1900E+02	0.1480E-06	0.2000E+02	0.1354E-06
0.2100E+02	0.1537E-06	0.2200E+02	0.1531E-06	0.2300E+02	0.1528E-06	0.2400E+02	0.1408E-06
0.2500E+02	0.1407E-06	0.2600E+02	0.1404E-06	0.2700E+02	0.1280E-06	0.2800E+02	0.1462E-06
0.2900E+02	0.1457E-06	0.3000E+02	0.1454E-06	0.3100E+02	0.1451E-06		

TIME VS CONCENTRATION AT NODE NUMBER 11

0.1000E+01	0.1477E-06	0.2000E+01	0.1474E-06	0.3000E+01	0.1471E-06	0.4000E+01	0.1412E-06
0.5000E+01	0.1436E-06	0.6000E+01	0.1433E-06	0.7000E+01	0.1431E-06	0.8000E+01	0.1380E-06
0.9000E+01	0.1412E-06	0.1000E+02	0.1409E-06	0.1100E+02	0.1406E-06	0.1200E+02	0.1365E-06
0.1300E+02	0.1405E-06	0.1400E+02	0.1403E-06	0.1500E+02	0.1400E-06	0.1600E+02	0.1368E-06
0.1700E+02	0.1419E-06	0.1800E+02	0.1417E-06	0.1900E+02	0.1414E-06	0.2000E+02	0.1392E-06
0.2100E+02	0.1457E-06	0.2200E+02	0.1454E-06	0.2300E+02	0.1451E-06	0.2400E+02	0.1439E-06
0.2500E+02	0.1436E-06	0.2600E+02	0.1433E-06	0.2700E+02	0.1355E-06	0.2800E+02	0.1396E-06
0.2900E+02	0.1394E-06	0.3000E+02	0.1391E-06	0.3100E+02	0.1388E-06		

TIME VS CONCENTRATION AT NODE NUMBER 24

0.1000E+01	0.2545E-06	0.2000E+01	0.2538E-06	0.3000E+01	0.2533E-06	0.4000E+01	0.2401E-06
0.5000E+01	0.2292E-06	0.6000E+01	0.2286E-06	0.7000E+01	0.2281E-06	0.8000E+01	0.2191E-06
0.9000E+01	0.2114E-06	0.1000E+02	0.2109E-06	0.1100E+02	0.2105E-06	0.1200E+02	0.2040E-06
0.1300E+02	0.1984E-06	0.1400E+02	0.1979E-06	0.1500E+02	0.1976E-06	0.1600E+02	0.1928E-06
0.1700E+02	0.1887E-06	0.1000E+02	0.1882E-06	0.1900E+02	0.1879E-06	0.2000E+02	0.1844E-06
0.2100E+02	0.1815E-06	0.2200E+02	0.1811E-06	0.2300E+02	0.1807E-06	0.2400E+02	0.1783E-06
0.2500E+02	0.1779E-06	0.2600E+02	0.1776E-06	0.2700E+02	0.1752E-06	0.2800E+02	0.1729E-06
0.2900E+02	0.1725E-06	0.3000E+02	0.1722E-06	0.3100E+02	0.1719E-06		

TIME VS CONCENTRATION AT NODE NUMBER 85

0.1000E+01	0.2679E-06	0.2000E+01	0.2674E-06	0.3000E+01	0.2668E-06	0.4000E+01	0.2694E-06
0.5000E+01	0.2702E-06	0.6000E+01	0.2697E-06	0.7000E+01	0.2692E-06	0.8000E+01	0.2685E-06
0.9000E+01	0.2667E-06	0.1000E+02	0.2661E-06	0.1100E+02	0.2656E-06	0.1200E+02	0.2628E-06
0.1300E+02	0.2592E-06	0.1400E+02	0.2586E-06	0.1500E+02	0.2581E-06	0.1600E+02	0.2540E-06
0.1700E+02	0.2495E-06	0.1800E+02	0.2490E-06	0.1900E+02	0.2485E-06	0.2000E+02	0.2438E-06
0.2100E+02	0.2390E-06	0.2200E+02	0.2384E-06	0.2300E+02	0.2380E-06	0.2400E+02	0.2331E-06
0.2500E+02	0.2326E-06	0.2600E+02	0.2322E-06	0.2700E+02	0.2274E-06	0.2800E+02	0.2228E-06
0.2900E+02	0.2223E-06	0.3000E+02	0.2218E-06	0.3100E+02	0.2214E-06		

Transport simulation from 1 Dec 5 to 31 Dec 5

MASS TRANSPORT BALANCE, CHEMICAL 3

NOTE: These "net" values are only for last day of time step
Net dispersive flux = -0.4456E-22
Net advective flux = 0.8429E-13
Net rate of mass accumulation = -0.1274E-05
Net rate of formation = 0.0000E+00
Net rate of mass decay = 0.1252E-05
MASS BALANCE ERROR = 0.2111E-07
NORMALIZED MASS BALANCE ERROR = 0.8358E-02

NOTE: These "cumulative" values are for the entire time step
Cumulative mass storage = 0.2897E-03
Cumulative mass decay = 0.3760E-04
Cumulative inflow mass = 0.3844E-03
Cumulative outflow mass = 0.6359E-03

ANNUAL SUMMARY OF CUMULATIVE CONCENTRATIONS

NOTE: these "cumulative" values are yearly summaries

Annual cumulative mass storage =	0.3103E-02
Annual cumulative mass decay =	0.3712E-03
Annual cumulative inflow mass =	0.3182E-02
Annual cumulative outflow mass =	0.5907E-02

TIME VS CONCENTRATION AT NODE NUMBER 1

0.1000E+01	0.3609E-04	0.2000E+01	0.3600E-04	0.3000E+01	0.3593E-04	0.4000E+01	0.3569E-04
0.5000E+01	0.3670E-04	0.6000E+01	0.3661E-04	0.7000E+01	0.3654E-04	0.8000E+01	0.3622E-04
0.9000E+01	0.3716E-04	0.1000E+02	0.3708E-04	0.1100E+02	0.3700E-04	0.1200E+02	0.3660E-04
0.1300E+02	0.3748E-04	0.1400E+02	0.3740E-04	0.1500E+02	0.3732E-04	0.1600E+02	0.3684E-04
0.1700E+02	0.3765E-04	0.1800E+02	0.3756E-04	0.1900E+02	0.3748E-04	0.2000E+02	0.3692E-04
0.2100E+02	0.3765E-04	0.2200E+02	0.3756E-04	0.2300E+02	0.3749E-04	0.2400E+02	0.3685E-04
0.2500E+02	0.3678E-04	0.2600E+02	0.3671E-04	0.2700E+02	0.3596E-04	0.2800E+02	0.3654E-04
0.2900E+02	0.3646E-04	0.3000E+02	0.3638E-04	0.3100E+02	0.3631E-04		

TIME VS CONCENTRATION AT NODE NUMBER 11

0.1000E+01	0.3545E-04	0.2000E+01	0.3539E-04	0.3000E+01	0.3531E-04	0.4000E+01	0.3554E-04
0.5000E+01	0.3609E-04	0.6000E+01	0.3602E-04	0.7000E+01	0.3595E-04	0.8000E+01	0.3612E-04
0.9000E+01	0.3660E-04	0.1000E+02	0.3654E-04	0.1100E+02	0.3646E-04	0.1200E+02	0.3656E-04
0.1300E+02	0.3698E-04	0.1400E+02	0.3691E-04	0.1500E+02	0.3684E-04	0.1600E+02	0.3686E-04
0.1700E+02	0.3721E-04	0.1800E+02	0.3714E-04	0.1900E+02	0.3706E-04	0.2000E+02	0.3701E-04
0.2100E+02	0.3727E-04	0.2200E+02	0.3720E-04	0.2300E+02	0.3713E-04	0.2400E+02	0.3700E-04
0.2500E+02	0.3693E-04	0.2600E+02	0.3685E-04	0.2700E+02	0.3637E-04	0.2800E+02	0.3636E-04
0.2900E+02	0.3629E-04	0.3000E+02	0.3622E-04	0.3100E+02	0.3614E-04		

TIME VS CONCENTRATION AT NODE NUMBER 24

0.1000E+01	0.3119E-04	0.2000E+01	0.3113E-04	0.3000E+01	0.3107E-04	0.4000E+01	0.3126E-04
0.5000E+01	0.3149E-04	0.6000E+01	0.3143E-04	0.7000E+01	0.3137E-04	0.8000E+01	0.3162E-04
0.9000E+01	0.3190E-04	0.1000E+02	0.3184E-04	0.1100E+02	0.3177E-04	0.1200E+02	0.3205E-04
0.1300E+02	0.3234E-04	0.1400E+02	0.3227E-04	0.1500E+02	0.3221E-04	0.1600E+02	0.3248E-04
0.1700E+02	0.3275E-04	0.1800E+02	0.3269E-04	0.1900E+02	0.3263E-04	0.2000E+02	0.3288E-04
0.2100E+02	0.3313E-04	0.2200E+02	0.3306E-04	0.2300E+02	0.3300E-04	0.2400E+02	0.3322E-04
0.2500E+02	0.3316E-04	0.2600E+02	0.3309E-04	0.2700E+02	0.3327E-04	0.2800E+02	0.3342E-04
0.2900E+02	0.3335E-04	0.3000E+02	0.3329E-04	0.3100E+02	0.3322E-04		

TIME VS CONCENTRATION AT NODE NUMBER 85

0.1000E+01	0.2596E-04	0.2000E+01	0.2591E-04	0.3000E+01	0.2586E-04	0.4000E+01	0.2625E-04
0.5000E+01	0.2662E-04	0.6000E+01	0.2657E-04	0.7000E+01	0.2651E-04	0.8000E+01	0.2686E-04
0.9000E+01	0.2719E-04	0.1000E+02	0.2714E-04	0.1100E+02	0.2709E-04	0.1200E+02	0.2741E-04
0.1300E+02	0.2772E-04	0.1400E+02	0.2767E-04	0.1500E+02	0.2761E-04	0.1600E+02	0.2791E-04
0.1700E+02	0.2821E-04	0.1800E+02	0.2815E-04	0.1900E+02	0.2810E-04	0.2000E+02	0.2839E-04
0.2100E+02	0.2867E-04	0.2200E+02	0.2862E-04	0.2300E+02	0.2856E-04	0.2400E+02	0.2884E-04
0.2500E+02	0.2879E-04	0.2600E+02	0.2873E-04	0.2700E+02	0.2901E-04	0.2800E+02	0.2928E-04
0.2900E+02	0.2923E-04	0.3000E+02	0.2917E-04	0.3100E+02	0.2911E-04		

Fairways Scenario -- 1st Three Pesticides
(chlorpyrifos, bensulide, metalaxyl)

```
**********************************************************************
Flow simulation from  1 Jan  5 to 31 Jan  5
**********************************************************************
**********************************************************************
Transport simulation from  1 Jan  5 to 31 Jan  5
**********************************************************************
**********************************************************************
Transport simulation from  1 Jan  5 to 31 Jan  5
**********************************************************************
**********************************************************************
Transport simulation from  1 Jan  5 to 31 Jan  5
**********************************************************************
**********************************************************************
Flow simulation from  1 Feb  5 to 28 Feb  5
**********************************************************************
**********************************************************************
Transport simulation from  1 Feb  5 to 28 Feb  5
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**********************************************************************
Transport simulation from  1 Feb  5 to 28 Feb  5
**********************************************************************
**********************************************************************
Transport simulation from  1 Feb  5 to 28 Feb  5
**********************************************************************
**********************************************************************
Flow simulation from  1 Mar  5 to 31 Mar  5
**********************************************************************
**********************************************************************
Transport simulation from  1 Mar  5 to 31 Mar  5
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**********************************************************************
Transport simulation from  1 Mar  5 to 31 Mar  5
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**********************************************************************
Transport simulation from  1 Mar  5 to 31 Mar  5
**********************************************************************
**********************************************************************
Flow simulation from  1 Apr  5 to 30 Apr  5
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**********************************************************************
Transport simulation from  1 Apr  5 to 30 Apr  5
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**********************************************************************
Transport simulation from  1 Apr  5 to 30 Apr  5
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**********************************************************************
Transport simulation from  1 Apr  5 to 30 Apr  5
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**********************************************************************
Flow simulation from  1 May  5 to 31 May  5
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********************************************************************************
Transport simulation from  1 May  5 to 31 May  5
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********************************************************************************
Transport simulation from  1 May  5 to 31 May  5
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********************************************************************************
Transport simulation from  1 May  5 to 31 May  5
********************************************************************************
********************************************************************************
Flow simulation from  1 Jun  5 to 30 Jun  5
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Transport simulation from  1 Jun  5 to 30 Jun  5
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Transport simulation from  1 Jun  5 to 30 Jun  5
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Transport simulation from  1 Jun  5 to 30 Jun  5
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********************************************************************************
Flow simulation from  1 Jul  5 to 31 Jul  5
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Transport simulation from  1 Jul  5 to 31 Jul  5
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Transport simulation from  1 Jul  5 to 31 Jul  5
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********************************************************************************
Transport simulation from  1 Jul  5 to 31 Jul  5
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Flow simulation from  1 Aug  5 to 31 Aug  5
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Transport simulation from  1 Aug  5 to 31 Aug  5
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Transport simulation from  1 Aug  5 to 31 Aug  5
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Transport simulation from  1 Aug  5 to 31 Aug  5
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********************************************************************************
Flow simulation from  1 Sep  5 to 30 Sep  5
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Transport simulation from  1 Sep  5 to 30 Sep  5
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Transport simulation from  1 Sep  5 to 30 Sep  5
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Transport simulation from  1 Sep  5 to 30 Sep  5
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********************************************************************************
Flow simulation from  1 Oct  5 to 31 Oct  5
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********************************************************************************
Transport simulation from  1 Oct  5 to 31 Oct  5
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Transport simulation from  1 Oct  5 to 31 Oct  5
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********************************************************************************
Transport simulation from  1 Oct  5 to 31 Oct  5
********************************************************************************
********************************************************************************
Flow simulation from  1 Nov  5 to 30 Nov  5
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********************************************************************************
Transport simulation from  1 Nov  5 to 30 Nov  5
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********************************************************************************
Transport simulation from  1 Nov  5 to 30 Nov  5
********************************************************************************
********************************************************************************
Transport simulation from  1 Nov  5 to 30 Nov  5
********************************************************************************
********************************************************************************
Flow simulation from  1 Dec  5 to 31 Dec  5
********************************************************************************

        SUMMARY OF VOLUMETRIC FLOW BALANCE OUTPUT
        ****************************************

        Elapsed simulation time =   0.3100E+02
        Current value of time increment =   0.1000E+01

        Fluid flux value at first node = -0.9898E-13
        Fluid flux value at last node = -0.7886E-10

        NOTE: These "net" values are only for last day of time step
        Net value of fluid flux = -0.7896E-10
        Net rate of volumetric storage = -0.7395E-10
        FLOW BALANCE ERROR = -0.5007E-11
        NORMALIZED BALANCE ERROR = -0.3275E-01

        NOTE: These "cumulative" values are for the entire time step
        Cumulative volumetric storage = -0.1233E-02
        Cumulative inflow volume =  0.4325E+03
        Cumulative outflow volume = -0.4319E+03
```

TIME VS HEAD AT NODE NUMBER 1

0.1000E+01	-0.3478E+03	0.2000E+01	-0.3540E+03	0.3000E+01	-0.3540E+03	0.4000E+01	-0.3478E+03
0.5000E+01	-0.3478E+03	0.6000E+01	-0.3540E+03	0.7000E+01	-0.3540E+03	0.8000E+01	-0.3478E+03
0.9000E+01	-0.3478E+03	0.1000E+02	-0.3540E+03	0.1100E+02	-0.3540E+03	0.1200E+02	-0.3478E+03
0.1300E+02	-0.3478E+03	0.1400E+02	-0.3540E+03	0.1500E+02	-0.3540E+03	0.1600E+02	-0.3478E+03
0.1700E+02	-0.3478E+03	0.1800E+02	-0.3540E+03	0.1900E+02	-0.3540E+03	0.2000E+02	-0.3478E+03
0.2100E+02	-0.3478E+03	0.2200E+02	-0.3540E+03	0.2300E+02	-0.3540E+03	0.2400E+02	-0.3478E+03
0.2500E+02	-0.3540E+03	0.2600E+02	-0.3540E+03	0.2700E+02	-0.3478E+03	0.2800E+02	-0.3478E+03
0.2900E+02	-0.3540E+03	0.3000E+02	-0.3540E+03	0.3100E+02	-0.3540E+03		

TIME VS HEAD AT NODE NUMBER 11

0.1000E+01	-0.3395E+03	0.2000E+01	-0.3440E+03	0.3000E+01	-0.3440E+03	0.4000E+01	-0.3395E+03
0.5000E+01	-0.3395E+03	0.6000E+01	-0.3440E+03	0.7000E+01	-0.3440E+03	0.8000E+01	-0.3395E+03
0.9000E+01	-0.3395E+03	0.1000E+02	-0.3440E+03	0.1100E+02	-0.3440E+03	0.1200E+02	-0.3395E+03
0.1300E+02	-0.3395E+03	0.1400E+02	-0.3440E+03	0.1500E+02	-0.3440E+03	0.1600E+02	-0.3395E+03
0.1700E+02	-0.3395E+03	0.1800E+02	-0.3440E+03	0.1900E+02	-0.3440E+03	0.2000E+02	-0.3395E+03
0.2100E+02	-0.3395E+03	0.2200E+02	-0.3440E+03	0.2300E+02	-0.3440E+03	0.2400E+02	-0.3395E+03
0.2500E+02	-0.3440E+03	0.2600E+02	-0.3440E+03	0.2700E+02	-0.3395E+03	0.2800E+02	-0.3395E+03
0.2900E+02	-0.3440E+03	0.3000E+02	-0.3440E+03	0.3100E+02	-0.3440E+03		

TIME VS HEAD AT NODE NUMBER 24

0.1000E+01	-0.3011E+03	0.2000E+01	-0.3050E+03	0.3000E+01	-0.3050E+03	0.4000E+01	-0.3011E+03
0.5000E+01	-0.3011E+03	0.6000E+01	-0.3050E+03	0.7000E+01	-0.3050E+03	0.8000E+01	-0.3011E+03
0.9000E+01	-0.3011E+03	0.1000E+02	-0.3050E+03	0.1100E+02	-0.3050E+03	0.1200E+02	-0.3011E+03
0.1300E+02	-0.3011E+03	0.1400E+02	-0.3050E+03	0.1500E+02	-0.3050E+03	0.1600E+02	-0.3011E+03
0.1700E+02	-0.3011E+03	0.1800E+02	-0.3050E+03	0.1900E+02	-0.3050E+03	0.2000E+02	-0.3011E+03
0.2100E+02	-0.3011E+03	0.2200E+02	-0.3050E+03	0.2300E+02	-0.3050E+03	0.2400E+02	-0.3011E+03
0.2500E+02	-0.3050E+03	0.2600E+02	-0.3050E+03	0.2700E+02	-0.3011E+03	0.2800E+02	-0.3011E+03
0.2900E+02	-0.3050E+03	0.3000E+02	-0.3050E+03	0.3100E+02	-0.3050E+03		

TIME VS HEAD AT NODE NUMBER 85

0.1000E+01	0.0000E+00	0.2000E+01	0.0000E+00	0.3000E+01	0.0000E+00	0.4000E+01	0.0000E+00
0.5000E+01	0.0000E+00	0.6000E+01	0.0000E+00	0.7000E+01	0.0000E+00	0.8000E+01	0.0000E+00
0.9000E+01	0.0000E+00	0.1000E+02	0.0000E+00	0.1100E+02	0.0000E+00	0.1200E+02	0.0000E+00
0.1300E+02	0.0000E+00	0.1400E+02	0.0000E+00	0.1500E+02	0.0000E+00	0.1600E+02	0.0000E+00
0.1700E+02	0.0000E+00	0.1800E+02	0.0000E+00	0.1900E+02	0.0000E+00	0.2000E+02	0.0000E+00
0.2100E+02	0.0000E+00	0.2200E+02	0.0000E+00	0.2300E+02	0.0000E+00	0.2400E+02	0.0000E+00
0.2500E+02	0.0000E+00	0.2600E+02	0.0000E+00	0.2700E+02	0.0000E+00	0.2800E+02	0.0000E+00
0.2900E+02	0.0000E+00	0.3000E+02	0.0000E+00	0.3100E+02	0.0000E+00		

Transport simulation from 1 Dec 5 to 31 Dec 5

MASS TRANSPORT BALANCE, CHEMICAL 1

NOTE: These "net" values are only for last day of time step
Net dispersive flux = 0.0000E+00
Net advective flux = 0.0000E+00
Net rate of mass accumulation = 0.000UE+00
Net rate of formation = 0.0000E+00
Net rate of mass decay = 0.0000E+00
MASS BALANCE ERROR = 0.0000E+00
NORMALIZED MASS BALANCE ERROR = 0.0000E+00

NOTE: These "cumulative" values are for the entire time step
Cumulative mass storage = 0.0000E+00
Cumulative mass decay = 0.0000E+00
Cumulative inflow mass = 0.0000E+00
Cumulative outflow mass = 0.0000E+00

ANNUAL SUMMARY OF CUMULATIVE CONCENTRATIONS

NOTE: These "cumulative" values are yearly summaries
Annual cumulative mass storage = 0.0000E+00
Annual cumulative mass decay = 0.0000E+00
Annual cumulative inflow mass = 0.0000E+00
Annual cumulative outflow mass = 0.0000E+00

TIME VS CONCENTRATION AT NODE NUMBER 1

0.1000E+01	0.0000E+00	0.2000E+01	0.0000E+00	0.3000E+01	0.0000E+00	0.4000E+01	0.0000E+00
0.5000E+01	0.0000E+00	0.6000E+01	0.0000E+00	0.7000E+01	0.0000E+00	0.8000E+01	0.0000E+00
0.9000E+01	0.0000E+00	0.1000E+02	0.0000E+00	0.1100E+02	0.0000E+00	0.1200E+02	0.0000E+00
0.1300E+02	0.0000E+00	0.1400E+02	0.0000E+00	0.1500E+02	0.0000E+00	0.1600E+02	0.0000E+00
0.1700E+02	0.0000E+00	0.1800E+02	0.0000E+00	0.1900E+02	0.0000E+00	0.2000E+02	0.0000E+00
0.2100E+02	0.0000E+00	0.2200E+02	0.0000E+00	0.2300E+02	0.0000E+00	0.2400E+02	0.0000E+00
0.2500E+02	0.0000E+00	0.2600E+02	0.0000E+00	0.2700E+02	0.0000E+00	0.2800E+02	0.0000E+00
0.2900E+02	0.0000E+00	0.3000E+02	0.0000E+00	0.3100E+02	0.0000E+00		

TIME VS CONCENTRATION AT NODE NUMBER 11

0.1000E+01	0.0000E+00	0.2000E+01	0.0000E+00	0.3000E+01	0.0000E+00	0.4000E+01	0.0000E+00
0.5000E+01	0.0000E+00	0.6000E+01	0.0000E+00	0.7000E+01	0.0000E+00	0.8000E+01	0.0000E+00
0.9000E+01	0.0000E+00	0.1000E+02	0.0000E+00	0.1100E+02	0.0000E+00	0.1200E+02	0.0000E+00
0.1300E+02	0.0000E+00	0.1400E+02	0.0000E+00	0.1500E+02	0.0000E+00	0.1600E+02	0.0000E+00
0.1700E+02	0.0000E+00	0.1800E+02	0.0000E+00	0.1900E+02	0.0000E+00	0.2000E+02	0.0000E+00
0.2100E+02	0.0000E+00	0.2200E+02	0.0000E+00	0.2300E+02	0.0000E+00	0.2400E+02	0.0000E+00
0.2500E+02	0.0000E+00	0.2600E+02	0.0000E+00	0.2700E+02	0.0000E+00	0.2800E+02	0.0000E+00
0.2900E+02	0.0000E+00	0.3000E+02	0.0000E+00	0.3100E+02	0.0000E+00		

TIME VS CONCENTRATION AT NODE NUMBER 24

0.1000E+01	0.0000E+00	0.2000E+01	0.0000E+00	0.3000E+01	0.0000E+00	0.4000E+01	0.0000E+00
0.5000E+01	0.0000E+00	0.6000E+01	0.0000E+00	0.7000E+01	0.0000E+00	0.8000E+01	0.0000E+00
0.9000E+01	0.0000E+00	0.1000E+02	0.0000E+00	0.1100E+02	0.0000E+00	0.1200E+02	0.0000E+00
0.1300E+02	0.0000E+00	0.1400E+02	0.0000E+00	0.1500E+02	0.0000E+00	0.1600E+02	0.0000E+00
0.1700E+02	0.0000E+00	0.1800E+02	0.0000E+00	0.1900E+02	0.0000E+00	0.2000E+02	0.0000E+00
0.2100E+02	0.0000E+00	0.2200E+02	0.0000E+00	0.2300E+02	0.0000E+00	0.2400E+02	0.0000E+00
0.2500E+02	0.0000E+00	0.2600E+02	0.0000E+00	0.2700E+02	0.0000E+00	0.2800E+02	0.0000E+00
0.2900E+02	0.0000E+00	0.3000E+02	0.0000E+00	0.3100E+02	0.0000E+00		

TIME VS CONCENTRATION AT NODE NUMBER 85

0.1000E+01	0.0000E+00	0.2000E+01	0.0000E+00	0.3000E+01	0.0000E+00	0.4000E+01	0.0000E+00
0.5000E+01	0.0000E+00	0.6000E+01	0.0000E+00	0.7000E+01	0.0000E+00	0.8000E+01	0.0000E+00
0.9000E+01	0.0000E+00	0.1000E+02	0.0000E+00	0.1100E+02	0.0000E+00	0.1200E+02	0.0000E+00
0.1300E+02	0.0000E+00	0.1400E+02	0.0000E+00	0.1500E+02	0.0000E+00	0.1600E+02	0.0000E+00
0.1700E+02	0.0000E+00	0.1800E+02	0.0000E+00	0.1900E+02	0.0000E+00	0.2000E+02	0.0000E+00
0.2100E+02	0.0000E+00	0.2200E+02	0.0000E+00	0.2300E+02	0.0000E+00	0.2400E+02	0.0000E+00
0.2500E+02	0.0000E+00	0.2600E+02	0.0000E+00	0.2700E+02	0.0000E+00	0.2800E+02	0.0000E+00
0.2900E+02	0.0000E+00	0.3000E+02	0.0000E+00	0.3100E+02	0.0000E+00		

Transport simulation from 1 Dec 5 to 31 Dec 5

MASS TRANSPORT BALANCE, CHEMICAL 2

NOTE: These "net" values are only for last day of time step
Net dispersive flux = 0.1394E-23
Net advective flux = 0.1578E-14
Net rate of mass accumulation = -0.3639E-07
Net rate of formation = 0.0000E+00
Net rate of mass decay = 0.3578E-07
MASS BALANCE ERROR = 0.6124E-09
NORMALIZED MASS BALANCE ERROR = 0.8485E-02

NOTE: These "cumulative" values are for the entire time step
Cumulative mass storage = 0.5659E-05
Cumulative mass decay = 0.1108E-05
Cumulative inflow mass = 0.7013E-05
Cumulative outflow mass = 0.1155E-04

ANNUAL SUMMARY OF CUMULATIVE CONCENTRATIONS

NOTE: These "cumulative" values are yearly summaries
Annual cumulative mass storage = 0.4566E-04
Annual cumulative mass decay = 0.7396E-05
Annual cumulative inflow mass = 0.6782E-04
Annual cumulative outflow mass = 0.1060E-03

TIME VS CONCENTRATION AT NODE NUMBER 1

0.1000E+01	0.1040E-05	0.2000E+01	0.1038E-05	0.3000E+01	0.1036E-05	0.4000E+01	0.1031E-05
0.5000E+01	0.1040E-05	0.6000E+01	0.1038E-05	0.7000E+01	0.1036E-05	0.8000E+01	0.1031E-05
0.9000E+01	0.1039E-05	0.1000E+02	0.1037E-05	0.1100E+02	0.1035E-05	0.1200E+02	0.1030E-05
0.1300E+02	0.1039E-05	0.1400E+02	0.1037E-05	0.1500E+02	0.1035E-05	0.1600E+02	0.1030E-05
0.1700E+02	0.1038E-05	0.1800E+02	0.1036E-05	0.1900E+02	0.1034E-05	0.2000E+02	0.1029E-05
0.2100E+02	0.1038E-05	0.2200E+02	0.1035E-05	0.2300E+02	0.1033E-05	0.2400E+02	0.1028E-05
0.2500E+02	0.1026E-05	0.2600E+02	0.1024E-05	0.2700E+02	0.1018E-05	0.2800E+02	0.1026E-05
0.2900E+02	0.1024E-05	0.3000E+02	0.1022E-05	0.3100E+02	0.1020E-05		

TIME VS CONCENTRATION AT NODE NUMBER 11

0.1000E+01	0.1033E-05	0.2000E+01	0.1031E-05	0.3000E+01	0.1028E-05	0.4000E+01	0.1029E-05
0.5000E+01	0.1032E-05	0.6000E+01	0.1030E-05	0.7000E+01	0.1028E-05	0.8000E+01	0.1029E-05
0.9000E+01	0.1031E-05	0.1000E+02	0.1029E-05	0.1100E+02	0.1027E-05	0.1200E+02	0.1028E-05
0.1300E+02	0.1031E-05	0.1400E+02	0.1029E-05	0.1500E+02	0.1027E-05	0.1600E+02	0.1028E-05
0.1700E+02	0.1030E-05	0.1800E+02	0.1028E-05	0.1900E+02	0.1026E-05	0.2000E+02	0.1027E-05
0.2100E+02	0.1030E-05	0.2200E+02	0.1028E-05	0.2300E+02	0.1026E-05	0.2400E+02	0.1026E-05
0.2500E+02	0.1024E-05	0.2600E+02	0.1022E-05	0.2700E+02	0.1020E-05	0.2800E+02	0.1020E-05
0.2900E+02	0.1018E-05	0.3000E+02	0.1016E-05	0.3100E+02	0.1014E-05		

TIME VS CONCENTRATION AT NODE NUMBER 24

0.1000E+01	0.9513E-06	0.2000E+01	0.9494E-06	0.3000E+01	0.9475E-06	0.4000E+01	0.9477E-06
0.5000E+01	0.9481E-06	0.6000E+01	0.9463E-06	0.7000E+01	0.9444E-06	0.8000E+01	0.9450E-06
0.9000E+01	0.9460E-06	0.1000E+02	0.9442E-06	0.1100E+02	0.9423E-06	0.1200E+02	0.9435E-06
0.1300E+02	0.9449E-06	0.1400E+02	0.9430E-06	0.1500E+02	0.9412E-06	0.1600E+02	0.9427E-06
0.1700E+02	0.9444E-06	0.1800E+02	0.9426E-06	0.1900E+02	0.9407E-06	0.2000E+02	0.9424E-06
0.2100E+02	0.9443E-06	0.2200E+02	0.9425E-06	0.2300E+02	0.9406E-06	0.2400E+02	0.9424E-06
0.2500E+02	0.9406E-06	0.2600E+02	0.9387E-06	0.2700E+02	0.9406E-06	0.2800E+02	0.9424E-06
0.2900E+02	0.9405E-06	0.3000E+02	0.9386E-06	0.3100E+02	0.9368E-06		

TIME VS CONCENTRATION AT NODE NUMBER 85

0.1000E+01	0.8128E-06	0.2000E+01	0.8112E-06	0.3000E+01	0.8096E-06	0.4000E+01	0.8156E-06
0.5000E+01	0.8215E-06	0.6000E+01	0.8199E-06	0.7000E+01	0.8183E-06	0.8000E+01	0.8238E-06
0.9000E+01	0.8291E-06	0.1000E+02	0.8275E-06	0.1100E+02	0.8259E-06	0.1200E+02	0.8308E-06
0.1300E+02	0.8356E-06	0.1400E+02	0.8340E-06	0.1500E+02	0.8323E-06	0.1600E+02	0.8368E-06
0.1700E+02	0.8411E-06	0.1800E+02	0.8394E-06	0.1900E+02	0.8378E-06	0.2000E+02	0.8417E-06
0.2100E+02	0.8456E-06	0.2200E+02	0.8440E-06	0.2300E+02	0.8423E-06	0.2400E+02	0.8459E-06
0.2500E+02	0.8443E-06	0.2600E+02	0.8426E-06	0.2700E+02	0.8460E-06	0.2800E+02	0.8494E-06
0.2900E+02	0.8477E-06	0.3000E+02	0.8460E-06	0.3100E+02	0.8443E-06		

Transport simulation from 1 Dec 5 to 31 Dec 5

MASS TRANSPORT BALANCE, CHEMICAL 3

NOTE: These "net" values are only for last day of time step
Net dispersive flux = 0.1394E-23
Net advective flux = 0.1578E-14
Net rate of mass accumulation = -0.3639E-07
Net rate of formation = 0.0000E+00
Net rate of mass decay = 0.3578E-07
MASS BALANCE ERROR = 0.6124E-09
NORMALIZED MASS BALANCE ERROR = 0.8485E-02

NOTE: These "cumulative" values are for the entire time step
Cumulative mass storage = 0.5659E-05
Cumulative mass decay = 0.1108E-05
Cumulative inflow mass = 0.7013E-05
Cumulative outflow mass = 0.1155E-04

ANNUAL SUMMARY OF CUMULATIVE CONCENTRATIONS

NOTE: These "cumulative" values are yearly summaries
Annual cumulative mass storage = 0.4566E-04
Annual cumulative mass decay = 0.7396E-05
Annual cumulative inflow mass = 0.6782E-04
Annual cumulative outflow mass = 0.1060E-03

TIME VS CONCENTRATION AT NODE NUMBER 1

0.1000E+01	0.1040E-05	0.2000E+01	0.1038E-05	0.3000E+01	0.1036E-05	0.4000E+01	0.1031E-05
0.5000E+01	0.1040E-05	0.6000E+01	0.1038E-05	0.7000E+01	0.1036E-05	0.8000E+01	0.1031E-05
0.9000E+01	0.1039E-05	0.1000E+02	0.1037E-05	0.1100E+02	0.1035E-05	0.1200E+02	0.1030E-05
0.1300E+02	0.1039E-05	0.1400E+02	0.1037E-05	0.1500E+02	0.1035E-05	0.1600E+02	0.1030E-05
0.1700E+02	0.1038E-05	0.1800E+02	0.1036E-05	0.1900E+02	0.1034E-05	0.2000E+02	0.1029E-05
0.2100E+02	0.1038E-05	0.2200E+02	0.1035E-05	0.2300E+02	0.1033E-05	0.2400E+02	0.1028E-05
0.2500E+02	0.1026E-05	0.2600E+02	0.1024E-05	0.2700E+02	0.1018E-05	0.2800E+02	0.1026E-05
0.2900E+02	0.1024E-05	0.3000E+02	0.1022E-05	0.3100E+02	0.1020E-05		

TIME VS CONCENTRATION AT NODE NUMBER 11

0.1000E+01	0.1033E-05	0.2000E+01	0.1031E-05	0.3000E+01	0.1028E-05	0.4000E+01	0.1029E-05
0.5000E+01	0.1032E-05	0.6000E+01	0.1030E-05	0.7000E+01	0.1028E-05	0.8000E+01	0.1029E-05
0.9000E+01	0.1031E-05	0.1000E+02	0.1029E-05	0.1100E+02	0.1027E-05	0.1200E+02	0.1028E-05
0.1300E+02	0.1031E-05	0.1400E+02	0.1029E-05	0.1500E+02	0.1027E-05	0.1600E+02	0.1028E-05
0.1700E+02	0.1030E-05	0.1800E+02	0.1028E-05	0.1900E+02	0.1026E-05	0.2000E+02	0.1027E-05
0.2100E+02	0.1030E-05	0.2200E+02	0.1028E-05	0.2300E+02	0.1026E-05	0.2400E+02	0.1026E-05
0.2500E+02	0.1024E-05	0.2600E+02	0.1022E-05	0.2700E+02	0.1020E-05	0.2800E+02	0.1020E-05
0.2900E+02	0.1018E-05	0.3000E+02	0.1016E-05	0.3100E+02	0.1014E-05		

TIME VS CONCENTRATION AT NODE NUMBER 24

0.1000E+01	0.9513E-06	0.2000E+01	0.9494E-06	0.3000E+01	0.9475E-06	0.4000E+01	0.9477E-06
0.5000E+01	0.9481E-06	0.6000E+01	0.9463E-06	0.7000E+01	0.9444E-06	0.8000E+01	0.9450E-06
0.9000E+01	0.9460E-06	0.1000E+02	0.9442E-06	0.1100E+02	0.9423E-06	0.1200E+02	0.9435E-06
0.1300E+02	0.9449E-06	0.1400E+02	0.9430E-06	0.1500E+02	0.9412E-06	0.1600E+02	0.9427E-06
0.1700E+02	0.9444E-06	0.1800E+02	0.9426E-06	0.1900E+02	0.9407E-06	0.2000E+02	0.9424E-06
0.2100E+02	0.9443E-06	0.2200E+02	0.9425E-06	0.2300E+02	0.9406E-06	0.2400E+02	0.9424E-06
0.2500E+02	0.9406E-06	0.2600E+02	0.9387E-06	0.2700E+02	0.9406E-06	0.2800E+02	0.9424E-06
0.2900E+02	0.9405E-06	0.3000E+02	0.9386E-06	0.3100E+02	0.9368E-06		

TIME VS CONCENTRATION AT NODE NUMBER 85

0.1000E+01	0.8128E-06	0.2000E+01	0.8112E-06	0.3000E+01	0.8096E-06	0.4000E+01	0.8156E-06
0.5000E+01	0.8215E-06	0.6000E+01	0.8199E-06	0.7000E+01	0.8183E-06	0.8000E+01	0.8238E-06
0.9000E+01	0.8291E-06	0.1000E+02	0.8275E-06	0.1100E+02	0.8259E-06	0.1200E+02	0.8308E-06
0.1300E+02	0.8356E-06	0.1400E+02	0.8340E-06	0.1500E+02	0.8323E-06	0.1600E+02	0.8368E-06
0.1700E+02	0.8411E-06	0.1800E+02	0.8394E-06	0.1900E+02	0.8378E-06	0.2000E+02	0.8417E-06
0.2100E+02	0.8456E-06	0.2200E+02	0.8440E-06	0.2300E+02	0.8423E-06	0.2400E+02	0.8459E-06
0.2500E+02	0.8443E-06	0.2600E+02	0.8426E-06	0.2700E+02	0.8460E-06	0.2800E+02	0.8494E-06
0.2900E+02	0.8477E-06	0.3000E+02	0.8460E-06	0.3100E+02	0.8443E-06		

Flow simulation from 1 Jan 5 to 31 Jan 5

Transport simulation from 1 Jan 5 to 31 Jan 5

Transport simulation from 1 Jan 5 to 31 Jan 5

Transport simulation from 1 Jan 5 to 31 Jan 5

Flow simulation from 1 Feb 5 to 28 Feb 5

Transport simulation from 1 Feb 5 to 28 Feb 5

Transport simulation from 1 Feb 5 to 28 Feb 5

Transport simulation from 1 Feb 5 to 28 Feb 5

Flow simulation from 1 Mar 5 to 31 Mar 5

Transport simulation from 1 Mar 5 to 31 Mar 5

Transport simulation from 1 Mar 5 to 31 Mar 5

Transport simulation from 1 Mar 5 to 31 Mar 5

Flow simulation from 1 Apr 5 to 30 Apr 5

Transport simulation from 1 Apr 5 to 30 Apr 5

Transport simulation from 1 Apr 5 to 30 Apr 5

Transport simulation from 1 Apr 5 to 30 Apr 5

Flow simulation from 1 May 5 to 31 May 5

Transport simulation from 1 May 5 to 31 May 5

Transport simulation from 1 May 5 to 31 May 5

Transport simulation from 1 May 5 to 31 May 5

Flow simulation from 1 Jun 5 to 30 Jun 5

Transport simulation from 1 Jun 5 to 30 Jun 5

Transport simulation from 1 Jun 5 to 30 Jun 5

Transport simulation from 1 Jun 5 to 30 Jun 5

Flow simulation from 1 Jul 5 to 31 Jul 5

Transport simulation from 1 Jul 5 to 31 Jul 5

Transport simulation from 1 Jul 5 to 31 Jul 5

Transport simulation from 1 Jul 5 to 31 Jul 5

Flow simulation from 1 Aug 5 to 31 Aug 5

Transport simulation from 1 Aug 5 to 31 Aug 5

Transport simulation from 1 Aug 5 to 31 Aug 5

Transport simulation from 1 Aug 5 to 31 Aug 5

Flow simulation from 1 Sep 5 to 30 Sep 5

Transport simulation from 1 Sep 5 to 30 Sep 5

Transport simulation from 1 Sep 5 to 30 Sep 5

```
*************************************************************************
*************************************************************************
Transport simulation from  1 Sep  5 to 30 Sep  5
*************************************************************************
*************************************************************************
Flow simulation from  1 Oct  5 to 31 Oct  5
*************************************************************************
*************************************************************************
Transport simulation from  1 Oct  5 to 31 Oct  5
*************************************************************************
*************************************************************************
Transport simulation from  1 Oct  5 to 31 Oct  5
*************************************************************************
*************************************************************************
Transport simulation from  1 Oct  5 to 31 Oct  5
*************************************************************************
*************************************************************************
Flow simulation from  1 Nov  5 to 30 Nov  5
*************************************************************************
*************************************************************************
Transport simulation from  1 Nov  5 to 30 Nov  5
*************************************************************************
*************************************************************************
Transport simulation from  1 Nov  5 to 30 Nov  5
*************************************************************************
*************************************************************************
Transport simulation from  1 Nov  5 to 30 Nov  5
*************************************************************************
*************************************************************************
Flow simulation from  1 Dec  5 to 31 Dec  5
*************************************************************************

        SUMMARY OF VOLUMETRIC FLOW BALANCE OUTPUT
        *****************************************

        Elapsed simulation time =   0.3100E+02
        Current value of time increment =   0.1000E+01


        Fluid flux value at first node = -0.9898E-13
        Fluid flux value at last node = -0.7886E-10

        NOTE: These "net" values are only for last day of time step
        Net value of fluid flux = -0.7896E-10
        Net rate of volumetric storage = -0.7395E-10
        FLOW BALANCE ERROR = -0.5007E-11
        NORMALIZED BALANCE ERROR = -0.3275E-01

        NOTE: These "cumulative" values are for the entire time step
        Cumulative volumetric storage = -0.1233E-02
        Cumulative inflow volume =  0.4325E+03
        Cumulative outflow volume = -0.4319E+03
```

TIME VS HEAD AT NODE NUMBER 1
****

0.1000E+01	-0.3478E+03	0.2000E+01	-0.3540E+03	0.3000E+01	-0.3540E+03	0.4000E+01	-0.3478E+03
0.5000E+01	-0.3478E+03	0.6000E+01	-0.3540E+03	0.7000E+01	-0.3540E+03	0.8000E+01	-0.3478E+03
0.9000E+01	-0.3478E+03	0.1000E+02	-0.3540E+03	0.1100E+02	-0.3540E+03	0.1200E+02	-0.3478E+03
0.1300E+02	-0.3478E+03	0.1400E+02	-0.3540E+03	0.1500E+02	-0.3540E+03	0.1600E+02	-0.3478E+03
0.1700E+02	-0.3478E+03	0.1800E+02	-0.3540E+03	0.1900E+02	-0.3540E+03	0.2000E+02	-0.3478E+03
0.2100E+02	-0.3478E+03	0.2200E+02	-0.3540E+03	0.2300E+02	-0.3540E+03	0.2400E+02	-0.3478E+03
0.2500E+02	-0.3540E+03	0.2600E+02	-0.3540E+03	0.2700E+02	-0.3478E+03	0.2800E+02	-0.3478E+03
0.2900E+02	-0.3540E+03	0.3000E+02	-0.3540E+03	0.3100E+02	-0.3540E+03		

TIME VS HEAD AT NODE NUMBER 11
****

0.1000E+01	-0.3395E+03	0.2000E+01	-0.3440E+03	0.3000E+01	-0.3440E+03	0.4000E+01	-0.3395E+03
0.5000E+01	-0.3395E+03	0.6000E+01	-0.3440E+03	0.7000E+01	-0.3440E+03	0.8000E+01	-0.3395E+03
0.9000E+01	-0.3395E+03	0.1000E+02	-0.3440E+03	0.1100E+02	-0.3440E+03	0.1200E+02	-0.3395E+03
0.1300E+02	-0.3395E+03	0.1400E+02	-0.3440E+03	0.1500E+02	-0.3440E+03	0.1600E+02	-0.3395E+03
0.1700E+02	-0.3395E+03	0.1800E+02	-0.3440E+03	0.1900E+02	-0.3440E+03	0.2000E+02	-0.3395E+03
0.2100E+02	-0.3395E+03	0.2200E+02	-0.3440E+03	0.2300E+02	-0.3440E+03	0.2400E+02	-0.3395E+03
0.2500E+02	-0.3440E+03	0.2600E+02	-0.3440E+03	0.2700E+02	-0.3395E+03	0.2800E+02	-0.3395E+03
0.2900E+02	-0.3440E+03	0.3000E+02	-0.3440E+03	0.3100E+02	-0.3440E+03		

TIME VS HEAD AT NODE NUMBER 24
****

0.1000E+01'	-0.3011E+03	0.2000E+01	-0.3050E+03	0.3000E+01	-0.3050E+03	0.4000E+01	-0.3011E+03
0.5000E+01	-0.3011E+03	0.6000E+01	-0.3050E+03	0.7000E+01	-0.3050E+03	0.8000E+01	-0.3011E+03
0.9000E+01	-0.3011E+03	0.1000E+02	-0.3050E+03	0.1100E+02	-0.3050E+03	0.1200E+02	-0.3011E+03
0.1300E+02	-0.3011E+03	0.1400E+02	-0.3050E+03	0.1500E+02	-0.3050E+03	0.1600E+02	-0.3011E+03
0.1700E+02	-0.3011E+03	0.1800E+02	-0.3050E+03	0.1900E+02	-0.3050E+03	0.2000E+02	-0.3011E+03
0.2100E+02	-0.3011E+03	0.2200E+02	-0.3050E+03	0.2300E+02	-0.3050E+03	0.2400E+02	-0.3011E+03
0.2500E+02	-0.3050E+03	0.2600E+02	-0.3050E+03	0.2700E+02	-0.3011E+03	0.2800E+02	-0.3011E+03
0.2900E+02	-0.3050E+03	0.3000E+02	-0.3050E+03	0.3100E+02	-0.3050E+03		

TIME VS HEAD AT NODE NUMBER 85
****

0.1000E+01	0.0000E+00	0.2000E+01	0.0000E+00	0.3000E+01	0.0000E+00	0.4000E+01	0.0000E+00
0.5000E+01	0.0000E+00	0.6000E+01	0.0000E+00	0.7000E+01	0.0000E+00	0.8000E+01	0.0000E+00
0.9000E+01	0.0000E+00	0.1000E+02	0.0000E+00	0.1100E+02	0.0000E+00	0.1200E+02	0.0000E+00
0.1300E+02	0.0000E+00	0.1400E+02	0.0000E+00	0.1500E+02	0.0000E+00	0.1600E+02	0.0000E+00
0.1700E+02	0.0000E+00	0.1800E+02	0.0000E+00	0.1900E+02	0.0000E+00	0.2000E+02	0.0000E+00
0.2100E+02	0.0000E+00	0.2200E+02	0.0000E+00	0.2300E+02	0.0000E+00	0.2400E+02	0.0000E+00
0.2500E+02	0.0000E+00	0.2600E+02	0.0000E+00	0.2700E+02	0.0000E+00	0.2800E+02	0.0000E+00
0.2900E+02	0.0000E+00	0.3000E+02	0.0000E+00	0.3100E+02	0.0000E+00		

Transport simulation from 1 Dec 5 to 31 Dec 5

MASS TRANSPORT BALANCE, CHEMICAL 1

NOTE: These "net" values are only for last day of time step
Net dispersive flux = -0.4235E-21
Net advective flux = 0.5951E-12
Net rate of mass accumulation = -0.8547E-05
Net rate of formation = 0.0000E+00
Net rate of mass decay = 0.8316E-05
MASS BALANCE ERROR = 0.2311E-06
NORMALIZED MASS BALANCE ERROR = 0.1370E-01

NOTE: These "cumulative" values are for the entire time step
Cumulative mass storage = 0.2843E-02
Cumulative mass decay = 0.3351E-03
Cumulative inflow mass = 0.1708E-07
Cumulative outflow mass = 0.2499E-02

ANNUAL SUMMARY OF CUMULATIVE CONCENTRATIONS

NOTE: These "cumulative" values are yearly summaries
Annual cumulative mass storage = 0.1075
Annual cumulative mass decay = 0.1650E-01
Annual cumulative inflow mass = 0.1125
Annual cumulative outflow mass = 0.2032

TIME VS CONCENTRATION AT NODE NUMBER 1

0.1000E+01	0.1191E-07	0.2000E+01	0.1196E-07	0.3000E+01	0.1194E-07	0.4000E+01	0.7732E-08
0.5000E+01	0.5652E-08	0.6000E+01	0.5677E-08	0.7000E+01	0.5666E-08	0.8000E+01	0.3644E-08
0.9000E+01	0.2645E-08	0.1000E+02	0.2657E-08	0.1100E+02	0.2652E-08	0.1200E+02	0.1694E-08
0.1300E+02	0.1221E-08	0.1400E+02	0.1227E-08	0.1500E+02	0.1225E-08	0.1600E+02	0.7772E-09
0.1700E+02	0.5569E-09	0.1800E+02	0.5597E-09	0.1900E+02	0.5586E-09	0.2000E+02	0.3522E-09
0.2100E+02	0.2508E-09	0.2200E+02	0.2521E-09	0.2300E+02	0.2516E-09	0.2400E+02	0.1577E-09
0.2500E+02	0.1590E-09	0.2600E+02	0.1586E-09	0.2700E+02	0.9775E-10	0.2800E+02	0.6883E-10
0.2900E+02	0.6923E-10	0.3000E+02	0.6909E-10	0.3100E+02	0.6896E-10		

TIME VS CONCENTRATION AT NODE NUMBER 11

0.1000E+01	0.2918E-07	0.2000E+01	0.2901E-07	0.3000E+01	0.2895E-07	0.4000E+01	0.2119E-07
0.5000E+01	0.1587E-07	0.6000E+01	0.1579E-07	0.7000E+01	0.1576E-07	0.8000E+01	0.1206E-07
0.9000E+01	0.9477E-08	0.1000E+02	0.9433E-08	0.1100E+02	0.9414E-08	0.1200E+02	0.7593E-08
0.1300E+02	0.6303E-08	0.1400E+02	0.6278E-08	0.1500E+02	0.6266E-08	0.1600E+02	0.5340E-08
0.1700E+02	0.4668E-08	0.1800E+02	0.4652E-08	0.1900E+02	0.4643E-08	0.2000E+02	0.4146E-08
0.2100E+02	0.3772E-08	0.2200E+02	0.3760E-08	0.2300E+02	0.3753E-08	0.2400E+02	0.3464E-08
0.2500E+02	0.3454E-08	0.2600E+02	0.3447E-08	0.2700E+02	0.3216E-08	0.2800E+02	0.3027E-08
0.2900E+02	0.3019E-08	0.3000E+02	0.3013E-08	0.3100E+02	0.3007E-08		

TIME VS CONCENTRATION AT NODE NUMBER 26

0.1000E+01	0.2108E-03	0.2000E+01	0.2103E-03	0.3000E+01	0.2099E-03	0.4000E+01	0.2020E-03
0.5000E+01	0.1944E-03	0.6000E-01	0.1939E-03	0.7000E+01	0.1935E-03	0.8000E+01	0.1863E-03
0.9000E+01	0.1793E-03	0.1000E+02	0.1789E-03	0.1100E+02	0.1786E-03	0.1200E+02	0.1719E-03
0.1300E+02	0.1655E-03	0.1400E+02	0.1651E-03	0.1500E+02	0.1648E-03	0.1600E+02	0.1587E-03
0.1700E+02	0.1528E-03	0.1800E+02	0.1525E-03	0.1900E+02	0.1522E-03	0.2000E+02	0.1466E-03
0.2100E+02	0.1411E-03	0.2200E+02	0.1408E-03	0.2300E+02	0.1405E-03	0.2400E+02	0.1354E-03
0.2500E+02	0.1350E-03	0.2600E+02	0.1348E-03	0.2700E+02	0.1298E-03	0.2800E+02	0.1250E-03
0.2900E+02	0.1247E-03	0.3000E+02	0.1245E-03	0.3100E+02	0.1242E-03		

TIME VS CONCENTRATION AT NODE NUMBER 85

0.1000E+01	0.5332E-03	0.2000E+01	0.5319E-03	0.3000E+01	0.5309E-03	0.4000E+01	0.5121E-03
0.5000E+01	0.4937E-03	0.6000E+01	0.4925E-03	0.7000E+01	0.4916E-03	0.8000E+01	0.4740E-03
0.9000E+01	0.4569E-03	0.1000E+02	0.4559E-03	0.1100E+02	0.4549E-03	0.1200E+02	0.4386E-03
0.1300E+02	0.4227E-03	0.1400E+02	0.4217E-03	0.1500E+02	0.4209E-03	0.1600E+02	0.4058E-03
0.1700E+02	0.3910E-03	0.1800E+02	0.3901E-03	0.1900E+02	0.3893E-03	0.2000E+02	0.3752E-03
0.2100E+02	0.3615E-03	0.2200E+02	0.3607E-03	0.2300E+02	0.3600E-03	0.2400E+02	0.3470E-03
0.2500E+02	0.3461E-03	0.2600E+02	0.3454E-03	0.2700E+02	0.3329E-03	0.2800E+02	0.3208E-03
0.2900E+02	0.3200E-03	0.3000E+02	0.3194E-03	0.3100E+02	0.3187E-03		

Transport simulation from 1 Dec 5 to 31 Dec 5

MASS TRANSPORT BALANCE, CHEMICAL 2

NOTE: These "net" values are only for last day of time step
Net dispersive flux = -0.1873E-21
Net advective flux = 0.2531E-12
Net rate of mass accumulation = -0.3956E-05
Net rate of formation = 0.0000E+00
Net rate of mass decay = 0.3858E-05
MASS BALANCE ERROR = 0.9826E-07
NORMALIZED MASS BALANCE ERROR = 0.1258E-01

NOTE: These "cumulative" values are for the entire time step
Cumulative mass storage = 0.1027E-02
Cumulative mass decay = 0.1497E-03
Cumulative inflow mass = 0.6125E-04
Cumulative outflow mass = 0.9352E-03

ANNUAL SUMMARY OF CUMULATIVE CONCENTRATIONS

NOTE: These "cumulative" values are yearly summaries
Annual cumulative mass storage = 0.5139E-02
Annual cumulative mass decay = 0.9410E-03
Annual cumulative inflow mass = 0.8048E-02
Annual cumulative outflow mass = 0.1223E-01

TIME VS CONCENTRATION AT NODE NUMBER 1

0.1000E+01	0.2003E-04	0.2000E+01	0.2001E-04	0.3000E+01	0.1997E-04	0.4000E+01	0.1591E-04
0.5000E+01	0.1546E-04	0.6000E+01	0.1544E-04	0.7000E+01	0.1541E-04	0.8000E+01	0.1225E-04
0.9000E+01	0.1185E-04	0.1000E+02	0.1184E-04	0.1100E+02	0.1182E-04	0.1200E+02	0.9355E-05
0.1300E+02	0.9017E-05	0.1400E+02	0.9007E-05	0.1500E+02	0.8989E-05	0.1600E+02	0.7085E-05
0.1700E+02	0.6794E-05	0.1800E+02	0.6787E-05	0.1900E+02	0.6774E-05	0.2000E+02	0.5310E-05
0.2100E+02	0.5062E-05	0.2200E+02	0.5057E-05	0.2300E+02	0.5047E-05	0.2400E+02	0.3933E-05
0.2500E+02	0.3941E-05	0.2600E+02	0.3933E-05	0.2700E+02	0.2998E-05	0.2800E+02	0.2821E-05
0.2900E+02	0.2820E-05	0.3000E+02	0.2814E-05	0.3100E+02	0.2808E-05		

TIME VS CONCENTRATION AT NODE NUMBER 11

0.1000E+01	0.2373E-04	0.2000E+01	0.2365E-04	0.3000E+01	0.2360E-04	0.4000E+01	0.2032E-04
0.5000E+01	0.1795E-04	0.6000E+01	0.1789E-04	0.7000E+01	0.1785E-04	0.8000E+01	0.1549E-04
0.9000E+01	0.1372E-04	0.1000E+02	0.1367E-04	0.1100E+02	0.1365E-04	0.1200E+02	0.1184E-04
0.1300E+02	0.1047E-04	0.1400E+02	0.1043E-04	0.1500E+02	0.1041E-04	0.1600E+02	0.9008E-05
0.1700E+02	0.7935E-05	0.1800E+02	0.7909E-05	0.1900E+02	0.7893E-05	0.2000E+02	0.6800E-05
0.2100E+02	0.5961E-05	0.2200E+02	0.5941E-05	0.2300E+02	0.5929E-05	0.2400E+02	0.5082E-05
0.2500E+02	0.5063E-05	0.2600E+02	0.5053E-05	0.2700E+02	0.4165E-05	0.2800E+02	0.3509E-05
0.2900E+02	0.3495E-05	0.3000E+02	0.3488E-05	0.3100E+02	0.3481E-05		

TIME VS CONCENTRATION AT NODE NUMBER 24

0.1000E+01	0.1477E-03	0.2000E+01	0.1473E-03	0.3000E+01	0.1470E-03	0.4000E+01	0.1367E-03
0.5000E+01	0.1273E-03	0.6000E+01	0.1269E-03	0.7000E+01	0.1267E-03	0.8000E+01	0.1184E-03
0.9000E+01	0.1109E-03	0.1000E+02	0.1106E-03	0.1100E+02	0.1103E-03	0.1200E+02	0.1037E-03
0.1300E+02	0.9764E-04	0.1400E+02	0.9738E-04	0.1500E+02	0.9719E-04	0.1600E+02	0.9178E-04
0.1700E+02	0.8680E-04	0.1800E+02	0.8658E-04	0.1900E+02	0.8641E-04	0.2000E+02	0.8191E-04
0.2100E+02	0.7774E-04	0.2200E+02	0.7755E-04	0.2300E+02	0.7739E-04	0.2400E+02	0.7358E-04
0.2500E+02	0.7340E-04	0.2600E+02	0.7325E-04	0.2700E+02	0.6973E-04	0.2800E+02	0.6642E-04
0.2900E+02	0.6626E-04	0.3000E+02	0.6613E-04	0.3100E+02	0.6599E-04		

TIME VS CONCENTRATION AT NODE NUMBER 85

0.1000E+01	0.1536E-03	0.2000E+01	0.1533E-03	0.3000E+01	0.1530E-03	0.4000E+01	0.1557E-03
0.5000E+01	0.1575E-03	0.6000E+01	0.1572E-03	0.7000E+01	0.1569E-03	0.8000E+01	0.1580E-03
0.9000E+01	0.1583E-03	0.1000E+02	0.1580E-03	0.1100E+02	0.1577E-03	0.1200E+02	0.1573E-03
0.1300E+02	0.1564E-03	0.1400E+02	0.1561E-03	0.1500E+02	0.1557E-03	0.1600E+02	0.1543E-03
0.1700E+02	0.1523E-03	0.1800E+02	0.1520E-03	0.1900E+02	0.1517E-03	0.2000E+02	0.1494E-03
0.2100E+02	0.1468E-03	0.2200E+02	0.1465E-03	0.2300E+02	0.1462E-03	0.2400E+02	0.1433E-03
0.2500E+02	0.1430E-03	0.2600E+02	0.1427E-03	0.2700E+02	0.1396E-03	0.2800E+02	0.1364E-03
0.2900E+02	0.1361E-03	0.3000E+02	0.1358E-03	0.3100E+02	0.1355E-03		

Transport simulation from 1 Dec 5 to 31 Dec 5

MASS TRANSPORT BALANCE, CHEMICAL 3

NOTE: These "net" values are only for last day of time step
Net dispersive flux = -0.1522E-20
Net advective flux = 0.1958E-12
Net rate of mass accumulation = -0.3397E-05
Net rate of formation = 0.0000E+00
Net rate of mass decay = 0.3321E-05
MASS BALANCE ERROR = 0.7602E-07
NORMALIZED MASS BALANCE ERROR = 0.1131E-01

NOTE: These "cumulative" values are for the entire time step
Cumulative mass storage = 0.8319E-03
Cumulative mass decay = 0.1199E-03
Cumulative inflow mass = 0.2784E-03
Cumulative outflow mass = 0.9877E-03

ANNUAL SUMMARY OF CUMULATIVE CONCENTRATIONS

NOTE: These "cumulative" values are yearly summaries
Annual cumulative mass storage = 0.1290E-01
Annual cumulative mass decay = 0.1835E-02
Annual cumulative inflow mass = 0.1473E-01
Annual cumulative outflow mass = 0.2576E-01

TIME VS CONCENTRATION AT NODE NUMBER 1

0.1000E+01	0.4290E-04	0.2000E+01	0.4282E-04	0.3000E+01	0.4274E-04	0.4000E+01	0.4114E-04
0.5000E+01	0.4114E-04	0.6000E+01	0.4106E-04	0.7000E+01	0.4098E-04	0.8000E+01	0.3978E-04
0.9000E+01	0.4013E-04	0.1000E+02	0.4004E-04	0.1100E+02	0.3996E-04	0.1200E+02	0.3915E-04
0.1300E+02	0.3987E-04	0.1400E+02	0.3978E-04	0.1500E+02	0.3970E-04	0.1600E+02	0.3927E-04
0.1700E+02	0.4038E-04	0.1800E+02	0.4028E-04	0.1900E+02	0.4020E-04	0.2000E+02	0.4016E-04
0.2100E+02	0.4168E-04	0.2200E+02	0.4157E-04	0.2300E+02	0.4149E-04	0.2400E+02	0.4182E-04
0.2500E+02	0.4173E-04	0.2600E+02	0.4164E-04	0.2700E+02	0.4204E-04	0.2800E+02	0.4416E-04
0.2900E+02	0.4404E-04	0.3000E+02	0.4396E-04	0.3100E+02	0.4387E-04		

TIME VS CONCENTRATION AT NODE NUMBER 11

0.1000E+01	0.4417E-04	0.2000E+01	0.4407E-04	0.3000E+01	0.4398E-04	0.4000E+01	0.4273E-04
0.5000E+01	0.4188E-04	0.6000E+01	0.4179E-04	0.7000E+01	0.4171E-04	0.8000E+01	0.4086E-04
0.9000E+01	0.4039E-04	0.1000E+02	0.4030E-04	0.1100E+02	0.4022E-04	0.1200E+02	0.3975E-04
0.1300E+02	0.3965E-04	0.1400E+02	0.3957E-04	0.1500E+02	0.3949E-04	0.1600E+02	0.3939E-04
0.1700E+02	0.3967E-04	0.1800E+02	0.3959E-04	0.1900E+02	0.3952E-04	0.2000E+02	0.3978E-04
0.2100E+02	0.4046E-04	0.2200E+02	0.4038E-04	0.2300E+02	0.4030E-04	0.2400E+02	0.4095E-04
0.2500E+02	0.4088E-04	0.2600E+02	0.4079E-04	0.2700E+02	0.4132E-04	0.2800E+02	0.4237E-04
0.2900E+02	0.4229E-04	0.3000E+02	0.4221E-04	0.3100E+02	0.4213E-04		

TIME VS CONCENTRATION AT NODE NUMBER 24

0.1000E+01	0.9485E-04	0.2000E+01	0.9463E-04	0.3000E+01	0.9445E-04	0.4000E+01	0.9153E-04
0.5000E+01	0.8874E-04	0.6000E+01	0.8854E-04	0.7000E+01	0.8836E-04	0.8000E+01	0.8578E-04
0.9000E+01	0.8333E-04	0.1000E+02	0.8314E-04	0.1100E+02	0.8297E-04	0.1200E+02	0.8071E-04
0.1300E+02	0.7858E-04	0.1400E+02	0.7841E-04	0.1500E+02	0.7825E-04	0.1600E+02	0.7629E-04
0.1700E+02	0.7446E-04	0.1800E+02	0.7430E-04	0.1900E+02	0.7415E-04	0.2000E+02	0.7248E-04
0.2100E+02	0.7094E-04	0.2200E+02	0.7079E-04	0.2300E+02	0.7063E-04	0.2400E+02	0.6926E-04
0.2500E+02	0.6911E-04	0.2600E+02	0.6897E-04	0.2700E+02	0.6773E-04	0.2800E+02	0.6660E-04
0.2900E+02	0.6645E-04	0.3000E+02	0.6632E-04	0.3100E+02	0.6619E-04		

TIME VS CONCENTRATION AT NODE NUMBER 85

0.1000E+01	0.1398E-03	0.2000E+01	0.1395E-03	0.3000E+01	0.1392E-03	0.4000E+01	0.1370E-03
0.5000E+01	0.1347E-03	0.6000E+01	0.1344E-03	0.7000E+01	0.1341E-03	0.8000E+01	0.1318E-03
0.9000E+01	0.1294E-03	0.1000E+02	0.1291E-03	0.1100E+02	0.1289E-03	0.1200E+02	0.1265E-03
0.1300E+02	0.1241E-03	0.1400E+02	0.1238E-03	0.1500E+02	0.1236E-03	0.1600E+02	0.1212E-03
0.1700E+02	0.1187E-03	0.1800E+02	0.1185E-03	0.1900E+02	0.1182E-03	0.2000E+02	0.1158E-03
0.2100E+02	0.1134E-03	0.2200E+02	0.1132E-03	0.2300E+02	0.1130E-03	0.2400E+02	0.1106E-03
0.2500E+02	0.1104E-03	0.2600E+02	0.1101E-03	0.2700E+02	0.1078E-03	0.2800E+02	0.1055E-03
0.2900E+02	0.1053E-03	0.3000E+02	0.1050E-03	0.3100E+02	0.1048E-03		

STUDY TITLE

Estimation of Pesticide Drift From Groundboom Application to Golf Courses-Use of the AGDISP Model

AUTHORS

Richard C. Honeycutt, Ph.D.
Jeff Tolle

COMPLETION DATE

June 14, 1991

PERFORMING LABORATORY

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High Point, North Carolina 27262

SUBMITTING LABORATORY

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LABORATORY PROJECT ID

H.E.R.A.C. Project No. 91-122RA
H.E.R.A.C. Report No. 91-107

TOTAL PAGES: 15

STATEMENT OF NO DATA CONFIDENTIALITY CLAIMS

No claim of confidentiality is made for any information contained in this study on the basis of its falling within the scope of FIFRA 10 (d) (1) (A), (B), or (C).

Company: Environmental and Turf Services

Company Agent: Dr. Stu Cohen Date: 6-17-91

Title: President Signature: [signature]

These data are the property of the Environmental and Turf Services, Inc., and as such, are considered to be confidential for all purposes other than compliance with FIFRA 10. Submission of these data in compliance with FIFRA does not constitute a waiver of any right to confidentiality which may exist under any other statute or in any other country.

GOOD LABORATORY PRACTICE STATEMENT

This study does not meet the Good Laboratory Practice Standards (Federal Register August 17, 1989 - EPA 40 CFR, Part 160) for the following reason: To the best of my knowledge, such modeling does not come under FIFRA GLP regulations. However, to the best of my knowledge, all GLP procedures as defined by the FIFRA regulations were adhered to during the course of this study.

R. Honeycutt
Richard C. Honeycutt, Ph.D.
Study Director

6-14-91
Date

TABLE OF CONTENTS

ABSTRACT

The AGDISP model was used to predict spray drift patterns of pesticides applied by ground boom application procedures to a golf course on the Kona Coast. The results of this modeling showed that for crosswinds more than 5 mph, the drift will reach areas more than 45 feet from the center of the boom.

Sensitivity analysis of the AGDISP model showed that boom height will effect spray drift but is a less sensitive parameter than crosswind. Lower boom heights give less drift. Other parameters such as terrain angle or horizontal velocity of the spray did not effect the drift patterns of pesticides applied in this manner.

INTRODUCTION

Drift of pesticides to non-target sites from application by ground or air has been of concern for some time. Recently, researchers have begun to focus on drift studies as demonstrated by the establishment of the Pesticide Industry Drift Task Force. Pesticide drift modeling has also begun to show promise with the advent of the Forest Service Aerial Spray Computer Model (FSCBG), as well as the AGDISP code (1,2) which can be adapted to estimation of pesticide drift resulting from ground applied pesticides. While the AGDISP code has been validated (2,3) for aerial applications, field validation for ground application is lacking. Currently, the EPA is evaluating the AGDISP model. The AGDISP code is still reasonably suited to predict the distribution of pesticides from drift away from sites treated by ground application.

The objective of this report is to determine the potential pattern of drift of pesticides applied to golf courses using ground boom application in order to plan pesticide applications to minimize off-site non-target contamination of water and land systems.

__Computer Model__: The AGDISP drift model was purchased from Continuum Dynamics, Inc., Princeton, New Jersey. The model was transferred and run using a Proturbo 386/20 PC computer with a math co-processor.

__Model Inputs__: The following AGDISP model inputs were available from various sources, including the Integrated Golf Course management Plan developed for the O'oma II project by Environmental & Turf Services, Inc.:

__Input__	__Remarks__
Tractor speed 0.67 m/s	From 2-5 km/hr typical tractor speed
Terrain angle 0 degrees	Terrain angle of 0 assumes a flat surface
Number of nozzles on the boom (12)	Based on boom with nozzles spaced 0.5 m apart
Evaporation fraction 0.10	Based on assumption of an evaporation of 10% of applied pesticide. This is an arbitrary but conservative estimate.
Flow rate 0.5 l/min	Based on typical low pressure sprayer (4)
Boom length (6 m)	(4)
Boom Height (0.5m, 18 inches)	(5)
Initial drop diameter (200 microns)	(4)
Wet Bulb/dry Bulb temperature difference (3.0° cent.) Humidity 60-80%.	Based on typical Hawaiian humidity, 75% is a conservative estimate.

Initial nozzle conditions for each nozzle:

Initial axial velocity: 0.0 m/s
Initial vertical velocity: 9.5 m/s (6)
Initial horizontal velocity: 0.67 m/s
Initial spatial variance: 2.5 m^2
Initial velocity variance: 1.1 m^2/sec^2 (6)

Crosswind 2.24 m/s based on 5 mph - maximum crosswind to be sprayed in.

__Golf Course Simulation Assumptions__:

1. Assume a crosswind speed of not more than 5 mph.
2. Assume a relative humidity of 75% (5).
3. Assume that pesticides will not be applied within 50 feet of a body of water or restricted land area.
4. Assume that 90% of the pesticide applied does not evaporate from ground surface.
5. Assume a flat surface.
6. Assume crosswind angle is 90 degrees to direction of the boom movement.
7. Assume a specific gravity of the spray material to be 1 gm./ml.

__Sensitivity Analysis Using AGDISP__:

Several parameters were varied during a number of AGDISP simulations in order to determine which parameters may impact drift of pesticides applied by ground. A listing of these parameters is shown below:

1. Crosswind: 0, 2.5, 5.0, 10. mph.
2. Terrain Angle: 0, 10 degrees
3. Boom Height: 0.3, 0.5, 1.0, 2, 4, 6, meters above ground.
4. Horizontal velocity of Spray: 0.67, 30 meters/second

RESULTS

AGDISP Simulation for Groundboom Application - Golf Courses:

Figures 1-3 show the predicted spray pattern distribution of a pesticide applied in water using a ground boom spray rig mounted 18 inches above the ground and traveling 5 mph. The effects of crosswind variance are shown in figures 1-3. At crosswinds of 0-5 mph drift will reach across less than 45 feet from the center of the spray. At cross winds above 5 mph, drift will reach past 45 feet.

Sensitivity Analysis of AGDISP for Groundboom Application of Pesticides:

Several parameters shown above were varied to test the sensitivity of the AGDISP model. As discussed above, variations in crosswinds were found to significantly effect drift patterns of pesticides applied by ground boom application equipment. Boom height appeared to be as less sensitive parameter than crosswind. For example with no crosswind, there is no difference in drift patterns between boom heights of 12, 18 and 36 inches; whereas with a crosswind of 10 mph, the material will drift twice as far with a 36 inch boom height compared to an 18 inch boom height. There was no difference in drift patterns when the horizontal velocity was varied between 0.67 to 30 meters/second. All parameters in this model were not tested for sensitivity since it was beyond the scope of the objectives of this study.

SUMMARY AND CONCLUSIONS

The AGDISP model was used to predict patterns of pesticide spray drift for pesticides applied using ground boom application equipment. At cross winds of less than 5 mph, spray drift will be minimized and retained with a 50 feet buffer zone on either side of the center of boom. If the golf course operator would like to avoid all drift beyond 50 feet from the center of the boom, applications of pesticides should not be made at crosswind speeds of more than 5 mph. Boom heights of less than 18 inches will tend to reduce drift.

Sensitivity analysis of the AGDISP model showed that the crosswind is a significant parameter for the model whereas boom height is a less sensitive parameter. Terrain angle and horizontal velocity of the spray were found not to be sensitive parameters. All parameters were not tested for sensitivity since this was beyond the scope of this study.

REFERENCES

1. Bowers, J. and Barry, J., "User Manual - Forest Service Aerial Spray Computer Model FSCBG (PC)," U. S. Department of Agriculture, Forest Service, FPM 89-1, April, 1989.

2. Bilanin, A., Teske, M., Barry, J., Ekbald, R., "AGDISP: The Aircraft Spray Dispersion Model, Code Development and Experimental Validation," American Society of Agricultural Engineers, Vol. 32 (1), January-February, 1989.

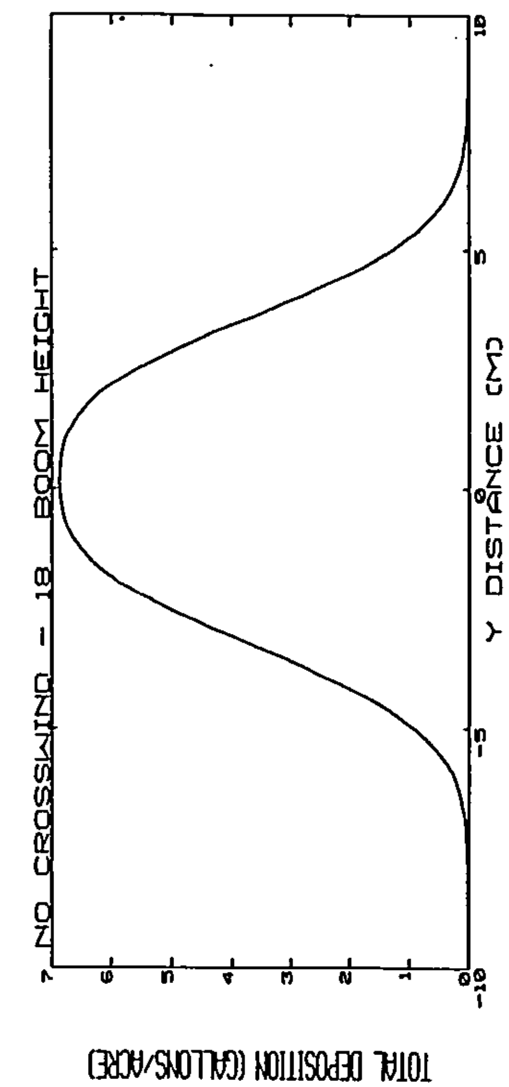
3. Teske, M., Bilanin, A., Ekbald, R., "Final Report: AGDISP Comparisons with the Mission Swath Width Characterization Studies," U. S. Department of Agriculture, Forest Service 3400, Forest Pest Management 8834 2801, May, 1988.

4. Personal communication with Steve Honeycutt, DELVAN Corp. Lexington, TN. (6-11-91)

5. Personal communication with Busta Mante at the Manua Lani Golf Course, Kailua Kona, Hawaii, June 14, 1991.

6. Kennedy, J. "Laser Droplet Interferometry Approach to Spray Drop Size Analysis", Pesticide Formulations and Application Systems. Vol (5), ASTM STP 915, Spencer, 1. and Kaneko, T. Eds., American Society for Testing and Materials, Philadelphia, 1986, pp 114-127.

FIGURE 1: SPRAY DRIFT PATTERN OF PESTICIDES-CROSSWIND 0 MPH



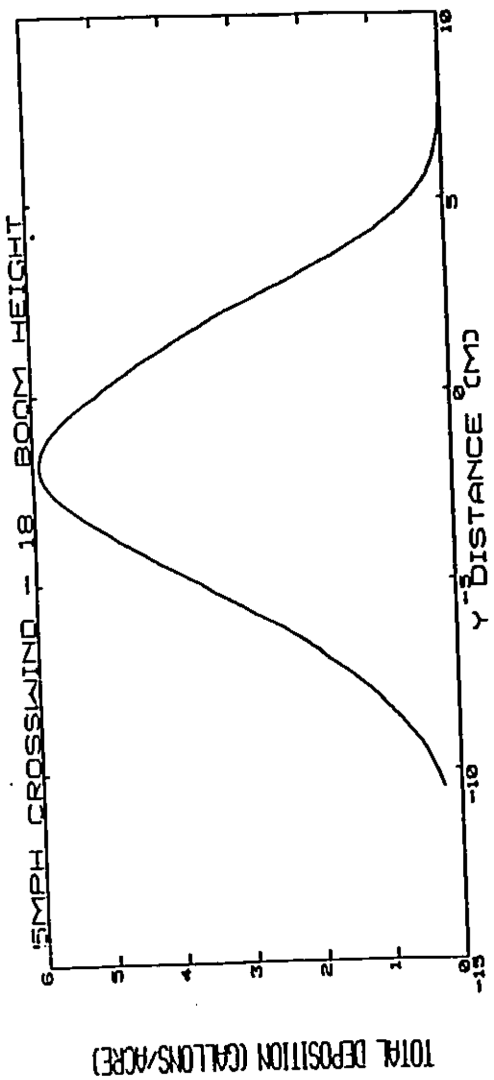


FIGURE 2: SPRAY DRIFT PATTERN OF PESTICIDES-CROSSWIND 5 MPH
CROSSWIND BLOWING FROM RIGHT TO LEFT

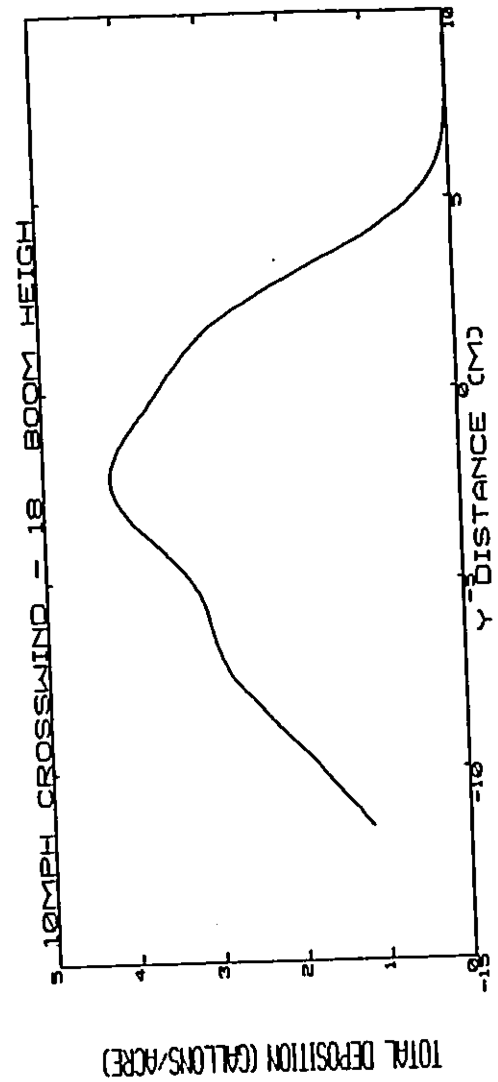


FIGURE 3: SPRAY DRIFT PATTERN OF PESTICIDES-CROSSWIND 10 MPH
CROSSWIND BLOWING FROM RIGHT TO LEFT

CORRECTION

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

FIGURE 2: SPRAY DRIFT PATTERN OF PESTICIDES-CROSSWIND 5 MPH
CROSSWIND BLOWING FROM RIGHT TO LEFT

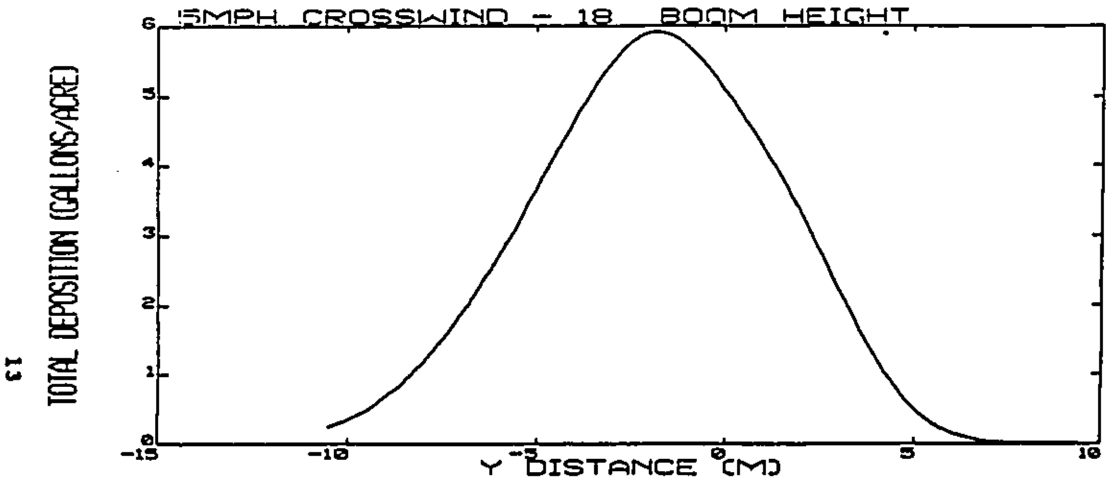


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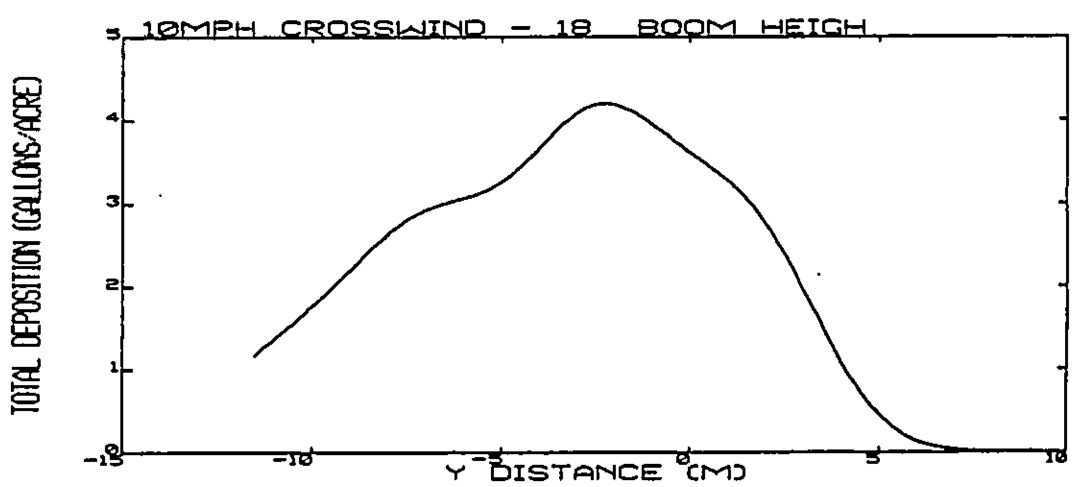
FIGURE 3: SPRAY DRIFT PATTERN OF PESTICIDES-CROSSWIND 10 MPH
CROSSWIND BLOWING FROM RIGHT TO LEFT



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SIGNATURE PAGE

Jeff Tolbe Consulting Scientist	6/14/91 Date
R. Honeycutt R. Honeycutt, Ph.D. Study Director	6-14-91 Date

Appendix D. Boring Logs of NELHA Monitoring Wells W-1 and W-2

APPENDIX A

Field Data

A total of sixteen (16) groundwater monitoring wells were installed at six (6) monitoring sites within the HOST Park/NELH Complex. The approximate locations of these sites are shown on the Site Plan, Plate 2.

The wells were drilled using a truck-mounted rotary drilling rig advancing HQ wireline coring tools. Rock core samples were retrieved for visual examination and classification by our geologist who continuously monitored the operations. A continuous log was maintained for the deepest well drilled at each monitoring site. These logs are presented on the Boring Logs, Plates A-1.1 through A-6.2.

As the wells were being drilled, installed and developed, temperature and conductivity surveys were performed on the groundwater in the wells as an aid to determining screen interval depths. These surveys are shown on Plates A-7 through A-22.

The final as-built sections of the monitoring wells are shown on Plates A-23 through A-28.

W.O. 1846-10 JANUARY 1989

(dk/513/as - 1846appa)

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BORING LOG

W.O. 1846-10 PLATE A-1.1

BORING NO. 1 DRIVING WT. 140 LBS. DATE OF DRILLING 11/30/88 TO 12/07/88

SURFACE ELEV. 102.0'± DROP 30 INCHES ∇ WATER LEVEL SEE NOTE

DEPTH (FEET)	SAMPLE	RUN NO.	REC (%)	RQD (%)	HARDNESS	WEATHERING	GRAPH SYM.	DESCRIPTION
0–4								GRAY BASALT BOULDERS, COBBLES AND GRAVEL (FILL)
5								GRAY COARSELY VESICULAR BASALT, MODERATELY FRACTURED (MEDIUM TO HIGH POROSITY)
10–15		1	100	67	H-VH	UW		GRADES TO VUGULAR AND SLIGHTLY FRACTURED
15–20		2	100	100				
20–25		3	60	33				BROWNISH GRAY VESICULAR BASALT, MODERATELY FRACTURED (HIGH POROSITY)
25–		4	35	80	H	UW-SW		GRADES TO VUGULAR AND MASSIVE (LOW TO MEDIUM POROSITY)

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BORING LOG

W.O. 1846-10 PLATE A-1.2

BORING NO. 1 (CONTINUED) DRIVING WT. 140 LBS. DATE OF DRILLING

SURFACE ELEV. DROP 30 INCHES ∇ WATER LEVEL

DEPTH (FEET)	SAMPLE	RUN NO.	REC (%)	RQD (%)	HARDNESS	WEATHERING	GRAPH SYM.	DESCRIPTION
		5	100	70	H	UW-SW		BROWNISH GRAY FINELY VESICULAR BASALT, MODERATELY FRACTURED (HIGH POROSITY)
35								GRADES TO VUGULAR AND MASSIVE (LOW TO MEDIUM POROSITY)
		6	100	85				
40					MH-H	UW-SW		BROWNISH GRAY FINELY VESICULAR BASALT, MODERATELY FRACTURED (HIGH POROSITY)
		7	90	50	VH	UW		GRAY VUGULAR BASALT, WIDELY FRACTURED (LOW TO MEDIUM POROSITY)
45								
		8	100	70				
50					H	UW-SW		BROWNISH GRAY FINELY TO COARSELY VESICULAR BASALT, MODERATELY TO SEVERELY FRACTURED (MEDIUM TO HIGH POROSITY)
		9	95	8				
55								GRADES TO VUGULAR AND WIDELY FRACTURED (LOW POROSITY)
		10	100	100	VH	UW		

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BORING LOG

W.O. 1846-10 PLATE A-1

ORING NO. 1 (CONTINUED) DRIVING WT. 140 LBS. DATE OF DRILLING

URFACE ELEV. DROP 30 INCHES ∇ WATER LEVEL

DEPTH (FEET)	SAMPLE	RUN NO.	REC (%)	RQD (%)	HARDNESS	WEATHERING	GRAPH SYM.	DESCRIPTION
					LH-MH	SW		RED FINELY TO COARSELY VESICULAR BASALT, SEVERELY FRACTURED (HIGH POROSITY)
		11	100	67	H-VH	UW		GRADES TO GRAY VUGULAR BASALT, SLIGHTLY FRACTURED (LOW TO MEDIUM POROSITY)
65								
		12	75	33	LH-MH	SW		BROWNISH GRAY FINELY VESICULAR BASALT, SEVERELY FRACTURED (HIGH POROSITY)
								GRADES TO VUGULAR BASALT, SLIGHTLY FRACTURED (LOW TO MEDIUM POROSITY)
70								
		13	85	80	H-VH	UW		
75								
		14	100	65				BROWNISH GRAY FINELY VESICULAR BASALT, MODERATELY TO SLIGHTLY FRACTURED (HIGH POROSITY)
80								
		15	100	33	MH-H	UW-SW		
85								
		16	100	65	VH	UW		GRADES TO COARSELY VESICULAR TO VUGULAR BASALT, SLIGHTLY FRACTURED (LOW TO MEDIUM POROSITY)

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BORING LOG

W.O. 1846-10 PLATE A-1.4

BORING NO. 1 (CONTINUED) DRIVING WT. 140 LBS DATE OF DRILLING________

SURFACE ELEV.________ DROP 30 INCHES ∇ WATER LEVEL________

DEPTH (FEET)	SAMPLE	RUN NO.	REC (%)	RQD (%)	HARDNESS	WEATHERING	GRAPH SYM.	DESCRIPTION
		17	100	100	VH	UW		BROWNISH GRAY COARSELY VESICULAR TO VUGULAR BASALT, SLIGHTLY FRACTURED (LOW TO MEDIUM POROSITY) GRADES TO MASSIVE (LOW POROSITY)
95		18	100	87				
100		19	85	50	MH	SW	∇	GRAY-BROWN FINELY VESICULAR BASALT, SEVERELY FRACTURED (HIGH POROSITY)
105		20	100	40				GRADES TO VUGULAR (MEDIUM TO HIGH POROSITY)
110		21	100	70	H	UW-SW		BROWN-GRAY VESICULAR BASALT, MODERATELY FRACTURED (MEDIUM TO HIGH POROSITY)
					VH	UW		GRADES TO VUGULAR, SLIGHTLY FRACTURED (LOW POROSITY)
115					LH-MH	SW		REDDISH TO BROWNISH GRAY FINELY VESICULAR BASALT, SEVERELY FRACTURED (HIGH POROSITY)
		22	100	65	[illegible]	UW		GRADES TO COARSELY VESICULAR BASALT, MODERATELY FRACTURED (MEDIUM POROSITY)

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BORING LOG

W.O. 1846-10 PLATE A-1.5

BORING NO. 1 (CONTINUED) DRIVING WT. 140 LBS DATE OF DRILLING________

SURFACE ELEV.________ DROP 30 INCHES ∇ WATER LEVEL________

DEPTH (FEET)	SAMPLE	RUN NO.	REC (%)	RQD (%)	HARDNESS	WEATHERING	GRAPH SYM.	DESCRIPTION
					H-VH	UW		REDDISH TO BROWNISH GRAY COARSELY VESICULAR BASALT, MODERATELY FRACTURED (MEDIUM (POROSITY)
		23	100	33	LH-MH	SW		GRAY-BROWN BASALT FRAGMENTS, LOOSE (HIGH POROSITY - CLINKER ZONE)
125					H-VH	UW-SW		BROWN-GRAY VUGULAR BASALT, MODERATELY FRACTURED (AA)
		24	55	10		SW		GRAY-BROWN VESICULAR BASALT FRAGMENTS, LOOSE (HIGH POROSITY - CLINKER ZONE)
130		25	100	80	H-VH	UW		GRAY BASALT WITH SOME VUGS, WIDELY FRACTURED (LOW TO MEDIUM POROSITY)
135								

BORING TERMINATED AT 135.0 FEET ON DECEMBER 7, 1988

GROUNDWATER LEVEL AT:

DEPTH	HOURS	DATE
92.8 FT	0715	12/06/88
101.5 FT	0850	12/07/88
101.9 FT	1420	12/07/88
102.0 FT	1240	12/08/88

* ELEVATIONS ESTIMATED FROM SITE PLAN BY R. M. TOWILL CORP., DATED MARCH 25, 1986.

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BORING LOG

W.O. 1846-10 PLATE A-21

BORING NO. 2 DRIVING WT. 140 LBS. DATE OF DRILLING 11/08/88 TO 11/09/88

SURFACE ELEV. 6.0'±** DROP 30 INCHES ∇ WATER LEVEL SEE NOTE

DEPTH (FEET)	SAMPLE	RUN NO.	REC (%)	RQD (%)	HARDNESS	WEATHERING	GRAPH SYM.	DESCRIPTION
								TAN-WHITE GRAVELLY SAND (BEACH SAND)
					H	UW		GRAY FINELY VESICULAR BASALT, SLIGHTLY FRACTURED (MEDIUM TO HIGH POROSITY)
5								6-INCH CAVITY
		1	100	58				
						SW	∇	RED BASALT FRAGMENTS, LOOSE (HIGH POROSITY)
								12-INCH CAVITY
		2	75	70	VH	UW		GRAY COARSELY VESICULAR BASALT, SLIGHTLY FRACTURED (MEDIUM POROSITY)
10						SW		RED BASALT FRAGMENTS, LOOSE (HIGH POROSITY – CLINKER ZONE)
		3	100	98	VH	UW		GRAY COARSELY VESICULAR TO VUGULAR DENSE BASALT, SLIGHTLY FRACTURED (MEDIUM POROSITY)
15								
					H	UW-SW		GRAY FINELY VESICULAR BASALT, MODERATELY TO SEVERELY FRACTURED (HIGH POROSITY)
		4	90	80	VH	UW		GRAY COARSELY VESICULAR TO DENSE VUGULAR BASALT, SLIGHTLY FRACTURED (MEDIUM POROSITY)
20								
		5	100	67	H	UW		GRAY VESICULAR BASALT, MODERATELY FRACTURED (MEDIUM TO HIGH POROSITY)
25					VH	UW		GRADES TO VUGULAR, MODERATELY FRACTURED (LOW TO MEDIUM POROSITY)
		6	60	25	LH-UH	UW		DARK GRAY FINELY VESICULAR BASALT, MODERATELY TO INTENSELY FRACTURED (HIGH POROSITY)
								10-INCH VOID

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BORING LOG

W.O. 1846-10 PLATE A-22

BORING NO. 2 (CONTINUED) DRIVING WT. 140 LBS. DATE OF DRILLING

SURFACE ELEV. DROP 30 INCHES ∇ WATER LEVEL

DEPTH (FEET)	SAMPLE	RUN NO.	REC (%)	RQD (%)	HARDNESS	WEATHERING	GRAPH SYM.	DESCRIPTION
								DARK GRAY BASALT CLINKER GRAVEL AND SAND, LOOSE (HIGH POROSITY – LITTORAL DEPOSIT)(SP/GP)
35		7	0	0				
40								
45		8	2	0				
50								
55								BORING TERMINATED AT 53.5 FEET ON NOVEMBER 9, 1988

GROUNDWATER LEVEL AT:

DEPTH	HOURS	DATE
6.1 FT	1010	11/08/88
5.8 FT	1435	11/08/88

**ELEVATIONS DETERMINED BY [illegible]

Appendix E. "An Evaluation of the Role of Coastal Development in Incidences of Ciguatera Fish Poisoning" by Marine Research Consultants

An Evaluation of the Role of Coastal Development In Incidences of Ciguatera Fish Poisoning

At the present time there is substantial concern regarding the connection between shoreline development and increases in incidences of a form of food poisoning termed ciguatera. Ciguatera is a circumtropical occurrence caused by the ingestion of a wide variety of fishes associated with coral reefs. Ciguatoxin (CTX) is the principal toxin involved (Scheuer et al. 1967) and is believed to accumulate via the marine food chain. Other toxins such as scaritoxin and maitotoxin (MTX) may also be implicated in production of the wide variety of gastroenterological and neurological symptoms reported for ciguatera.

Ciguatera poisoning is not a recent phenomenon; reports of the poisoning in the Pacific date back to 1606, when Spanish sailors suffered from ciguatera in the New Hebrides (Withers 1982). Recent outbreaks have been documented in the Pacific in Hawaii, Japan, New Caledonia, Guam, Fiji, and Okinawa, and in the Atlantic throughout the Caribbean and Florida (Ballantine et al.1985).

The microscopic organism implicated as the source of the ciguatera toxin (termed the elaborator) is a photosynthetic benthic dinoflagellate, *Gambierdiscus toxicus* that was first identified in the Gambier Islands of French Polynesia. The dinoflagellate occurs as an epiphyte on various species of filamentous or calcareous macroalgae and coral detritus. However it is not known whether chemotaxis or purely physical parameters govern the selectivity of the host alga by the dinoflagellate.

It is important to note that the presence of the dinoflagellate does not guarantee toxic conditions. Gillespie et al. (1985) found high concentrations of *G. toxicus* along the Queensland coast which showed no presence of ciguatoxin. Apparently *G. toxicus* can exist and grow in the wild in a non-ciguatoxic state. It is possible that elaboration of ciguatoxin requires specific conditions which are not necessarily the same as those required for growth of *G. toxicus*. Thus, the development of blooms of *G. toxicus* and the stimulation of toxin production may be two separable and distinguishable events triggered by different factors.

Present knowledge of the environmental controls of *G. toxicus* remain obscure although many theories have been suggested regarding environmental triggering of high concentrations of toxic cells. Toxic outbreaks of ciguatera are sporadic and unpredictable with patchy distribution in both space and time. Such patchy distribution of higher population numbers is likely a result of the weak swimming ability of the organism together with the tendency to attach to surfaces (Taylor 1979).

Although important questions remain unanswered, it appears that primary features of the distribution of the organism have become established: it is positively correlated with finely branched, bushy branched macroalgae and sunlight. In general, highest concentrations of *G. toxicus* occur in shallow (0.5 - 3 m) sheltered areas in which filamentous seaweeds are not intensively grazed, and where land runoff and turbulence is minimal (small islands, arid coasts or where strong oceanic currents closely approach the coast). In a study of the distribution of *G. toxicus* in the eastern Caribbean, Taylor (1985) found populations dropped substantially during the stormy, rainy season, and showed a marked increase when the weather improved. He also found that shelter from wave stress was important with populations favoring lee locales, but not regions receiving substantial runoff from land.

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Ciguatera outbreaks often appear to follow disturbance of coral reefs by manmade or natural causes. While it is clear that every instance of reef disturbance is not followed by an upsurge in fish toxicity (Banner 1974), Yasumoto et al.(1980) have postulated that reef disruption provides sites for the attachment of the algal hosts, resulting in ciguatera initiation through the eventual appearance of high populations of the organism. The literature contains numerous references to the occurrence of ciguatera six months to a year after hurricanes (summarized in Taylor 1985). Colonization studies suggest that it may take four months before *G. toxicus* appears on new algal growth (Bagnis et. al 1985).

The theory linking disruption of the reef surface to toxic outbreaks has been extended to implicate shoreline development as a cause of increased incidences of ciguatera. Projects that include excavation of the reef for such facilities as entrance channels and marinas inevitably result in bared substratum during the period of

construction. As described above, the successional sequence of recolonization of bared surfaces may include a phase where host macroalgae proliferate, resulting in an possible increase in toxic cells. As there appears to be some incidences where outbreaks follow disturbances that clear substrate, such a scenario following excavation is possibility. However, it is important to note that the areal extent of cleared substratum by excavation is likely to be very minor compared to the damage to reefs caused by major storms or hurricanes. In addition, the process of baring substrata owing to excavation is a one-time event, while storms, though unpredictable and sporadic in occurrence, occur repeatedly in the same area. Thus, while some shoreline development activities may temporarily increase the potential for ciguatera, such potential appears to be minor compared to natural events.

Excavation of the backshore area, with no open connections to the ocean does not appear to provide any potential for increased incidences of ciguatera in the natural environment. Such construction activity does not result in alteration (e.g. clearing) of substrata. While new surfaces are created within the artificial basin that might be suitable for growth of the host algae, the lack of a passage to the open ocean prevents movement of potentially toxic cells to the marine environment.

Another perceived impact of human activities is that runoff of fertilizers and biocides can elicit ciguatera outbreaks. Such theories defy scientific evidence as well as logic for a variety of reasons. Biocides by definition function by killing organisms; thus it is not readily conceivable that these chemicals could act in a biostimulatory manner.

It has been suggested that fertilizers used on golf course can provide a stimulus for ciguatera outbreaks. Controlled experiments showed that only silicates, and not phosphate or nitrates resulted in increased abundances of *G. toxicus* (Caire et al. 1985). In Hawaii, silicates occur in very high concentrations in naturally occurring groundwater (about 500 times higher than ocean water), and are not a component of fertilizers or other turf chemicals. Thus, any stimulation of ciguateric activity owing to silicates is a result of natural processes and is not coupled to shoreline development.

It has been demonstrated in the laboratory that the principal nutrients composing plant fertilizers (nitrogen and phosphorus) do not cause increases in toxic cell abundances. There is also additional logical evidence that nutrients from fertilizers cannot be implicated in enhancing the potential of toxic outbreaks. Naturally occurring groundwater flows into the ocean along the west Hawaii coastline at a rate of about 2 to 6 million gallons per day. Nitrogen content of groundwater is approximately 400 times seawater while phosphorus content of groundwater is about 30 times seawater. At the minimum groundwater flow rate of 2 million gallons approximately 90 pounds of NO_3^- and 5 pounds of PO_4^{-3} are added to the ocean along each mile of shoreline per day. At a maximum flow rate nearly 300 pounds of NO_3^- and 15 pounds of PO_4^{-3} reach each mile of the nearshore environment each day. For the entire coastline of west Hawaii input of NO_3^- is about 9,000 pounds per day, and input of PO_4^{-3} is about 500 pounds per day. Thus, the natural loading of these two nutrients to the marine environment is substantial along the entire coastline. If, contrary to stated findings, there were a response of *G. toxicus* to plant nutrients, such stimulation would occur continuously and would represent the normal situation.

Numerous studies in golf courses in Hawaii, as well on courses around the world (Petrovic 1990), show that about 10% of applied fertilizer nitrogen and 1% of fertilizer phosphorus may leach through the turf/soil layer to underlying groundwater. Studies conducted off golf courses on west Hawaii reveal that such inputs are generally not detectable along open coastlines owing to rapid mixing by waves and currents. In areas of restricted circulation, such as embayments, nutrient delivery from groundwater is contained in a surface layer that generally does not come into contact with the benthos, where macroalgal hosts are found (Dollar and Atkinson, submitted). Thus, at all levels of consideration, there are no grounds for implying that inputs of nutrients could provide a basis for augmenting toxic outbreaks.

Analysis of State of Hawaii health records also provide some circumstantial basis for assessing the connection between shoreline development and ciguatera outbreaks. As shoreline resorts have been in existence for several decades, it is reasonable to expect that if a connection exists between shoreline development and ciguatera, there would be some relationship between locale and number of reported incidences. Outside of Waikiki, the most concentrated area of resort development in the state is on the west Maui coastline between Kapalua and Kihei. Between 1984 and 1988, there were 4 reported cases of ciguatera within this region. By comparison, during the same time period 63 cases were reported from west Hawaii. Geographical breakdown of the west Hawaii incidences showed 35 cases in the Milolii area, 13 in the Kawaihae area, 5 in Kailua area, and 7 in the South Point area (see map). The predonderance of toxic occurrences in west Hawaii compared to Maui suggests that there is no clear-cut relationship between shoreline activity and toxicity.

It is also apparent that the areas of highest number of toxic incidences on west Hawaii are far removed from any development. However, the areas of highest incidences are locations

of greatest fishing effort. The high number of reported cases may therefore be a response to larger proportions of local populations ingesting reef fish, rather than a difference in environmental conditions that trigger outbreaks. Elevated levels of ciguatera in regions of high fishing pressure may also be a consequence of indirect environmental alteration. Intense fishing effort may decrease populations of resident herbivorous fish that normally feed on the host algae of *G. toxicus*. The lack of grazing pressure may result in increased populations of these algae, which in turn could provide a favorable environment for increases in ciguatoxic cells. To date no scientific studies have endeavored to explore the relationship between fishing pressure and ciguatera outbreaks.

In summary, more questions than answers remain regarding causal factors associated with ciguatera fish poisoning. Scientific studies from around the world have narrowed down some of the environmental factors that are favorable (and unfavorable) to the organisms responsible for the disease. Linkages between environmental events and outbreaks have been implied, but are not consistent enough in nature to constitute definitive cause-and-effect relationships. Baring of substrata has been associated with outbreaks owing to increased occurrence of host algae as part of the successional process. If such a pathway occurs, it would seen reasonable that alteration of substrata by humans would be minor in comparison to natural events (storms) which destroy massive amounts of reef on a intermittent, but ongoing basis. Overfishing can also be invoked as an environmental impact that could also lead to increases in populations of host algae.

There is no evidence in the scientific literature linking outbreaks of ciguatoxin to nutrients contained in fertilizers. Even if there were some documentation of such effects, it is not likely that shoreline activities would cause changes in patterns of abundance. Nitrogen and phosphorus are present in substantial concentrations in groundwater that enters the ocean in large quantities through natural processes. Nutrients are therefore not in limited supply in nearshore areas, and any effects to ciguatera occurrence will occur in response to natural input. By comparison, nutrient subsidies to natural groundwater flow from resorts is small, and existing studies have not revealed incidences where existing development has resulted in situations of significant input of chemicals to the marine environment. Therefore, there are no reasonable mechanisms for shoreline development to provide the stimulus for ciguatera

REFERENCES

Bagnis, R. 1969. Naissance et developpment d'une flambee de ciguatera dans un atoll des Tuamotus. Bull. Jap. Soc. Sci. fish. 45:67-71.

Ballantine, D. L., A. T. Bardales, and T. R. Tosteson. Seasonal abundance of *Gambierdiscus toxicus* and *Ostreopsis sp.* in coastal waters of southwest Puerto Rico. Proc. 5th Int. Coral Reef Cong. Vol. 4. 417-422.

Banner, A. H. 1974. The biological origin and transmission of ciguatoxin. In: Humm, H. J. and C. E. Lane (eds.). Bioactive Componds from the Séa. pp.15-36. Marcel Decker, Inc. N.Y.

Caire, J. F., Raymond, A. and R. Bagnis. 1985. Ciguatera: study of the setting up and the evolution of *Gambierdiscus toxicus* population on an artificial substrate introduced in an atoll lagoon with follow up of associated environmental factors. Proc. 5th Int. Coral Reef Cong. Vol. 4 429-435.

Dollar, S. J. and M. J. Atkinson. submitted. Effects of nutrient subsidies from groundwater to nearshore marine ecosystems off the Island of Hawaii.

Gillespie, N., R. Lewis, J. Burke, and M. Holmes. 1985. The significance of the absence of ciguatoxin in a wild population of *G. toxicus*. Proc. 5th Int. Coral Reef Cong. Vol. 4. 437-441.

Patrovic, A. M. 1990. The fate of nitrogenous fertilizers applied to turfgrass. J. Env. Qual. 19:1-14.

Scheuer, P. J. W. Takahashi, J. Tsutsumi and T. Yoshida. 1967. Ciguatoxin. Isolation and chemical nature. Science 155:1267-1268.

Taylor, F. J. R. 1979. A description of the benthic dinoflagellate associated with maitotoxin and ciguatoxin, including observations on Hawaiian material. In: Taylor, D. L and Seliger (eds.), Toxic Dinoflagellate Blooms. pp. 71-76. Elsevier/North-Holland.

Taylor, F. J. R. 1985. The distribution of the dinoflagellate *Gambierdiscus toxicus* in the eastern Caribbean. Proc. 5th Int. Coral Reef Cong. Vol 4. 423-428.

Withers, N. W. 1982. Ciguatera fish poisoning. Ann. Rev. Med. 33:97-111.

Yasumoto, T. and 7 others. 1980. Environmental sudies on a toxic dinoflagellate responsible for ciguatera. Bull. Jap. Soc. Sci. Fish. 46:1397-1401.

TABLE 1
ANNUAL INCIDENCE RATES OF CIGUATERA FISH POISONING PER 100,000 POPULATION BY ISLAND AND YEAR: 1984 - 1988

YEAR	POPULATION	NO. CASES	ANNUAL INCIDENCE PER 100,000 POPULATION
OAHU			
1984	802,351	38	4.7
1985	812,784	29	3.6
1986	818,487	13	1.6
1987	830,597	40	4.8
1988	838,194 est.	27	3.2
KAUAI			
1984	44,167	17	38.5
1985	44,679	47	105.0
1986	46,440	8	17.2
1987	47,600	12	25.2
1988	47,700 est	6	12.5
MAUI			
1984	74,750	5	6.7
1985	76,462	5	6.5
1986	78,790	0	0
1987	81,100	11	13.6
1988	90,300 est	10	11.1
HAWAII			
1984	107,169	26	25.2
1985	108,910	33	30.3
1986	112,039	53	47.3
1987	114,434	43	37.6
1988	115,200 est	39	33.9
STATE			
1984	1,037,206	86	8.3
1985	1,051,481	114	10.8
1986	1,064,732	74	7.0
1987	1,082,500	106	9.8
1988	1,091,394 est	82	7.5
	TOTAL	462	AVERAGE 8.7

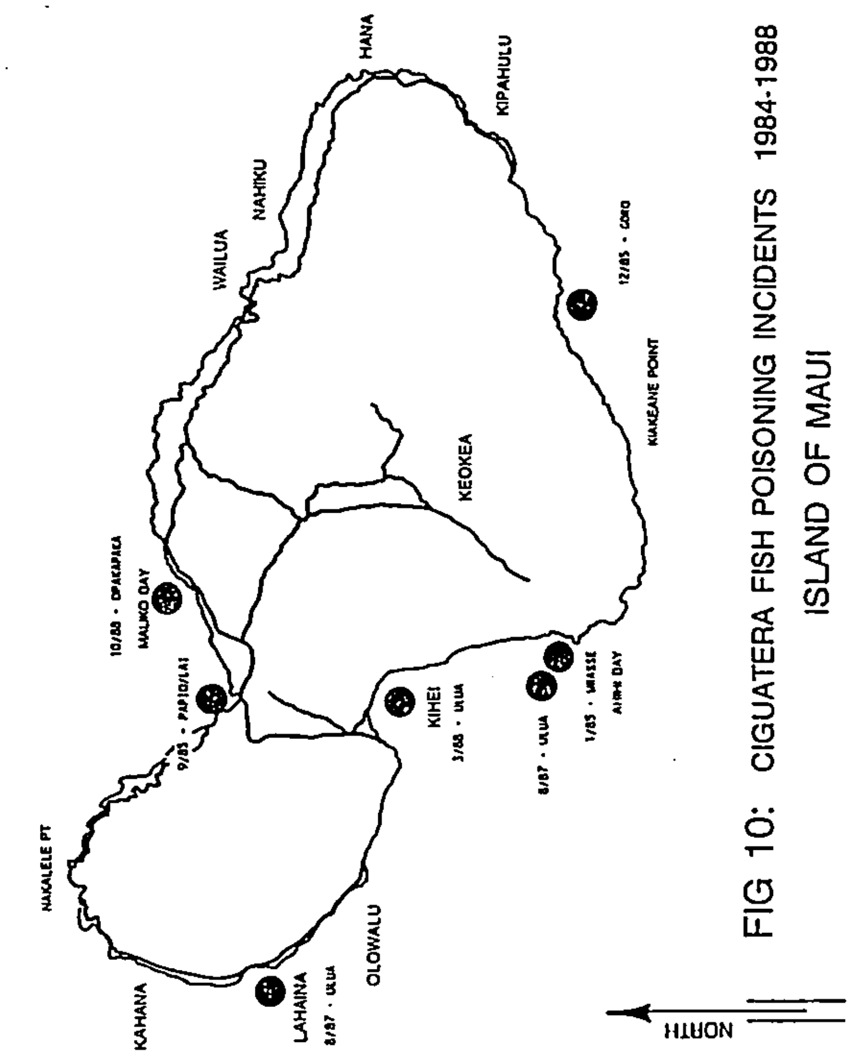


FIG 10: CIGUATERA FISH POISONING INCIDENTS 1984-1988
ISLAND OF MAUI

FIG 7: CIGUATERA FISH POISONING INCIDENTS 1984-1988

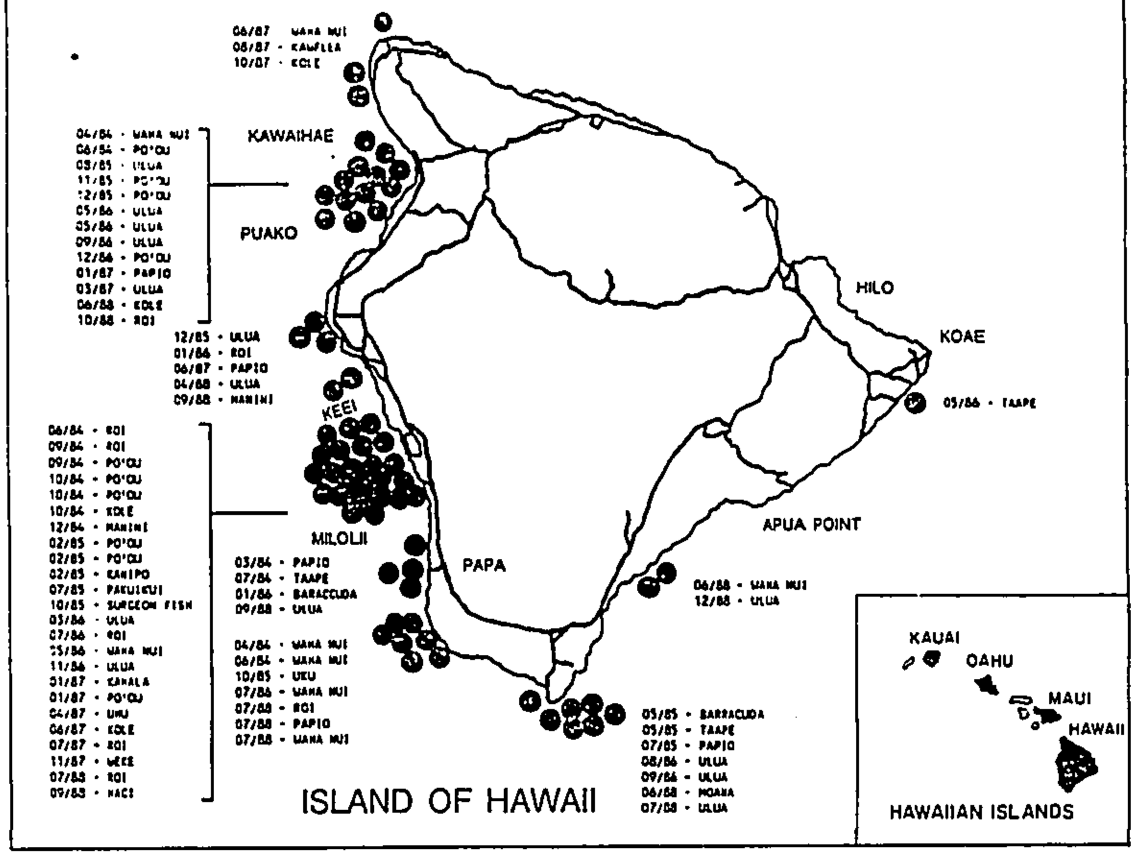
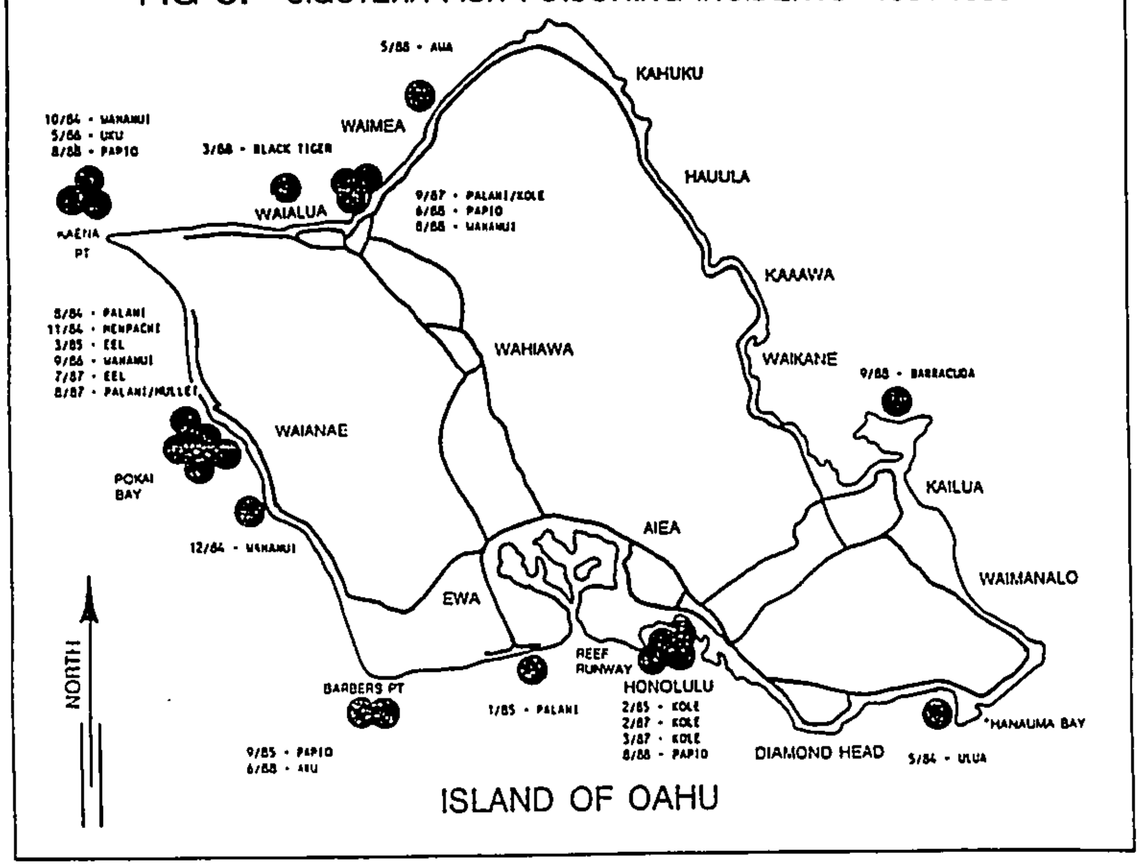


FIG 9: CIGUTERA FISH POISONING INCIDENTS 1984-1988



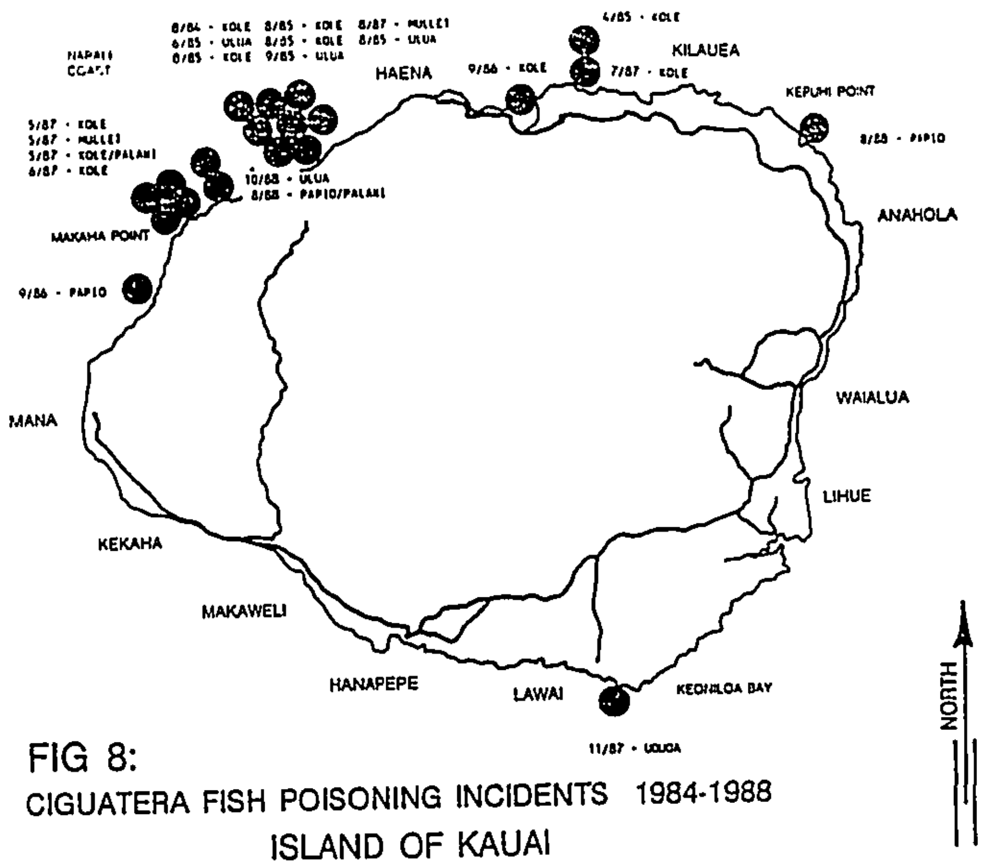


FIG 8:
CIGUATERA FISH POISONING INCIDENTS 1984-1988
ISLAND OF KAUAI

APPENDIX H

DESCRIPTION OF O'OMA II ANCHIALINE POND

Marine Research Consultants

MARINE
RESEARCH
CONSULTANTS

217 PROSPECT ST. F-2
HONOLULU, HI 96813
808-599-4181

September 9, 1991

Scott Ezer
Helber, Hastert & Fee
733 Bishop St. Suite 2590
Honolulu, HI 96813

Dear Scott:

On August 24, 1991 I examined the anchialine pond feature located at the southern boundary of the Ooma property. Below is a brief description of the pond along with results of water chemistry analyses.

As described in the archeology report, the pond is located in a sinkhole with a floor elevation several feet lower than the surrounding lava fields. The anchialine pond in the center of the sinkhole is faced on the seaward side by rock walls. The area of water coverage observed during our survey at high tide was about 1 m^2. Water depth at the deepest point in the pond was about 0.5 m. The water column throughout the pond was extremely clear, with no apparent turbidity from suspended sediments or phytoplankton. No layers of surface algae or organic scums that are often noted on older ponds were present.

The dominant biota in the ponds were the red shrimp opae'ula (*Halocaridina rubra* and *Metabateus lohena*), and the glass shrimp *Palaemon debilis*). All species of shrimp were abundant in the pond. The three snails common to anchialine ponds (*Assiminea sp., Melania sp.* and *Theodoxus cariosa* were also observed. No fish were noted.

Water chemistry constituents measured in a single sample were as follows: NO_3^- = 62.98 μM; NH_4^+ = 0.71 μM; PO_4^{-3} = 2.55 μM; Si = 524.91 μM; Total nitrogen = 65.41 μM; total phosphorus = 1.72 μM; turbidity = 0.12 ntu; and salinity = 12.959 °/oo. None of these measurements appears to indicate any unusual characteristics of the pond chemistry. Based on a groundwater sample taken from a potable well upslope of Honokohau, the pond:well ratio of Si is the same as the pond:well ratio of NO_3^-. Such agreement indicates that there is presently no detectable nutrient subsidy to the pond from sources other than uncomtaminated groundwater. The extremely low turbidity value also verifies the lack of suspended material that could ultimately affect tidal exhange in the pond. In summary, the existing chemical and biotic structure of the pond depicts the classic representation of anchialine pools in West Hawaii that have not been affected by activities of man.

Sincerely,

Steven Dollar, Ph.D.

APPENDIX I

LETTER FROM DR. RICHARD BROCK TO MS. TONI FORTIN

SEP 3 1991

University of Hawaii at Manoa

Hawaii Institute of Marine Biology
P.O.Box 1346 • Coconut Island • Kaneohe, Hawaii 96744-1346
Cable Address: UNIHAW

22 August 1991

Ms. Toni Fortin
Kahala Capital Corp.
25-5751 Kuakini Highway, Suite 202
Kailua-Kona, Hawaii 96740

<u>SUBJECT</u>: Review of O'oma II Recreation Lake and Golf Course Development on Adjacent Anchialine Pools

Dear Ms. Fortin,

By way of background, I am the Pond Manager for the Waikoloa Anchialine Pond Preserve located at Waikoloa, Hawaii. This program is administered under the University of Hawaii Foundation with funds placed in a trust account for this purpose. Since 1986, I have carried out water quality and biological studies in these ponds and for 15 years prior to that, I have conducted similar activities elsewhere on the Kona and Ka'u coastlines. Dr. Steven Dollar has asked me to comment on the potential impacts that may occur to anchialine pool resources at Kohanaiki with the development of the proposed 7 acre marine water feature and golf course on your O'oma project site. He has provided me with the results of numerical modeling for the groundwater resources of the area, specifically, a salinity isohaline contour map, a similar map showing predicted lines of nitrate nitrogen concentrations in the groundwater and a table of water quality characteristics from anchialine pools at Kohanaiki.

I am sure that you are well aware of the difficulties in accurately predicting response of many biological communities to subtle environmental changes. However, much of our research has shown that anchialine pond organisms appear to be very tolerant to large changes in water chemistry and other environmental factors. For example, one of the most characteristic species, the little red shrimp or 'opae'ula (<u>Halocardina</u> <u>rubra</u>) is found naturally in anchialine pond water with salinities from about 0.5 to about 25ppt; we have kept this species in the laboratory in salinities ranging from freshwater to seawater with no ill effects. At Waikoloa we have witnessed drastic changes in the concentration of inorganic nutrients derived from the golf courses present on the property. Nitrate nitrogen increased from 40uM prior to golf course development to more than 120uM during the "grow-in" of the Kings Golf Course. We have demonstrated that these changes are due to the development and operation of the golf courses at Waikoloa. Despite these tremendous changes in the concentration of inorganic nutrients, we have not encountered any quantifiable ill-effects to the biota.

As I alluded to above, we sample chemical parameters in the ground, anchialine and nearshore marine waters at numerous other localities on the Kona coast. Our dataset comprises more than 450 water quality samples collected annually and probably represents one of the most comprehensive longterm water quality datasets available for the West Hawaii coast. In summarizing this information, two main points emerge: the first is that within a given location we find very little variation in the water quality characteristics from year to year (assuming that no nearby development is occurring) and secondly, that there is tremendous variation in the parameters that we measure between sites. Thus locations with absolutely no surrounding development may have very low inorganic nutrient concentrations or they may be extremely high. The "take home" message here is that the biota of anchialine ponds is found in all of these systems thus appears to thrive under a wide natural range in water chemistry parameters.

The end result is that despite the statistically significant increases in the concentration of inorganic nutrients that we have seen at Waikoloa with continuing development, these increases remain within the range of concentrations that we encounter at sites that have absolutely no surrounding development.

In summary, anchialine biota appears to live under tremendously variable conditions with respect to water chemistry (including nitrate nitrogen). Additionally, anchialine pools may be very ephemeral in geological time; they may be created by a lava flow and buried by the next flow two months or two hundred years later. Generally, natural infilling of pond basins limits the life expentancy of many pools to less than a couple of hundred years. Most aquatic ecosystems evolve and exist for reasonably long periods of time (i.e., thousands of years), but with Hawaiian anchialine pools this may not be the case. If so, this would argue that the biota has evolved to (1) rapidly colonize habitat once it is created and (2) that these species are also capable of surviving under a variety of environmental conditions.

How does this relate to your project? First the proposed marine recreation pool will increase the salinity from 1 to more than 20ppt in the northern Kohanaiki anchialine pools. As per the salinity isohaline contour map, maximum expected salinities will be close to 30ppt, a level that should not impact the anchialine biota. The predicted changes in nitrate nitrogen in the northern Kohanaiki ponds due to golf course development at O'oma fall into the range presently seen in some Kona coast anchialine pools thus I would not anticipate a negative impact.

Interestingly, there are a number of organisms found in Hawaiian anchialine pools that are found nowhere else; some of these species are presently only known from just a few ponds. One characteristic of these rare anchialine species is that they are restricted to anchialine pools with salinities greater than 12 to 15ppt and the salinity is usually greater than 20ppt. To my knowledge, none of these rare species are present in the Kohanaiki anchialine pools. Using the OI Consultants, Inc. salinity data available to me for the Kohanaiki pools, the mean salinity is 12.6ppt (n=25). Increasing the salinity in the northern Kohanaiki pools via your development raises an intriguing question of whether we could cause the appearance of these rare shrimp species where they apparently do not presently occur by proceeding with the development.

There is a cautionary note that should be added here -- many of the ponds at Kohanaiki have been infested with exotic fishes that have upset the ecological balance in those pools. Without the native herbivorous shrimp present (they are essentially absent in pools with exotic fishes due to predation) the processes of natural infilling of the ponds may be increased. The additional nutrient inputs may serve to enhance the growth of vegetation and the deposition of leaf litter and detritus. I suggest that if your project were to go forward, you may wish to consider a cooperative effort with the owners of the Kohanaiki pools for the eradication of the exotic fishes from the pools. As part of our management program at Waikoloa, we have spent considerable time developing a strategy for removing fishes from pools; this technology could be used in clearing the Kohanaiki anchialine pools.

I hope that these thoughts are of use to you in your planning process. If you wish to discuss any of the above, I may be reached during the day at 956-2859 or in the evenings at home at 737-3890. Thank you for the opportunity to comment on your interesting project!

Sincerely yours,

R.E. Brock

Richard E. Brock, Ph.D.

APPENDIX J

ASSESSMENT OF COASTAL DEVELOPMENT AND CIGUATERA FISH POISONING

Marine Research Consultants

An Evaluation of the Role of Coastal Development in Incidences of Ciguatera Fish Poisoning

At the present time there is substantial concern regarding the connection between shoreline development and increases in incidences of a form of food poisoning termed ciguatera. Ciguatera is a circumtropical occurrence caused by the ingestion of a wide variety of fishes associated with coral reefs. Ciguatoxin (CTX) is the principal toxin involved (Scheuer et al. 1967) and is believed to accumulate via the marine food chain. Other toxins such as scaritoxin and maitotoxin (MTX) may also be implicated in production of the wide variety of gastroenterological and neurological symptoms reported for ciguatera.

Ciguatera poisoning is not a recent phenomenon; reports of the poisoning in the Pacific date back to 1606, when Spanish sailors suffered from ciguatera in the New Hebrides (Withers 1982). Recent outbreaks have been documented in the Pacific in Hawaii, Japan, New Caledonia, Guam, Fiji, and Okinawa, and in the Atlantic throughout the Caribbean and Florida (Ballantine et al. 1985).

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It is important to note that the presence of the dinoflagellate does not guarantee toxic conditions. Gillespie et al. (1985) found high concentrations of *G. toxicus* along the Queensland coast which showed no presence of ciguatoxin. Apparently *G. toxicus* can exist and grow in the wild in a non-ciguatoxic state. It is possible that elaboration of ciguatoxin requires specific conditions which are not necessarily the same as those required for growth of *G. toxicus*. Thus, the development of blooms of *G. toxicus* and the stimulation of toxin production may be two separable and distinguishable events triggered by different factors.

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Although important questions remain unanswered, it appears that primary features of the distribution of the organism have become established: it is positively correlated with finely branched, bushy branched macroalgae and sunlight. In general, highest concentrations of *G. toxicus* occur in shallow (0.5 - 3 m) sheltered areas in which filamentous seaweeds are not intensively grazed, and where land runoff and turbulence is minimal (small islands, arid coasts or where strong oceanic currents closely approach the coast). In a study of the distribution of *G. toxicus* in the eastern Caribbean, Taylor (1985) found populations dropped substantially during the stormy, rainy season, and showed a marked increase when the weather improved. He also found that shelter from wave stress was important with populations favoring lee locales, but not regions receiving substantial runoff from land.

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Excavation of the backshore area, with no open connections to the ocean does not appear to provide any potential for increased incidences of ciguatera in the natural environment. Such construction activity does not result in alteration (e.g. clearing) of substrata. While new surfaces are created within the artificial basin that might be suitable for growth of the host algae, the lack of a passage to the open ocean prevents movement of potentially toxic cells to the marine environment.

Another perceived impact of human activities is that runoff of fertilizers and biocides can elicit ciguatera outbreaks. Such theories defy scientific evidence as well as logic for a variety of reasons. Biocides by definition function by killing organisms; thus it is not readily conceivable that these chemicals could act in a biostimulatory manner.

It has been suggested that fertilizers used on golf course can provide a stimulus for ciguatera outbreaks. Controlled experiments showed that only silicates, and not phosphate or nitrates resulted in increased abundances of *G. toxicus* (Caire et·al. 1985). In Hawaii, silicates occur in very high concentrations in naturally occurring groundwater (about 500 times higher than ocean water), and are not a component of fertilizers or other turf chemicals. Thus, any stimulation of ciguateric activity owing to silicates is a result of natural processes and is not coupled to shoreline development.

It has been demonstrated in the laboratory that the principal nutrients composing plant fertilizers (nitrogen and phosphorus) do not cause increases in toxic cell abundances. There is also additional logical evidence that nutrients from fertilizers cannot be implicated in enhancing the potential of toxic outbreaks. Naturally occurring groundwater flows into the ocean along the west Hawaii coastline at a rate of about 2 to 6 million gallons per day. Nitrogen content of groundwater is approximately 400 times seawater while phosphorus content of groundwater is about 30 times seawater. At the minimum groundwater flow rate of 2 million gallons approximately 90 pounds of NO_3^- and 5 pounds of PO_4^{-3} are added to the ocean along each mile of shoreline per day. At a maximum flow rate nearly 300 pounds of NO_3^- and 15 pounds of PO_4^{-3} reach each mile of the nearshore environment each day. For the entire coastline of west Hawaii input of NO_3^- is about 9,000 pounds per day, and input of PO_4^{-3} is about 500 pounds per day. Thus, the natural loading of these two nutrients to the marine environment is substantial along the entire coastline. If, contrary to stated findings, there were a response of *G. toxicus* to plant nutrients, such stimulation would occur continuously and would represent the normal situation.

Numerous studies in golf courses in Hawaii, as well on courses around the world (Petrovic 1990), show that about 10% of applied fertilizer nitrogen and 1% of fertilizer phosphorus may leach through the turf/soil layer to underlying groundwater. Studies conducted off golf courses on west Hawaii reveal that such inputs are generally not detectable along open coastlines owing to rapid mixing by waves and currents. In areas of restricted circulation, such as embayments, nutrient delivery from groundwater is contained in a surface layer that generally does not come into contact with the benthos, where macroalgal hosts are found (Dollar and Atkinson, submitted). Thus, at all levels of consideration, there are no grounds for implying that inputs of nutrients could provide a basis for augmenting toxic outbreaks.

Analysis of State of Hawaii health records also provide some circumstantial basis for assessing the connection between shoreline development and ciguatera outbreaks. As shoreline resorts have been in existence for several decades, it is reasonable to expect that if a connection exists between shoreline development and ciguatera, there would be some relationship between locale and number of reported incidences. Outside of Waikiki, the most concentrated area of resort development in the state is on the west Maui coastline between Kapalua and Kihei. Between 1984 and 1988, there were 4 reported cases of ciguatera within this region. By comparison, during the same time period 63 cases were reported from west Hawaii. Geographical breakdown of the west Hawaii incidences showed 35 cases in the Milolii area, 13 in the Kawaihae area, 5 in Kailua area, and 7 in the South Point area (see map). The predonderance of toxic occurrences in west Hawaii compared to Maui suggests that there is no clear-cut relationship between shoreline activity and toxicity.

It is also apparent that the areas of highest number of toxic incidences on west Hawaii are far removed from any development. However, the areas of highest incidences are locations of greatest fishing effort. The high number of reported cases may therefore be a response to larger proportions of local populations ingesting reef fish, rather than a difference in environmental conditions that trigger outbreaks. Elevated levels of ciguatera in regions of high fishing pressure may also be a consequence of indirect environmental alteration. Intense fishing effort may decrease populations of resident herbivorous fish that normally feed on the host algae of *G. toxicus*. The lack of grazing pressure may result in increased populations of these algae, which in turn could provide a favorable environment for increases in ciguatoxic cells. To date no scientific studies have endeavored to explore the relationship between fishing pressure and ciguatera outbreaks.

In summary, more questions than answers remain regarding causal factors associated with ciguatera fish poisoning. Scientific studies from around the world have narrowed down some of the environmental factors that are favorable (and unfavorable) to the organisms responsible for the disease. Linkages between environmental events and outbreaks have been implied, but are not consistent enough in nature to constitute definitive cause-and-effect relationships. Baring of substrata has been associated with outbreaks owing to increased occurrence of host algae as part of the successional process. If such a pathway occurs, it would seen reasonable that alteration of substrata by humans would be minor in comparison to natural events (storms) which destroy massive amounts of reef on a intermittent, but ongoing basis. Overfishing can also be invoked as an environmental impact that could also lead to increases in populations of host algae.

There is no evidence in the scientific literature linking outbreaks of ciguatoxin to nutrients contained in fertilizers. Even if there were some documentation of such effects, it is not likely that shoreline activities would cause changes in patterns of abundance. Nitrogen and phosphorus are present in substantial concentrations in groundwater that enters the ocean in large quantities through natural processes. Nutrients are therefore not in limited supply in nearshore areas, and any effects to ciguatera occurrence will occur in response to natural input. By comparison, nutrient subsidies to natural groundwater flow from resorts is small, and existing studies have not revealed incidences where existing development has resulted in situations of significant input of chemicals to the marine environment. Therefore, there are no reasonable mechanisms for shoreline development to provide the stimulus for ciguatera

REFERENCES

Bagnis, R. 1969. Naissance et developpment d'une flambee de ciguatera dans un atoll des Tuamotus. Bull. Jap. Soc. Sci. fish. 45:67-71.

Ballantine, D. L., A. T. Bardales, and T. R. Tosteson. Seasonal abundance of *Gambierdiscus toxicus* and *Ostreopsis sp.* in coastal waters of southwest Puerto Rico. Proc. 5th Int. Coral Reef Cong. Vol. 4. 417-422.

Banner, A. H. 1974. The biological origin and transmission of ciguatoxin. In: Humm, H. J. and C. E. Lane (eds.). Bioactive Componds from the Sea. pp.15-36. Marcel Decker, Inc. N.Y.

Caire, J. F., Raymond, A. and R. Bagnis. 1985. Ciguatera: study of the setting up and the evolution of *Gambierdiscus toxicus* population on an artificial substrate introduced in an atoll lagoon with follow up of associated environmental factors. Proc. 5th Int. Coral Reef Cong. Vol. 4 429-435.

Dollar, S. J. and M. J. Atkinson. submitted. Effects of nutrient subsidies from groundwater to nearshore marine ecosystems off the Island of Hawaii.

Gillespie, N., R. Lewis, J. Burke, and M. Holmes. 1985. The significance of the absence of ciguatoxin in a wild population of *G. toxicus*. Proc. 5th Int. Coral Reef Cong. Vol. 4. 437-441.

Petrovic, A. M. 1990. The fate of nitrogenous fertilizers applied to turfgrass. J. Env. Qual. 19:1-14.

Scheuer, P. J. W. Takahashi, J. Tsutsumi and T. Yoshida. 1967. Ciguatoxin. Isolation and chemical nature. Science 155:1267-1268.

Taylor, F. J. R. 1979. A description of the benthic dinoflagellate associated with maitotoxin and ciguatoxin, including observations on Hawaiian material. In: Taylor, D. L and Seliger (eds.), Toxic Dinoflagellate Blooms. pp. 71-76. Elsevier/North-Holland.

Taylor, F. J. R. 1985. The distribution of the dinoflagellate *Gambierdiscus toxicus* in the eastern Caribbean. Proc. 5th Int. Coral Reef Cong. Vol 4. 423-428.

Withers, N. W. 1982. Ciguatera fish poisoning. Ann. Rev. Med. 33:97-111.

Yasumoto, T. and 7 others. 1980. Environmental sudies on a toxic dinoflagellate responsible for ciguatera. Bull. Jap. Soc. Sci. Fish. 46:1397-1401.

TABLE 1
ANNUAL INCIDENCE RATES OF CIGUATERA FISH POISONING PER 100,000 POPULATION BY ISLAND AND YEAR: 1984 - 1988

YEAR	POPULATION	NO. CASES	ANNUAL INCIDENCE PER 100,000 POPULATION
OAHU			
1984	802,351	38	4.7
1985	812,784	29	3.6
1986	818,487	13	1.6
1987	830,597	40	4.8
1988	838,194 est.	27	3.2
KAUAI			
1984	44,167	17	38.5
1985	44,679	47	105.0
1986	46,440	8	17.2
1987	47,600	12	25.2
1988	47,700 est.	6	12.5
MAUI			
1984	74,750	5	6.7
1985	76,462	5	6.5
1986	78,790	0	0
1987	81,100	11	13.6
1988	90,300 est.	10	11.1
HAWAII			
1984	107,169	26	25.2
1985	108,910	33	30.3
1986	112,039	53	47.3
1987	114,434	43	37.6
1988	115,200 est.	39	33.9
STATE			
1984	1,037,206	86	8.3
1985	1,051,481	114	10.8
1986	1,064,732	74	7.0
1987	1,082,500	106	9.8
1988	1,091,394 est.	82	7.5
	TOTAL	462	AVERAGE 8.7

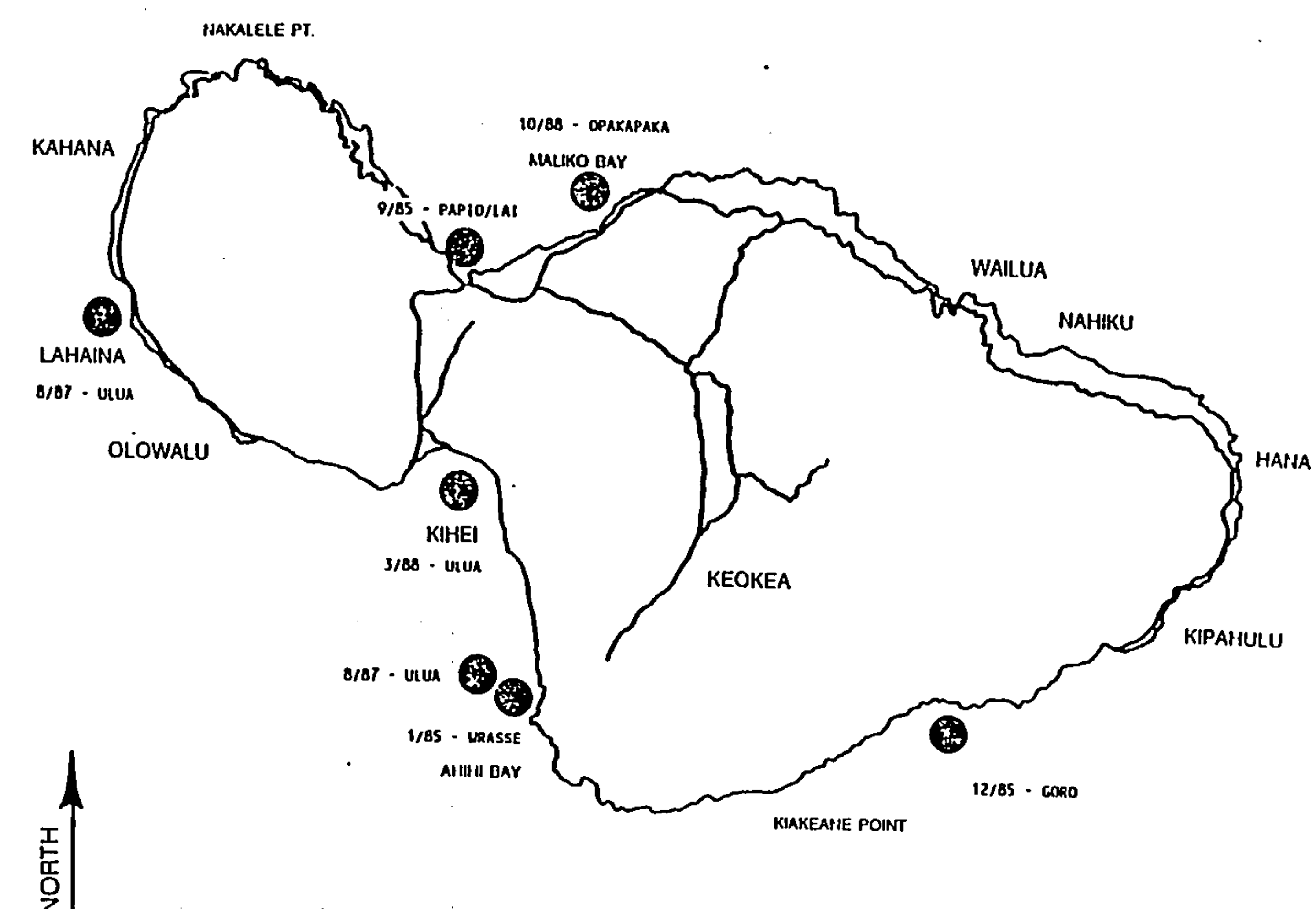


FIG 10: CIGUATERA FISH POISONING INCIDENTS 1984-1988
ISLAND OF MAUI

FIG 7: CIGUATERA FISH POISONING INCIDENTS 1984-1988

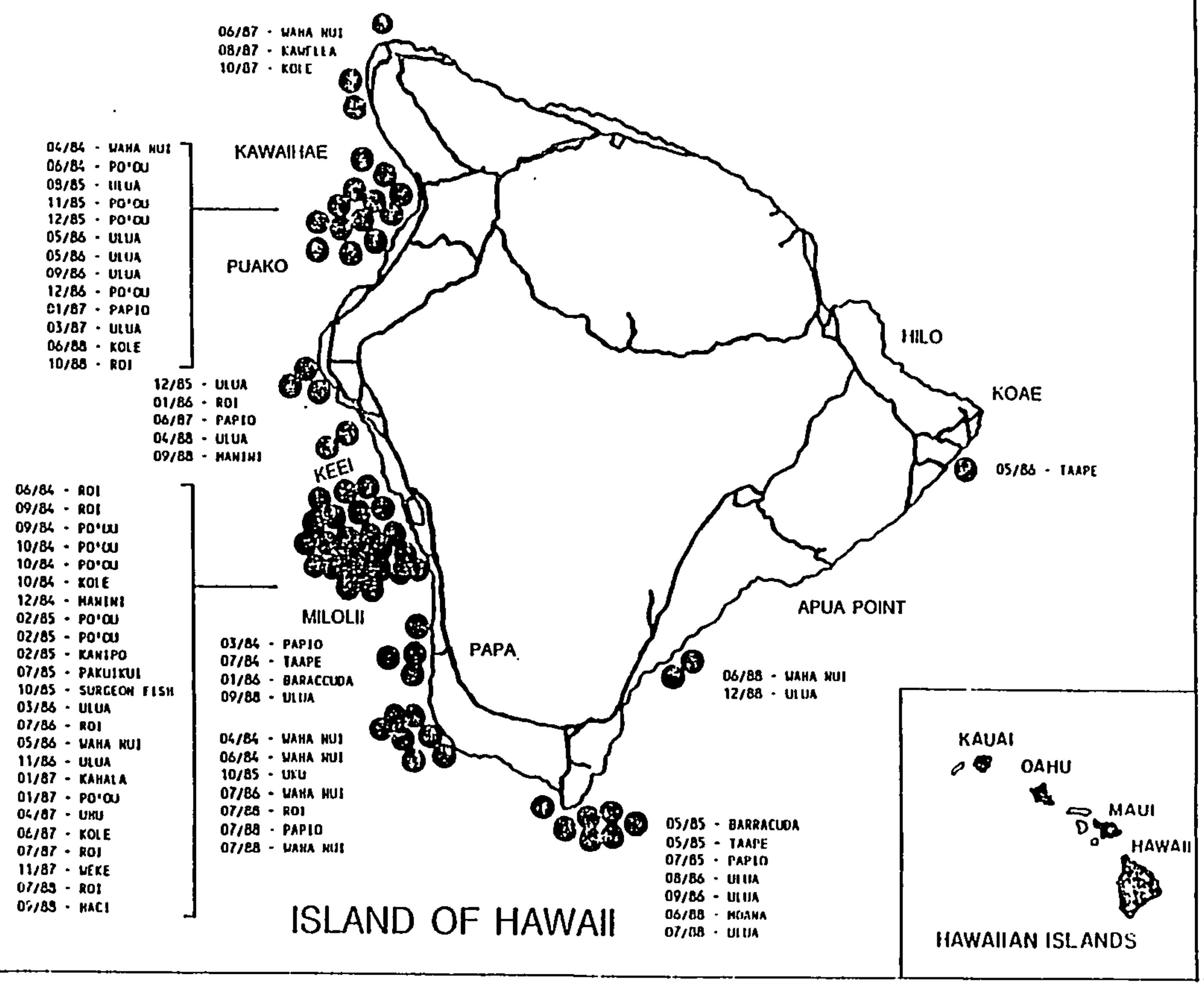
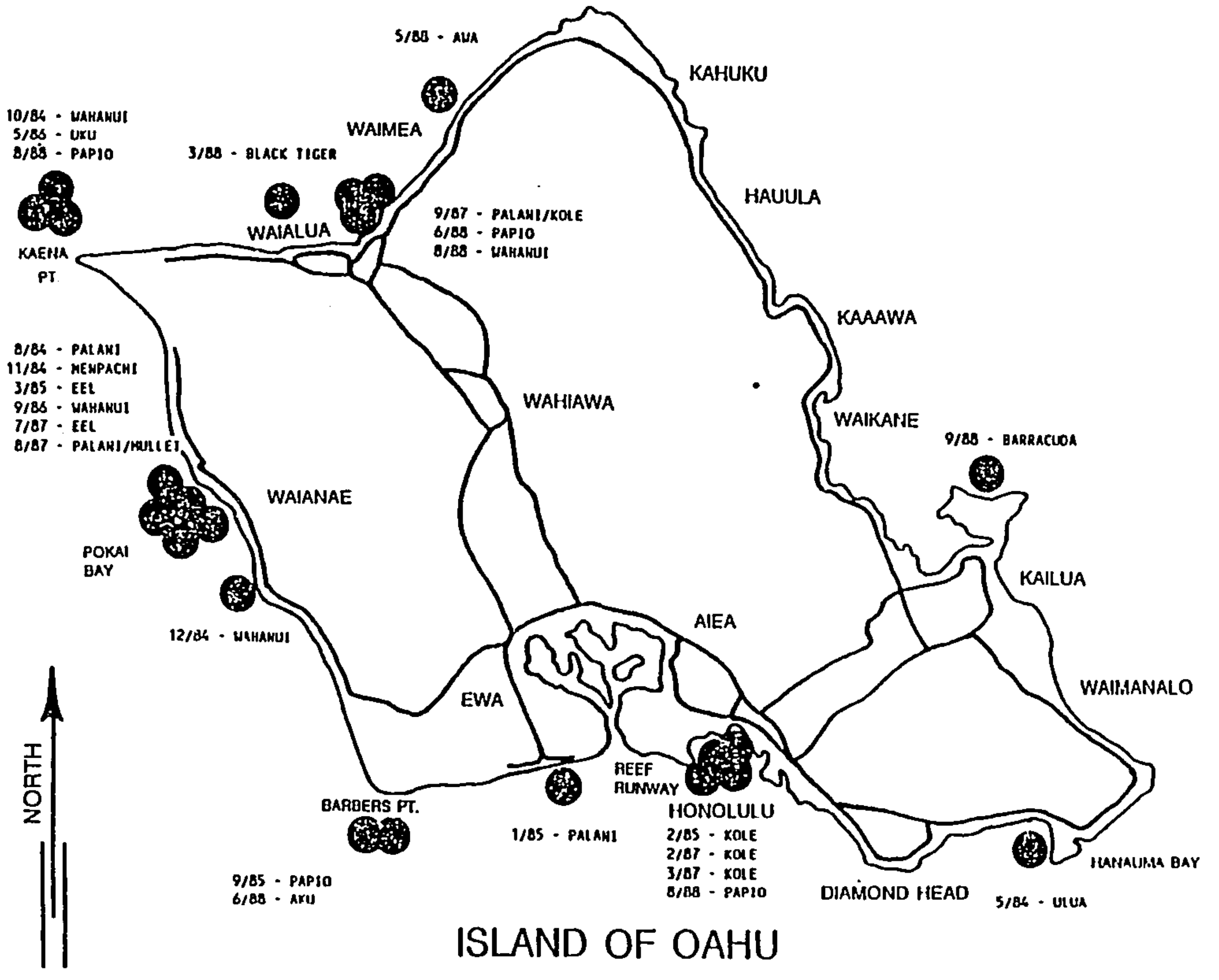


FIG 9: CIGUTERA FISH POISONING INCIDENTS 1984-1988



ISLAND OF OAHU

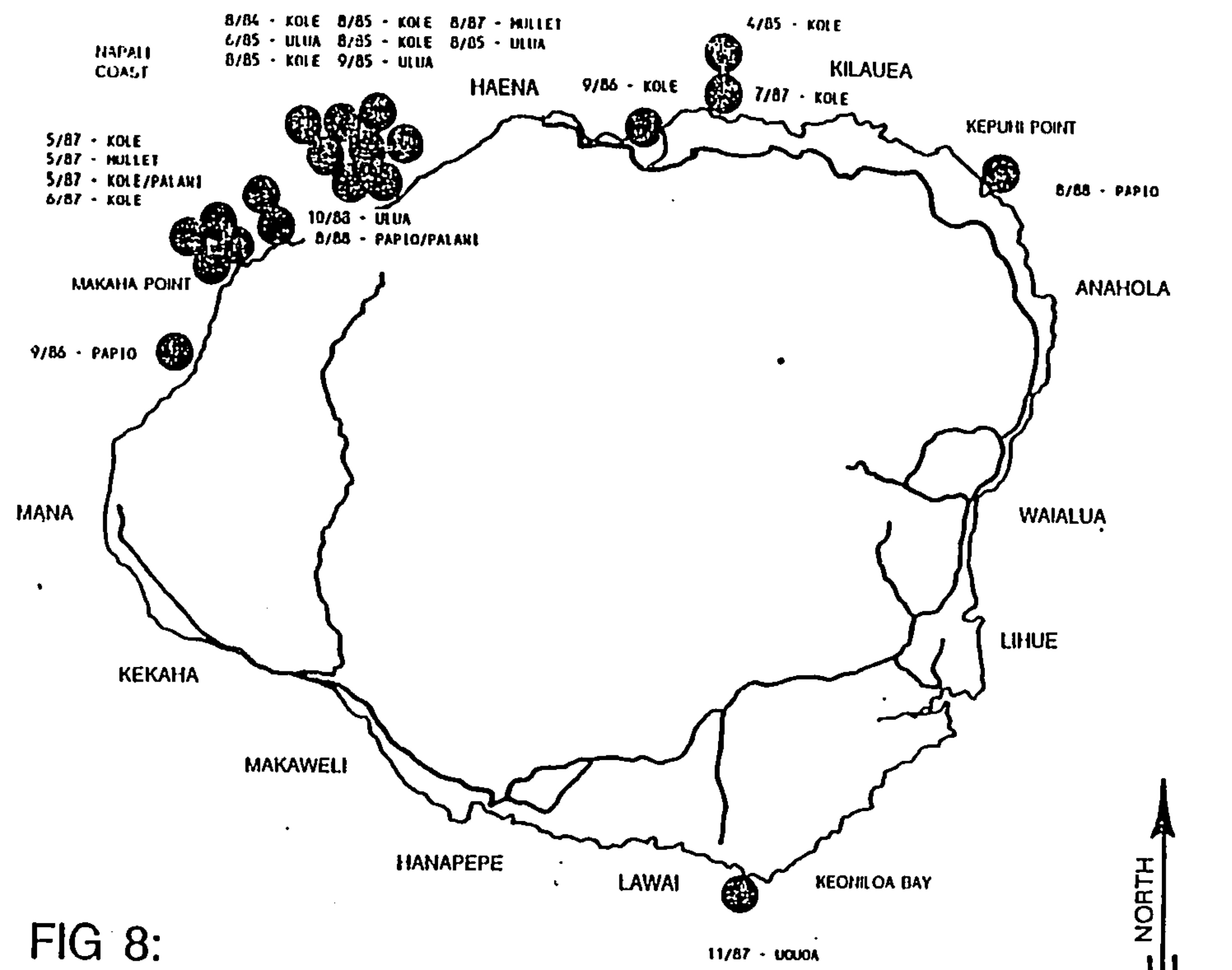


FIG 8:
CIGUATERA FISH POISONING INCIDENTS 1984-1988
ISLAND OF KAUAI

APPENDIX K

UPDATED BOTANICAL ASSESSMENT

Char & Associates

CHAR & ASSOCIATES
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November 1990

BOTANICAL ASSESSMENT
'O'OMA II PROJECT SITE
NORTH KONA, HAWAI'I

INTRODUCTION

The project site consists of approximately 300 acres of land, which extends from the ocean mauka to Queen Ka'ahumanu Highway. It is adjacent to and south of the HOST Park and north of the proposed Kohanaiki Resort. About 83 acres, next to the Queen Ka'ahumanu Highway, were received in an exchange from the State of Hawai'i and are zoned "Urban". The remaining 217 acres are zoned "Conservation".

On 31 October 1990, field studies to up-date an earlier botanical survey (Char 1986) were conducted. The earlier survey made in May 1986 was used in preparing the Environmental Impact Statement for the 'O'oma II development. In the present assessment, special emphasis is placed on the area occupied by the strand vegetation since it is subject to use and may have changed since last surveyed.

DESCRIPTION OF THE VEGETATION

The scientific names used in the following discussion are in accordance with the most recent taxonomic treatment of the Hawaiian flora by Wagner et al. (1990). Two broadly defined vegetation types are recognized on the subject property and described below.

Scrub Vegetation: With the exception of the narrow belt of strand vegetation along the coast, scrub vegetation covers almost 95% of the site. This vegetation type is composed of various grass and shrub species on pahoehoe and 'a'a lava flows. Fountain grass (Pennisetum setaceum) is the most abundant species, however, locally common in places are pili grass (Heteropogon contortus) and Natal redtop (Rhynchyletrum repens). Common throughout this scrubland are smaller shrubs (subshrubs) of 'uhaloa (Waltheria indica), 'ilima (Sida fallax), and indigo (Indigofera suffruticosa). Widely scattered throughout the site are taller plants of kiawe (Prosopis pallida), Christmas berry (Schinus terebinthifolius), a'ali'i (Dodonaea viscosa), the native caper or maiapilo (Capparis sandwichiana), and noni (Morinda citrifolia). The more scoriaceous 'a'a flows support some of the species previously mentioned but in fewer numbers.

Strand Vegetation: The coastal strand vegetation varies from 300 ft. to as little as 50 ft. in width. Substrate is sand or coralline rubble. Beach naupaka (Scaevola sericea) forms rather dense stands, 3 to 5 ft. high, along the entire coast. Tree heliotrope (Tourneforthia argentea), from 8 to 12 ft. high, is also abundant, especially along the northern half of the coast. Native species common to occasional in this vegetation type include the native caper or maiapilo, 'ilima, Fimbristylis cymosa, 'uhaloa, 'aki'aki or beach dropseed grass (Sporobolus virginicus), nohu (Tribulus cistoides), alena (Boerhavia glabrata), pa'u-o-Hi'i-aka (Jacquemontia ovalifolia), and pohuehue (Ipomoea pes-caprae). The more rocky areas or areas with coralline rubble support clumps of the silver-leaved hinahina (Heliotropium anomalum).

DISCUSSION

In order to up-date the 'O'oma II botanical survey conducted in May 1986, a reconnaissance survey of the site was made in October

1990. No officially listed threatened and endangered plants (U. S. Fish and Wildlife Service 1989) occur on the site; nor are there any plants proposed or candidate for such status on the site (U. S. Fish and Wildlife Service 1990).

Although the vegetation appeared greener and somewhat denser during the present survey, very little or no change was noted on the pahoehoe and 'a'a lava flows which support scrub vegetation. The earlier survey was made during a drier part of the year.

The strand vegetation mauka of the coastal road has remained about the same. We did observe a few more species not found during the earlier survey. Most of these are weedy, annuals which appear after the rains and include hairy crabgrass (Digitaria setigera), spiny amaranth (Amaranthus spinosus), red-flowered boerhavia (Boerhavia coccinea), puncture vine (Tribulus terrestris), and kipukai (Heliotropium curassavicum).

Certain portions of the strand vegetation makai of the coastal road show some damage from use not observed during the 1986 survey. Vehicular traffic along the road was about one vehicle every 15 minutes, surprising for a weekday. In some areas, the sand has started to move and pile up along the seaward side of the road, forming small banks and covering the lower branches of the naupaka shrubs. On the northern half of the site, closer to the HOST Park property, the coastal area appears to be more actively used. This is where the sand and coralline beach is widest. Because of vehicular traffic, most of the ground cover plants, as 'aki'aki, 'ilima, hinahina, etc., are found at the base of the naupaka and tree heliotrope plants where they are protected. Many of the tree heliotrope, usually a much-branched, bushy shrub, have been cut so that the lower branches have been removed.

References

Char, W. P. 1986. Terrestrial botanical survey. In: W. P. Char and M. S. Kjargaard. Biological survey, Proposed 'O'oma II project, North Kona, island of Hawai'i. pp. 2-11. Prepared for Helber, Hastert, Van Horn & Kimura. June 1986.

U. S. Fish and Wildlife Service. 1989. Endangered and threatened wildlife and plants. 50 CFR 17.11 & 17.12.

U. S. Fish and Wildlife Service. 1990. Endangered and threatened wildlife and plants. Review of plant taxa for listing as Endangered or Threatened Species; Notice of review. Federal Register 55(35): 6184-6229.

Wagner, W. L., D. R. Herbst, and S. H. Sohmer. 1990. Manual of the flowering plants of Hawai'i. University of Hawai'i and Bishop Museum Press, Honolulu.

APPENDIX L

NOISE ASSESSMENT

Darby & Associates

D.L. ADAMS ASSOCIATES, LTD.
dba
DARBY
& ASSOCIATES
ACOUSTICAL CONSULTANTS

#90-45
November 19, 1990

Kahala Capital Corporation
75-5751 Kuakini Hwy.
Kailua-Kona, Hawaii 96740

Attention: Ms. Toni Fortin

RE: O'OMA II DEVELOPMENT

Dear Ms. Fortin:

In this report we present our findings on environmental noise aspects of the subject project.

1. <u>SUMMARY OF FINDINGS</u>

1.1 Aircraft movements are the most significant existing noise source affecting the site. Otherwise, most of the site is exposed to relatively low noise levels, with wind, surf and occasional distant traffic being the only noticeable sounds. Existing daytime, background (L90) noise levels are generally less than 40 dBA.

1.2 The most dominant aircraft noise is that from interisland jets flying over the western section of the site after taking off from Runway 17 at Keahole-Kona Airport. Less commonly, aircraft also fly over the site on their final approach to Runway 35.

1.3 The existing Day-Night Average Sound Levels (Ldn's) due to aircraft noise, estimated from the results of a series of 24-hour and single-event noise measurements performed at the site between September 12 and 25, 1990, show reasonably good agreement with the published 1990 aircraft noise contours. However, these data indicate that the published 1990 Ldn 60 and 65 contours overestimate the current noise exposure levels by two to three points (probably, because of variations between the flight departure tracks assumed in the predictions and those actually used).

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1.4 The proposed future runway extension at Keahole-Kona Airport, and the gradual introduction of progressively quieter aircraft, should reduce future (year 2005) aircraft noise exposure levels at the project site to about 5 dBA below existing values.

1.5 Single-event aircraft noise data recorded automatically during the 24-hour noise measurements indicate that, apart from scheduled passenger aircraft, there were typically two or three jet aircraft departures each night (between 10 pm and 6 am). These were probably the older (Stage 2) B-737 aircraft used for night freight operations.

1.6 The proposed single and multi-family residential areas will be subjected to existing noise exposure levels of Ldn 58 or less, which is in compliance with the State Department of Transportation's Ldn 60 residential area limit.

1.7 The proposed hotel and inn will be subjected to existing aircraft noise exposure levels of Ldn 63 or less. Some land-use compatibility guidelines note that transient lodging buildings may be constructed in areas subjected to noise exposures of up to Ldn 65 without any special sound insulation.

1.8 A generally-recognized limit for noise levels inside residential and transient lodging buildings, due to aircraft operations, is Ldn 45. Proposed single-event criteria include a Maximum Noise Level (Lmax) of 50 dBA or less and a maximum Sound Exposure Level (SEL) of 60 to 65 dBA in habitable rooms.

1.9 Although not mandatory, measures such as the following would provide a higher-than-normal degree of sound insulation and should, therefore, reduce any impact from aircraft noise (particularly from night flights) on the residential building occupants:

(1) Use sliding windows and sliding glass doors (with double strength or 1/4" thick monolithic glass), that seal well in the closed position.

(2) Avoid jalousie windows, or restrict their use to the less noise-sensitive areas (bathrooms, laundries, etc.).

(3) Air-condition noise-sensitive areas (to allow windows to be kept closed for noise reduction purposes).

1.10 Some additional "sound proofing" could also reduce the intrusive noise from aircraft movements to levels more in keeping with a quality hotel or inn environment. Additional measures could include laminated single-glazed, or acoustically double-glazed, guestroom windows and sliding glass doors, selected on the basis of providing an exterior-to-interior noise reduction of 30 to 35 dBA.

1.11 No significant noise impacts are foreseen due to increased surface traffic caused by the project. Similarly, no significant impacts should occur due to noise from golf course maintenance, the club house, stationary equipment, or construction if the allowable noise levels in the State DOH noise regulations adopted by the City/County of Honolulu are also applied to this project.

2. PROJECT DESCRIPTION

The proposed O'oma II Development, located just south of the Keahole-Kona Airport, includes single and multi-family residential areas, transient accommodation areas, an Ocean Science Center, an 18-hole golf course and a *Marine Park* (see *Figure 1*). The site is just north of the proposed Kohanaiki Resort, but there are no existing noise-sensitive areas nearby.

3. THE EXISTING ACOUSTICAL ENVIRONMENT

3.1 General

Aircraft movements are the most significant existing noise source affecting the site. Otherwise, most of the site is exposed to relatively low noise levels, with wind, surf and occasional distant traffic being the only noticeable sounds.

The most dominant aircraft noise is that from interisland jets flying over the western section of the site after taking off from Runway 17 at Keahole-Kona Airport. Less commonly, aircraft also fly over the site on their final approach to Runway 35.

To assess existing aircraft noise exposure levels, measurements were made at the ten locations shown in Figure 1 during three site visits, between September 12 and 25, 1990. Noise levels were recorded using Larson-Davis Laboratories Sound Level Meters Type 700 and 800B.

3.2 Measurement Results

Tables 1, 2 and 3 present summaries of the single-event jet aircraft noise levels monitored during the site visits, in terms of the Maximum Noise Level (Lmax) and the Sound Exposure Level (SEL) recorded during each aircraft movement. (SEL is the Equivalent Continuous Noise Level normalized to a period of one second.) Apart from the periods noted in Table 2, Runway 17 was being used during all the single-event noise measurements (i.e., aircraft were landing from the north and taking off to the south).

The data in Tables 1, 2 and 3 show that the noisiest aircraft were the DC-9 and the older (Stage 2) B-737 interisland jets, which produced SEL's of up to 85 to 90 dBA and Lmax's of up to 75 to 80 dBA at the proposed single and multi-family residential areas. The corresponding noise levels at the proposed hotel and inn locations were approximately 5 dBA higher.

Statistical noise levels were also recorded over 24-hour periods at Locations #2, #4, #7 and #9. The results, in terms of the hourly Equivalent Continuous Noise Levels (Leq's) and the noise levels exceeded for 1%, 10%, 50% and 90% of each hour (L1, L10, L50 and L90, respectively), are presented in Figures 2, 3, 4, 5 and 6. These data showed that the existing background (L90) noise levels at the site were quite low (typically, less than 40 dBA during the daytime).

Single-event aircraft noise levels recorded automatically during these 24-hour measurements indicate that, apart from scheduled passenger aircraft, there were typically two or three jet aircraft departures each night (between 10 pm and 6 am). These were probably Stage 2, B-737 aircraft used for night freight operations.

3.3 Estimated Aircraft Noise Exposure Levels

The estimated Day-Night Average Sound Levels (Ldn's) at each of the measurement locations, due to aircraft noise, are shown in Figure 7 in relation to the published 1990 aircraft noise contours. These data were determined from the noise exposure levels actually recorded at each of the long-term measurement locations (after making corrections for background noise), and the numerical differences between the single-event noise levels recorded simultaneously at the respective locations.

The Ldn levels due to aircraft noise (estimated from the measurement results obtained between September 12 and 25, 1990) show reasonably good agreement with the published 1990 contours. However, these data indicate that the published 1990 Ldn 60 and 65 contours overestimate the current noise exposure levels by two to three points (probably, because of variations between the flight departure tracks assumed in the predictions and those actually used). In other words, the existing Ldn 60 and 65 (and, possibly, the Ldn 70) aircraft noise contours should be further west than indicated by the published 1990 aircraft noise map.

The proposed future runway extension at Keahole-Kona Airport, and the gradual introduction of progressively quieter aircraft, should reduce future (year 2005) aircraft noise exposure levels at the project site to about 5 dBA below existing values (see Figure 8).

4. NOISE STANDARDS AND GUIDELINES

4.1 Exterior Noise

Land-use compatibility guidelines are commonly presented in terms of the Day-Night Average Sound Level (Ldn), a measure of noise exposure over a typical 24-hour period.

For example, the U.S. Environmental Protection Agency (Reference 1) and the Department of Housing and Urban Development (HUD) [Reference 2] and other federal agencies (References 3 through 5) specify that residential and other noise-sensitive developments can normally be constructed in areas subjected to noise exposure levels of up to Ldn 65, with no special noise control measures required in buildings of conventional construction. Sites exposed to Ldn's in the range of 65 to 75 dBA are considered normally unacceptable for residential development, with building approval subject to additional noise control measures. These criteria are generally consistent with the land use compatibility guidelines shown in Figure 9 obtained from Reference 6.

In Hawaii, the State Department of Transportation Airports Division stipulates an aircraft noise exposure limit of Ldn 60 for residential buildings (Reference 7).

The Federal Highway Administration (FHWA) provides criteria for defining traffic noise impact as well as a noise prediction model (Reference 8).

At this time, only the City/County of Honolulu has adopted the State Department of Health (DOH) noise regulations given in References 9 and 10 and, therefore, these allowable noise limits are not enforced in Hawaii County.

It is to be noted that land use compatibility guidelines are typically less restrictive for transient lodging buildings such as hotels and motels, which are normally air conditioned and better acoustically insulated than conventional residential buildings. For example, the guidelines presented in Figure 9 imply that transient lodging buildings may be constructed in areas subjected to noise exposures of up to Ldn 65 without any special sound insulation.

4.2 Interior Noise

When aircraft noise exposure levels at a proposed development site exceed the appropriate criteria (such as Ldn 60 for residential areas in Hawaii), the buildings should be designed on the basis of achieving acceptable interior noise levels, which can be specified in terms of Ldn and/or Lmax. For example, HUD has a design goal of Ldn 45 or less for the interior spaces of dwelling units. The California Department of Transportation's "Airport Land Use Planning Handbook" (Reference 11) recommends an Lmax of 40 dBA or less due to aircraft noise in sleeping areas of residential and transient lodging buildings (although a less restrictive Lmax criterion, of 50 dBA is more commonly adopted).

Wyle Laboratories, a firm of acoustical consultants involved with soundproofing homes near some of the major airports in the US, has proposed maximum interior SEL's of 60 to 65 dBA in habitable rooms (References 12 and 13). The corresponding Lmax values are about 50 dBA and 55 dBA, respectively.

5. POTENTIAL IMPACTS AND DESCRIPTION OF CONTROLS

5.1 Aircraft Noise

Figure 6 indicates that the proposed single and multi-family residential areas within the O'oma II development will be subjected to existing aircraft noise exposure levels of Ldn 58 or less, which is in compliance with the State Department of Transportation's Ldn 60 residential area limit.

However, the data in Tables 1, 2 and 3 show that the proposed residential areas will be subjected to SEL's of up to 85 to 90 dBA from the noisier interisland jets (including the night freighters) and to corresponding maximum noise levels of about 75 to 80 dBA. Although not mandatory, measures such as the following would provide a higher-than-normal degree of sound insulation and should, therefore, reduce any impact from aircraft noise (particularly from the night flights) on the residential building occupants:

(1) Use sliding windows and sliding glass doors (with double strength or 1/4" thick monolithic glass), that seal well in the closed position.

(2) Avoid jalousie windows, or restrict their use to the less noise-sensitive areas (bathrooms, laundries, etc.).

(3) Air-condition noise-sensitive areas (to allow windows to be kept closed for noise reduction purposes).

The above measures should provide an exterior-to-interior noise reduction of around 25 dBA, resulting in interior levels due to aircraft noise of Ldn 33 or less (with windows closed), which is clearly in compliance with HUD's Ldn 45 guideline, and in interior SEL's of up to 60 to 65 dBA from the noisier aircraft.

Figure 7 indicates that the proposed hotel and inn will be subjected to existing aircraft noise exposure levels of Ldn 63 or less. Assuming conventional building designs and constructions, with air-conditioned guestrooms and sliding glass doors providing access to guestroom lanais, the estimated exterior-to-interior noise reduction should be around 25 dBA (if the doors are well sealed, when closed). Thus, noise exposure levels inside the guestrooms due to aircraft noise should be Ldn 38 or less (with windows and sliding glass doors closed), which is clearly in compliance with the Ldn 45 criterion mentioned earlier. Note that jalousie windows should not be used in guestrooms.

The proposed hotel and inn will be subjected to SEL's of, typically, 90 to 95 dBA from the noisier interisland jets (including the night freighters) and to corresponding maximum noise levels of about 80 to 85 dBA. Without any special sound insulation measures (apart from using sliding glass doors and windows provided with high quality weather stripping), the SEL's inside guestrooms due to the noisier aircraft could be in the range of 65 to 70 dBA, i.e., above the proposed 60 to 65 dBA criteria discussed earlier.

Although not mandatory, some additional "sound proofing" could reduce the intrusive noise from aircraft movements to levels more in keeping with a quality hotel or inn environment. Additional measures could include laminated single-glazed, or acoustically double-glazed, guestroom windows and sliding glass doors, selected on the basis of providing an exterior-to-interior noise reduction of 30 to 35 dBA.

Public areas in the proposed hotel and inn, including lobbies, bars, restaurants and specialty shops, could, at times, be exposed to aircraft noise levels of up to about 80 dBA (if the open designs so common to Hawaii are used). Although the noise could be high enough to momentarily interfere with people's speech and telephone communication in these public areas, the total exposure time to the noise will be relatively small (typically, less than 20 seconds per aircraft movement, i.e., less than one minute per hour, assuming an average of three flights per hour). Of course, any noise impact could be reduced to insignificant levels by completely enclosing the proposed public areas. If an open condition is to exist, the noise impact can be partly reduced by several decibels by incorporating sound absorbing treatments on the finish surfaces.

5.2 Traffic Noise Impact

The projected traffic volume report (Reference 14) was evaluated with respect to future traffic noise impact. The increase in traffic noise along Queen Kaahunanu Highway due to project completion is seen to be about 1-1/2 dB to the south of the project and less than 1 dB to the north. This degree of increase is not considered significant. The predicted traffic noise levels from the project access road at the condominiums and the home lots are less than 65 dB Day-Night Average Sound Level (Ldn) assuming a posted speed limit of 25 mph in the noise sensitive areas and that the structures are setback at least 100 feet from the center of the roadway. This noise level meets federal standards for housing. It is also to be noted that the condos and the homes are to be air conditioned and interior noise levels from traffic should be most acceptable to all persons.

5.3 Golf Course Maintenance Noise

Noise from equipment associated with ground maintenance activities, including lawn mowers and leaf blowers, could have an adverse impact on the proposed nearby condominiums and homes particularly when the equipment is near the housing. However, noisy equipment is also incompatible and disruptive with golf play. All equipment powered by internal combustion engines will have exhaust mufflers. Schedules will be developed so noisier maintenance operations do not occur near residences before 7 a.m. The noise from ground maintenance operations will not cause "unreasonable" or "excessive" noise as defined in Reference 9.

5.4 Noise From The Club House

Noise from sources at and near the club house, such as the kitchen, refrigeration and air conditioning equipment, exhaust fans, golf cart chargers, pumps and other stationary equipment, should be inaudible at the closest proposed condominium (which is more than 250 ft away) if these noise sources meet the allowable noise levels in Reference 9. If live music and entertainment are planned inside the club house, provided the building structure incorporates an adequate degree of "sound proofing," noise from these activities will also be inaudible at the closest homes. A public address system near the club house using state-of-the-art "low level," directional loudspeakers, should have minimal impact on nearby residential areas.

5.5 Stationary Equipment And Other Noises From Resort And Commercial Operations

Noise from the sewage treatment plant, air conditioning, pumps, fans, trash compactors, and any other stationary equipment in the resort and commercial complexes will not exceed the allowable noise levels in Reference 9. Trash pickup and delivery vehicles will be operated and scheduled to cause minimum disturbance to neighboring residential units if complaints arise. Minimally, these operations will meet the requirements in Reference 9.

Property commercial uses also will not cause "unreasonable" or "excessive" noise as defined in Reference 9.

5.6 Noise Impact From Construction

Development of the project site will involve grubbing, 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 process. Typical construction equipment noise ranges in dB(A) are shown in Figure 7. Earthmoving equipment such as bulldozers and diesel powered trucks will probably be the loudest equipment used during the construction of housing units. Since it is anticipated that noise generated during construction will exceed allowable limits in Reference 9, a permit will be obtained from DOH assuming Hawaii County adopts the regulations in the future. DOH may grant permits to operate 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 trafficways will satisfy the noise level requirements defined in Reference 10.

If blasting is used in the excavation of the lagoon for the proposed Marine Park, there will always be undisturbed land between the lagoon and the open sea such that there will be no overpressure pulses to injury endangered species. (namely humpback whales and green sea turtles) or major marine mammals.

Sincerely,

John Shearer

John C. Shearer

Encl.

REFERENCES

1. "Towards a National Strategy for Noise Control," U.S. Environmental Protection Agency, April 1977.

2. "HUD Environmental Criteria and Standards," Department of Housing and Urban Development, Federal Register, Vol. 44, No. 135, July 12, 1979. Amended 49 FR 880, January 6, 1984.

3. "Noise Control and Compatibility Planning for Airports," Federal Aviation Administration, August 5, 1983.

4. "Guidelines for Considering Noise in Land Use Planning and Control," Federal Interagency Committee on Urban Noise, June 1980.

5. "Environmental Protection-Planning in the Noise Environment," Department of the Air Force, the Arby, and the Navy, June 15, 1978.

6. American National Standard for Sound Level Descriptors for Determination of Compatible Land Use, American National Standards, ANSI S3.23-1980, May 30, 1980.

7. Working Paper No. 2, Inventory of Existing Mitigation Programs and Noise Map Information, Honolulu International Airport Master Plan Update and Noise Compatibility Program, Prepared by KFC Airport, Inc., October 1988.

8. "FHWA Highway Traffic Noise Prediction Model," Federal Highway Administration, December 1978.

9. "Chapter 43 - Community Noise Control for Oahu, "Department of Health, State of Hawaii, Administration Rule, Title 11, 1981.

10. "Chapter 42 - Vehicular Noise Control for Oahu," Department of Health, State of Hawaii, Administrative Rules, Title 11, 1981.

11. "Airport Land Use Planning Handbook," California Department of Transportation, Division of Aeronautics, July 1983.

12. "Deficiencies of Ldn Discussed at Conference," Airport Noise Report, Vol. 1, No. 14, July 24, 1989, PP 131-132.

13. "Wyle Surveys Shows Homeowner Satisfaction," Airport Noise Report, Vol. 1, No. 14, July 24, 1989, PP 129-130.

14. Projected 1998 Traffic, O'Oma II, by R. S. Okaneku, September 24, 1990.

TABLE 1

SUMMARY OF JET AIRCRAFT NOISE LEVELS RECORDED AT THE SITE OF THE PROPOSED O'OMA II DEVELOPMENT ON SEPTEMBER 12, 1990

Time	Aircraft Type	Location #1		Location #2		Location #3	
		Lmax (dBA)	SEL (dBA)	Lmax (dBA)	SEL (dBA)	Lmax (dBA)	SEL (dBA)
10:46 am	B-737	74.5	83.4	75.0	85.5	NA	NA
11:04	B-737	67.3	77.2	69.5	80.0	NA	NA
11:21	DC-9	77.3	87.3	81.0	91.5	83.5	93.9
12:08 pm	B-737	74.8	86.1	79.0	89.5	84.8	93.4
12:19	DC-8	71.0	80.7	76.0	86.5	80.3	86.8
12:32	DC-9	80.5	89.9	82.0	92.0	85.0	95.2
12:34	B-737	76.5	85.8	80.0	89.0	81.5	90.6
1:41	B-737	76.0	83.6	74.5	85.2	77.8	87.6
1:42	DC-9	78.3	87.4	81.0	90.5	85.9	95.9
2:08	B-737	78.0	88.3	81.5	91.5	87.3	96.6
2:14	B-737	79.0	88.2	80.5	90.5	86.8	95.8
2:25	DC-9	76.1	87.3	78.5	89.5	84.0	94.3
3:00	B-737 (Stage 3)	64.8	74.1	64.0	75.0	70.0	79.1
3:16	B-737	76.8	85.4	76.5	85.5	79.3	88.3
3:23	B-737	73.5	83.1	74.0	85.1	75.5	87.3
3:32	DC-9	78.5	88.1	81.5	91.5	83.5	94.1
3:41	B-737	72.5	81.8	72.0	82.5	73.0	83.5
4:22	B-737	79.0	88.1	79.0	88.5	83.0	92.6
4:27	Executive Jet	57.8	67.8	NA	NA	65.5	75.1
4:44	DC-9	78.5	87.8	78.5	89.0	83.3	92.5
5:09	DC-9	81.8	89.4	80.5	90.0	85.3	95.2
5:18	B-737 (Stage 3)	63.3	72.1	62.5	72.0	65.8	75.9
5:27	B-737	74.8	84.4	76.5	86.0	79.8	89.8
5:45	DC-9	NA	NA	84.1	94.4	NA	NA
5:47	B-737	NA	NA	74.8	85.4	NA	NA
6:18	B-737	73.0	84.1	76.5	88.0	NA	NA
6:57	B-737	NA	NA	73.5	84.6	NA	NA
7:33	DC-10	NA	NA	65.5	75.5	NA	NA
7:49	B-737	NA	NA	74.5	85.1	NA	NA
8:01	DC-9	NA	NA	81.0	91.0	NA	NA
8:07	B-737	NA	NA	72.0	82.5	NA	NA

Note: NA indicates data not available.

TABLE 2

SUMMARY OF JET AIRCRAFT NOISE LEVELS RECORDED AT THE SITE OF THE PROPOSED O'OMA II DEVELOPMENT ON SEPTEMBER 21, 1990

Time	Aircraft Type	Location #4 Lmax (dBA)	Location #4 SEL (dBA)	Location #5 Lmax (dBA)	Location #5 SEL (dBA)	Location #6 Lmax (dBA)	Location #6 SEL (dBA)
7:44 am	B-737	74.0	84.0	80.5	87.9	NA	NA
8:02	B-737	77.5	87.0	80.0	89.8	NA	NA
8:07	DC-9	78.0	89.0	89.8	97.6	NA	NA
9:15	DC-9	81.5	91.5	90.5	99.7	NA	NA
9:27	B-737	79.0	89.0	86.8	95.8	NA	NA
9:48	DC-9	83.0	92.5	93.0	101.5	NA	NA
10:14	B-737 (Stage 3)	70.0	79.5	NA	NA	NA	NA
10:19	B-737	77.5	89.0	87.5	96.9	NA	NA
10:39	DC-9	82.0	95.5	90.0	100.3	NA	NA
10:41	B-737	81.5	92.0	90.3	100.3	NA	NA
11:04	B-737 (Stage 3)	68.0	77.5	77.5	85.4	NA	NA
11:53	* B-737	69.0	78.1	90.8	98.5	NA	NA
11:58	* DC-9	61.5	69.8	85.5	92.1	NA	NA
12:34 pm	* B-737	NA	NA	NA	NA	NA	NA
1:19	* B-737	61.0	70.5	NA	NA	68.8	80.3
1:25	* DC-9	65.0	74.3	NA	NA	72.0	82.1
1:34	* B-737	65.5	77.5	NA	NA	76.6	85.8
1:56	* DC-9	64.0	71.5	NA	NA	74.0	81.1
2:03	* B-737	69.5	80.5	NA	NA	87.0	95.8
2:17	* B-737 (Stage 3)	61.5	70.4	NA	NA	68.0	76.1
2:49	* DC-9	67.0	76.5	NA	NA	73.3	81.1
3:01	* B-737	64.0	74.0	NA	NA	74.5	83.4
3:14	* B-737	64.5	74.5	NA	NA	71.8	82.1
3:54	* B-737 (Stage 3)	62.5	72.7	NA	NA	65.3	76.1
4:00	* DC-9	63.0	74.0	NA	NA	69.5	79.4
4:18	B-737	79.0	89.5	NA	NA	82.3	92.4
4:45	DC-9	81.0	90.5	NA	NA	83.0	92.2
4:56	DC-9	80.0	91.0	NA	NA	85.1	94.4
5:14	B-737 (Stage 3)	70.0	79.0	NA	NA	71.5	81.8
5:30	B-737	75.5	85.0	NA	NA	NA	NA
5:47	B-737	NA	NA	NA	NA	76.3	86.9
5:48	DC-9	NA	NA	NA	NA	NA	NA

Note: NA indicates data not available.

* -- Runway 35 in use

TABLE 3

SUMMARY OF JET AIRCRAFT NOISE LEVELS RECORDED AT THE SITE
OF THE PROPOSED O'OMA II DEVELOPMENT ON SEP. 24 - 25, 1990

Time	Aircraft Type	Location #8 Lmax (dBA)	Location #8 SEL (dBA)	Location #9 Lmax (dBA)	Location #9 SEL (dBA)	Location #10 Lmax (dBA)	Location #10 SEL (dBA)
9/24/90							
12:57 pm	B-737	82.5	91.8	NA	NA	NA	NA
1:41	DC-9	78.3	86.8	NA	NA	NA	NA
1:45	B-737	82.5	92.2	NA	NA	NA	NA
2:05	B-737	85.0	93.8	NA	NA	NA	NA
2:12	B-737	79.8	89.9	NA	NA	NA	NA
2:26	DC-9	NA	NA	NA	NA	NA	NA
2:59	B-737 (Stage 3)	77.8	85.2	NA	NA	NA	NA
3:17	B-737	80.0	89.4	78.0	88.0	NA	NA
3:25	B-737	84.8	93.9	82.5	91.5	NA	NA
3:30	DC-9	84.8	94.7	84.0	93.5	NA	NA
4:18	B-737	77.8	85.9	74.5	83.5	NA	NA
4:48	DC-9	NA	NA	74.0	82.0	NA	NA
4:56	DC-9	NA	NA	81.5	91.5	NA	NA
5:16	B-737 (Stage 3)	NA	NA	68.5	74.3	64.5	75.3
5:28	B-737	NA	NA	80.5	89.5	78.3	87.3
5:45	DC-9	NA	NA	89.5	99.0	83.8	92.8
6:04	B-737	NA	NA	89.0	98.0	83.0	92.9
6:18	B-737	NA	NA	85.5	94.5	79.0	88.4
9/25/90							
12:19 pm	DC-8	NA	NA	79.5	89.0	74.0	84.0
12:33	DC-9	NA	NA	81.5	90.0	74.3	84.1
12:35	B-737	NA	NA	82.5	92.0	79.5	89.1
1:44	DC-9	NA	NA	82.0	91.5	80.5	89.0
1:45	B-737	NA	NA	80.0	90.5	75.0	86.7
1:59	Executive Jet	NA	NA	84.0	91.0	74.8	84.4
2:15	B-737	NA	NA	80.5	91.0	79.0	88.0
2:26	DC-9	NA	NA	82.5	92.5	79.0	88.9
2:36	B-737	NA	NA	78.0	87.5	74.3	84.7
2:39	P-3	NA	NA	70.0	76.5	78.3	85.3
2:47	P-3	NA	NA	78.0	87.0	70.5	80.8
2:48	P-3	NA	NA	73.5	81.0	65.8	75.1
2:51	B-737 (Stage 3)	NA	NA	72.5	81.0	68.3	77.8

Note: NA indicates data not available.

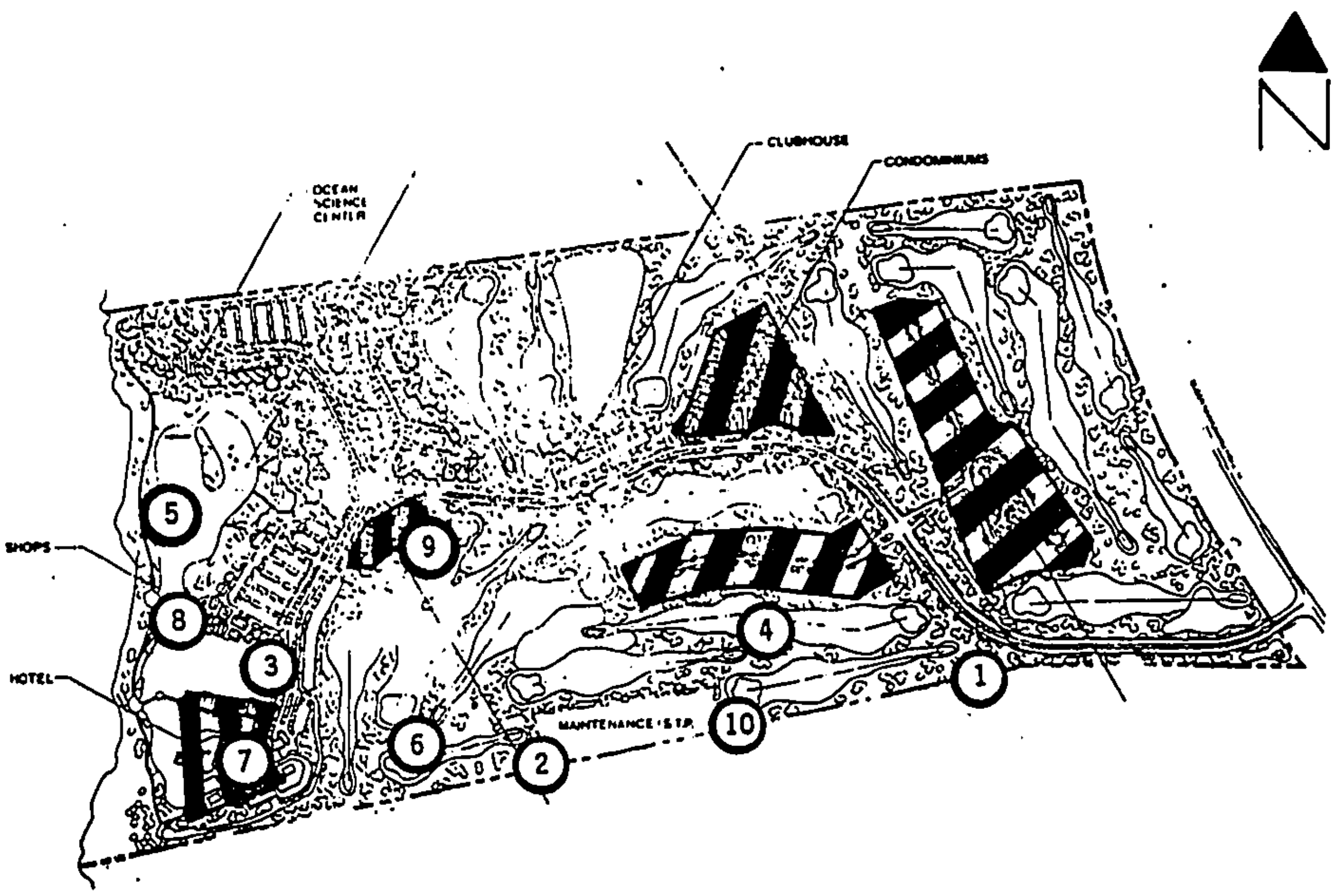

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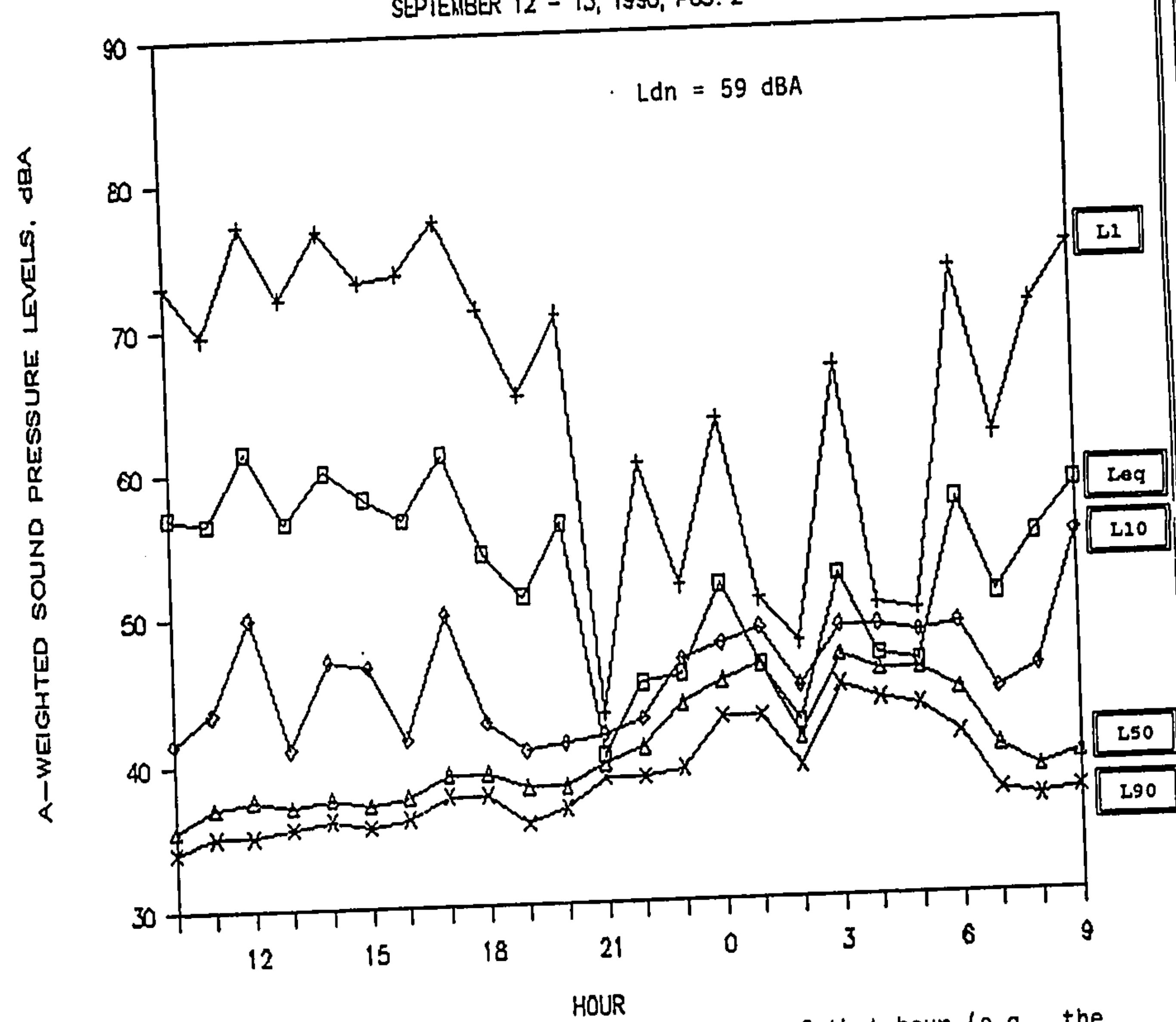
Figure 1 Site Plan of Proposed O'Oma II Development Showing Noise Measurement Locations

A-WEIGHTED SOUND LEVELS vs TIME

SEPTEMBER 12 - 13, 1990, POS. 2



Note: Each hour's data are plotted at the commencement of that hour (e.g., the levels recorded between 10 and 11 am are plotted at 10 am).

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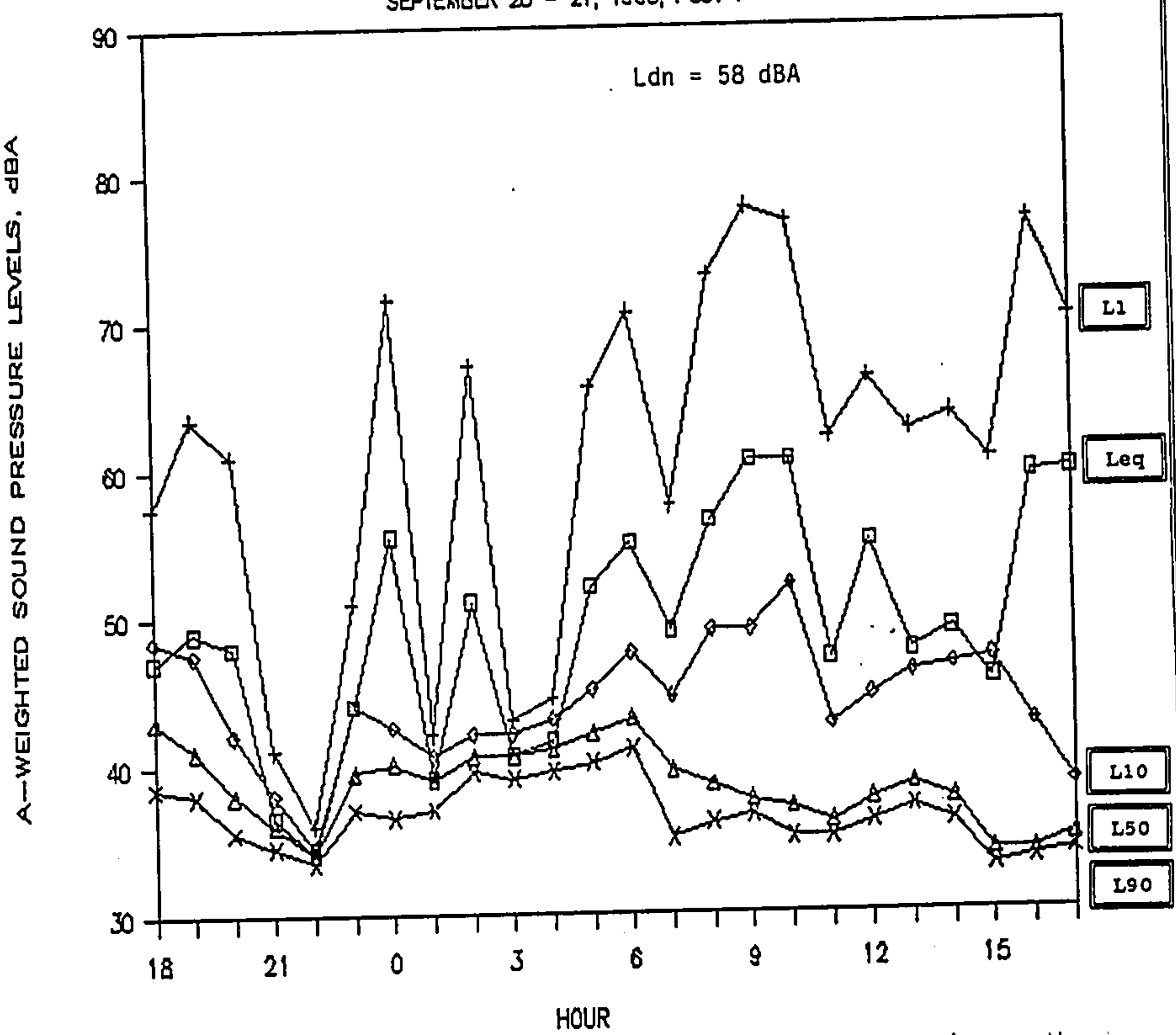
Figure 2 Statistical Noise Levels Measured at Location #2 over a 24 - Hour Period Commencing at 10 am on 9/12/90

A-WEIGHTED SOUND LEVELS vs TIME

SEPTEMBER 20 - 21, 1990, POS. 4



Note: Each hour's data are plotted at the commencement of that hour (e.g., the levels recorded between 10 and 11 am are plotted at 10 am).

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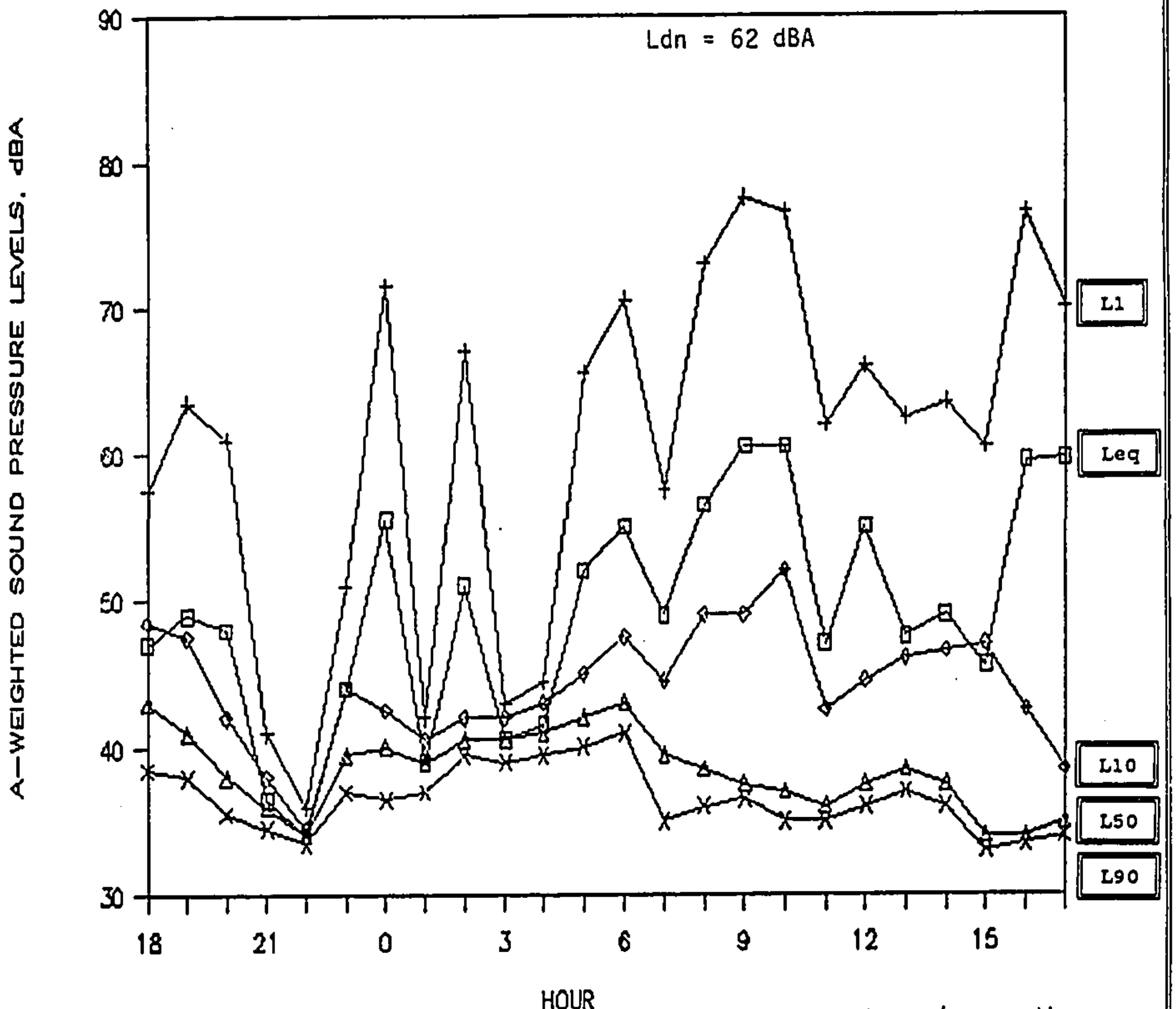
Figure 3 Statistical Noise Levels Measured at Location #4 over a 24 - Hour Period Commencing at 6 pm on 9/20/90

A–WEIGHTED SOUND LEVELS vs TIME

SEPTEMBER 20 – 21, 1990, POS. 4



Note: Each hour's data are plotted at the commencement of that hour (e.g., the levels recorded between 10 and 11 am are plotted at 10 am).

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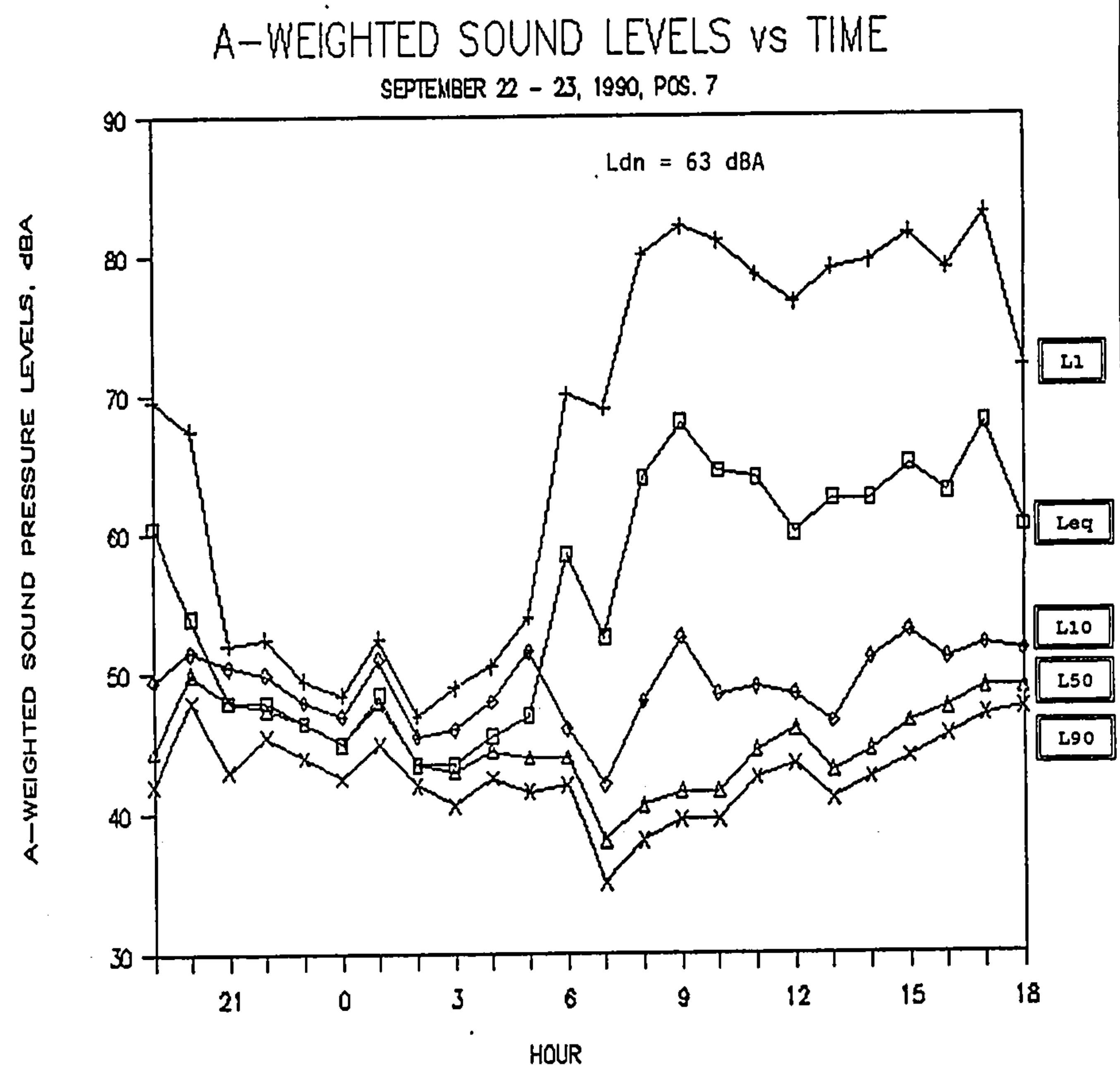
Figure 4 Statistical Noise Levels Measured at Location #7 over a 24 - Hour Period Commencing at 7 pm on 9/21/90



Note Each hour's data are plotted at the commencement of that hour (e.g., the levels recorded between 10 and 11 am are plotted at 10 am).

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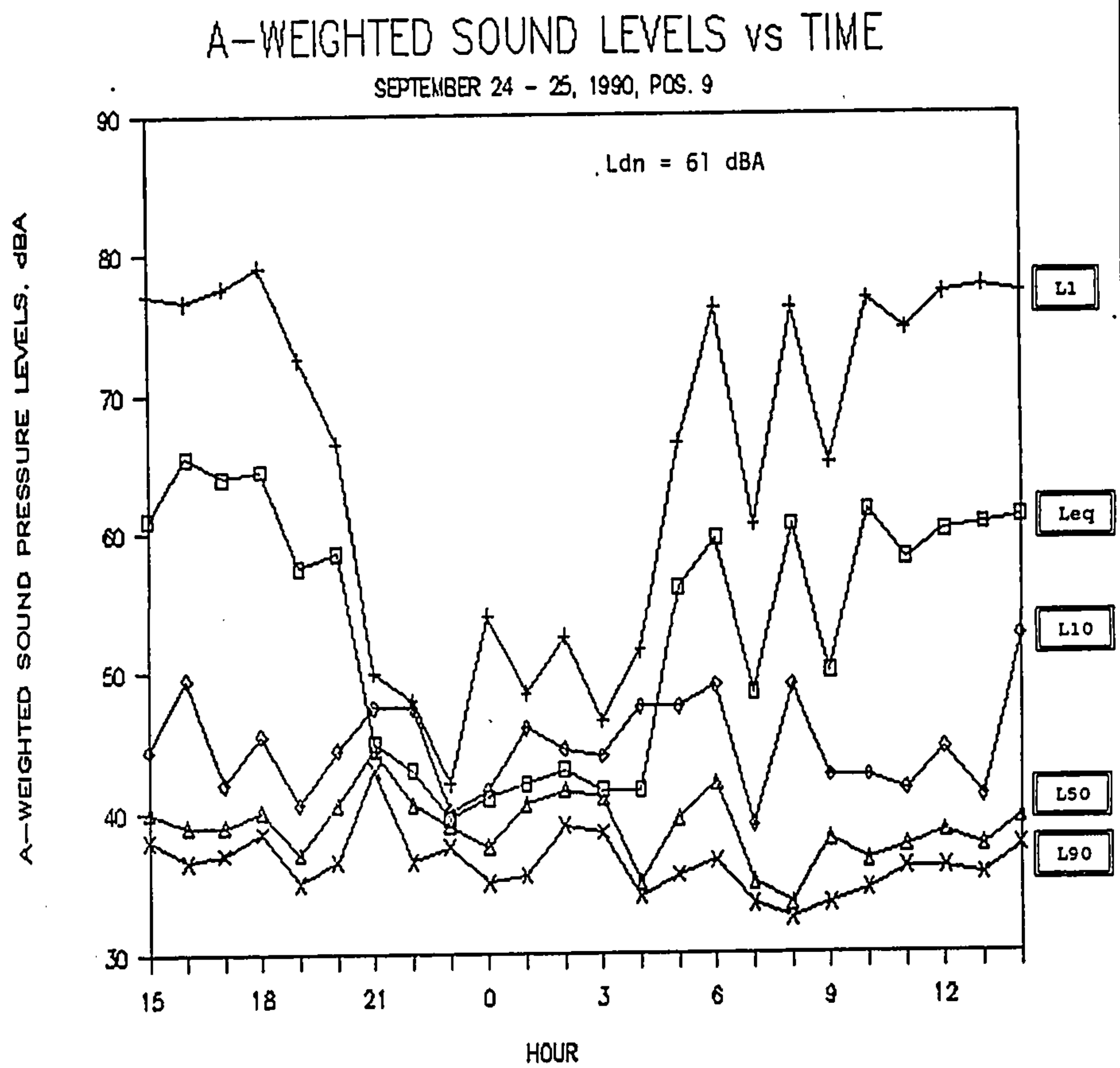
Figure 5 Statistical Noise Levels Measured at Location #7 over a 24 - Hour Period Commencing at 7 pm on 9/22/90



Note: Each hour's data are plotted at the commencement of that hour (e.g., the levels recorded between 10 and 11 am are plotted at 10 am).

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Figure 6 Statistical Noise Levels Measured at Location #9 over a 24 - Hour Period Commencing at 3 pm on 9/24/90

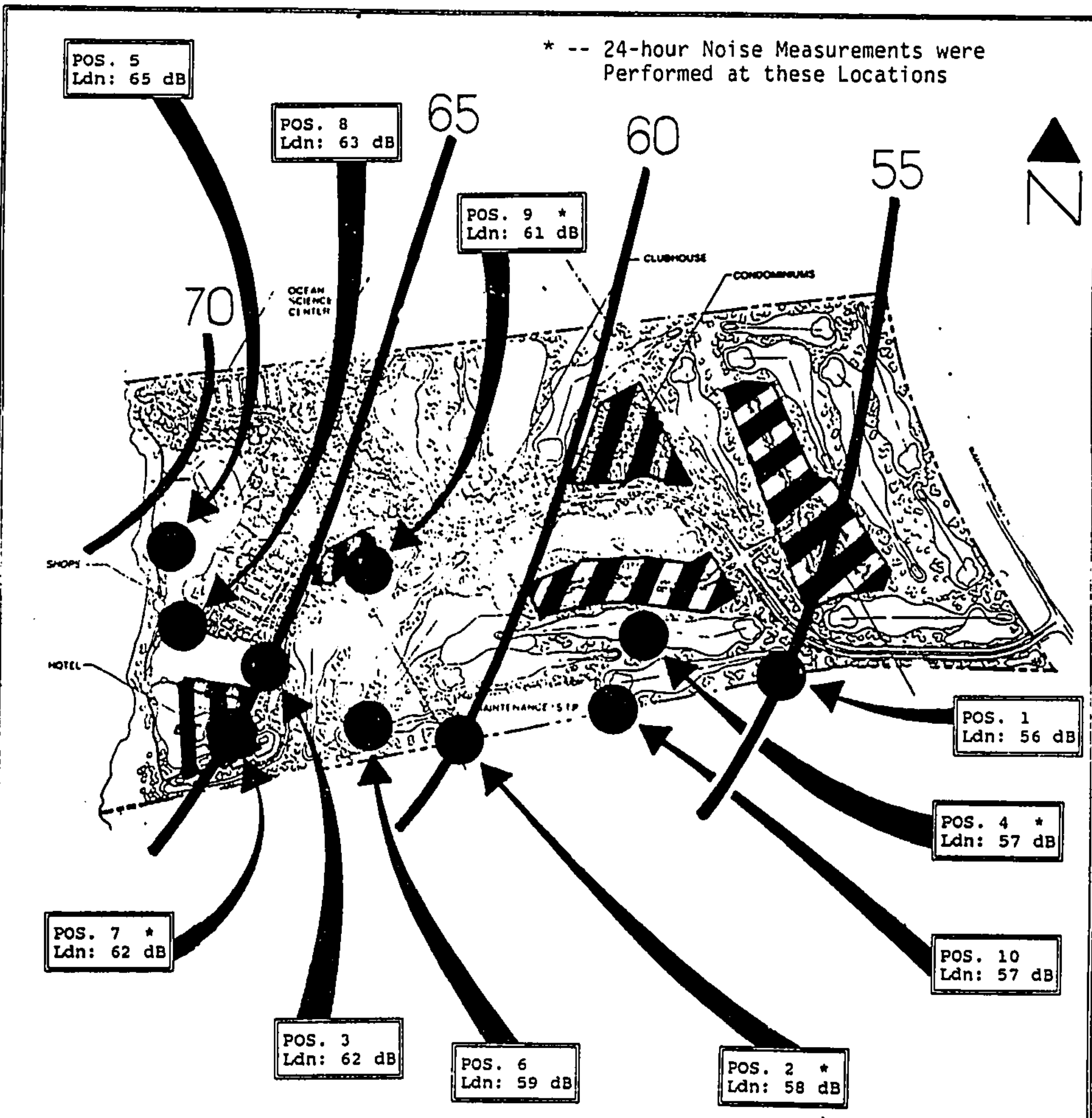

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Figure 7 Site Plan of Proposed O'Oma II Development Showing Estimated Existing Ldn's Due To Aircraft Noise In Relating To Published 1990 Aircraft Noise Contours

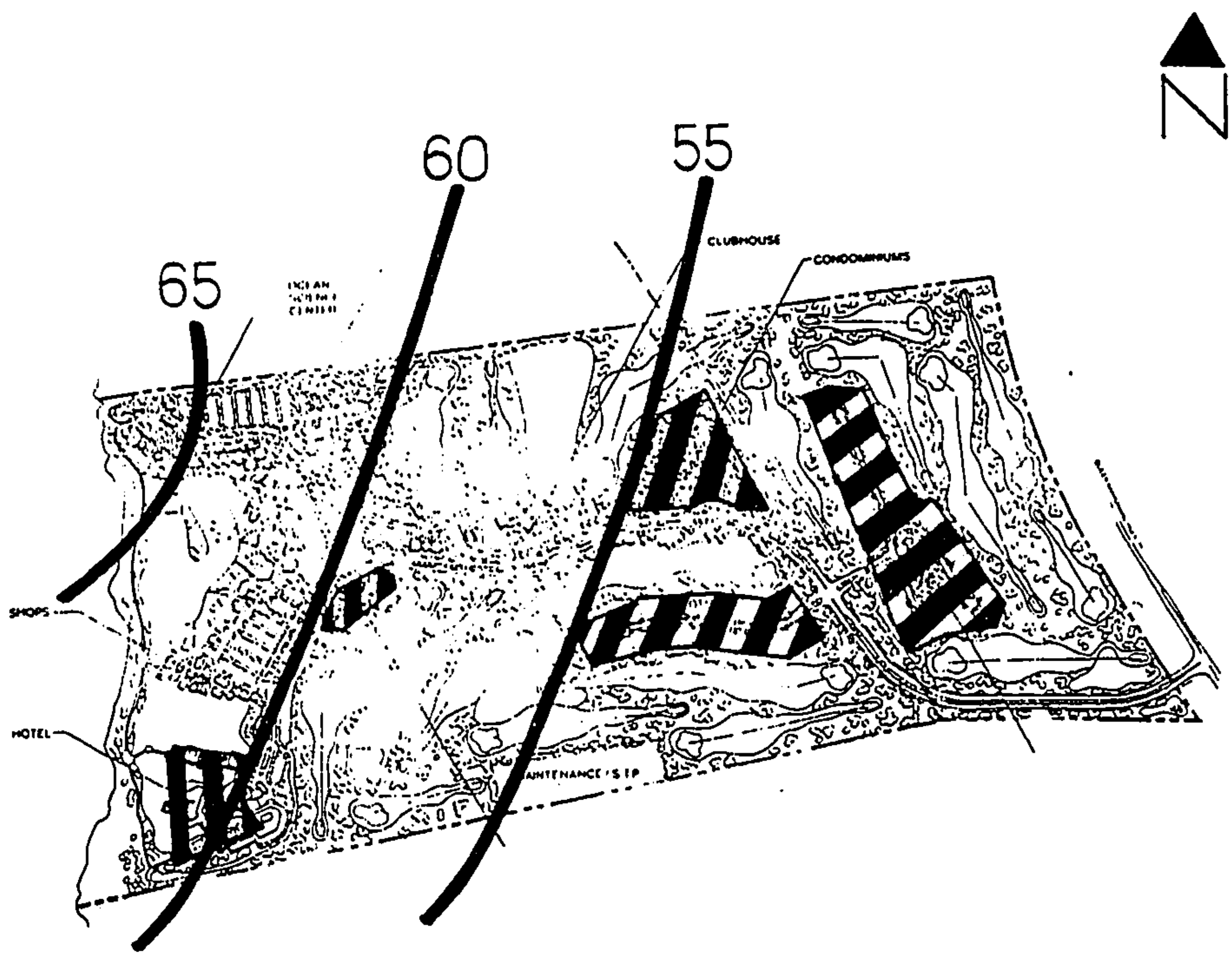

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Figure 8 Site Plan of Proposed O'Oma II Development Showing Published Future (Year 2005) Aircraft Noise Contours

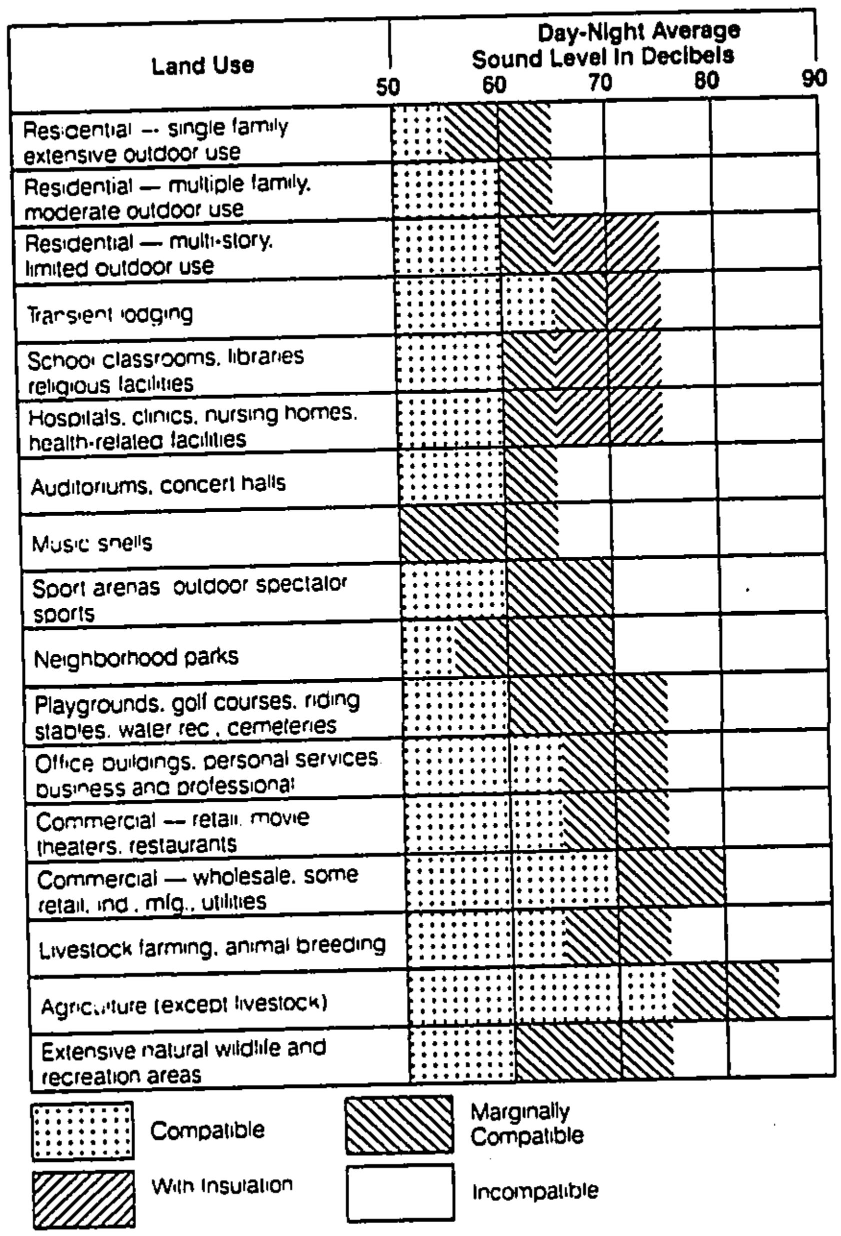

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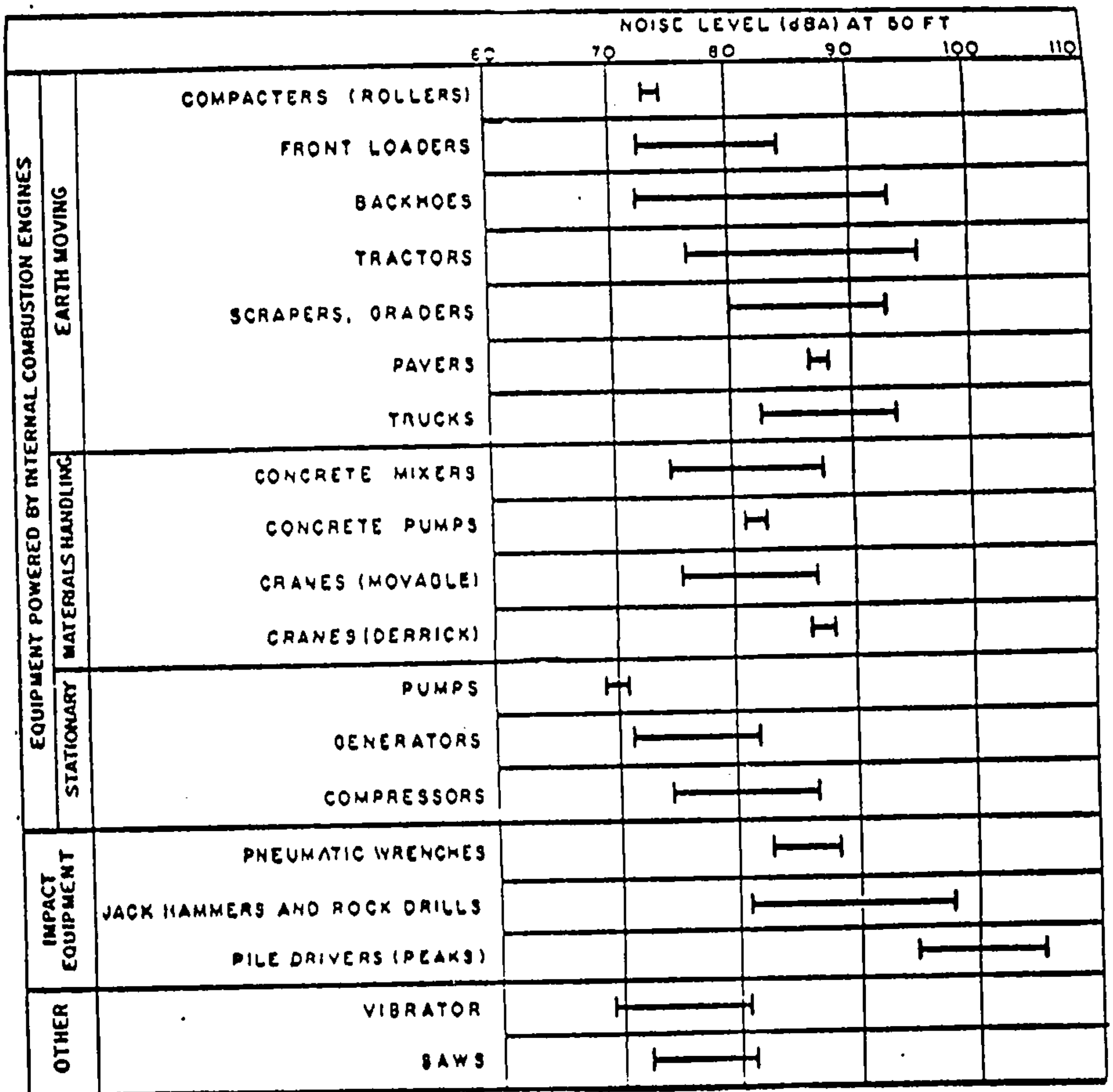
Figure 9 Land Use Compatibility For Buildings As Commonly Constructed (From Appendix To ANSI 53.23 - 1980)



Note: Based on Limited Available Data Samples

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Figure 10 Construction Equipment Noise Ranges

APPENDIX M

AIR QUALITY ASSESSMENT

B.D. Neal & Associates

AIR QUALITY STUDY
FOR THE PROPOSED O'OMA PROJECT
NORTH KONA, HAWAII

Prepared for:

Kahala Capital Corporation

November 1990

B. D. NEAL & ASSOCIATES

Applied Meteorology • Air Quality • Computer Science

P.O. BOX 6552, CAPTAIN COOK, HAWAII 96704-6552

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CONTENTS

TABLES

1.0 INTRODUCTION AND PROJECT DESCRIPTION

Kahala Capital Corporation is proposing to build a mixed-use development in the North Kona District on the Island of Hawaii. The project site is 1 mile south of Keahole Airport and 7 miles north of Kailua-Kona. When fully developed, the proposed O'oma Project will occupy 300 acres of land extending from the ocean mauka to Queen Kaahumanu Highway. Major elements of the proposed project include an 18-hole golf course, a 550-room hotel, a 50-unit inn, a shopping village, an ocean science center, a water recreation park, 230 condominium units, 100 single-family house lots, and a 7-acre swimming lagoon and beach park. Construction of the proposed project will begin as soon as all of the necessary government approvals can be obtained. Full build-out is projected to be achieved by 1998.

The purpose of this study is to describe existing air quality in the project area and to assess the potential short-term and long-term direct and indirect air quality impacts that could result from construction and use of the proposed facilities as planned. Measures to mitigate these impacts are suggested where possible and appropriate.

2.0 AMBIENT AIR QUALITY STANDARDS

Ambient concentrations of air pollution are regulated by both national and state ambient air quality standards (AAQS). National AAQS are specified in Section 40, Part 50 of the Code of Federal Regulations (CFR), while State of Hawaii AAQS are defined in Chapter 11-59 of the Hawaii Administrative Rules. Table 1 summarizes both the national and the state AAQS that are specified in the cited documents. As indicated in the table, AAQS have been established for six air pollutants. These regulated air pollutants include: particulate matter, sulfur dioxide, nitrogen dioxide, carbon monoxide, ozone and lead. National AAQS are stated in terms of primary and secondary standards. National primary standards are designed to protect the public health with an "adequate margin of safety". National secondary standards, on the other hand, define levels of air quality necessary to protect the public welfare from "any known or anticipated adverse effects of a pollutant". Secondary public welfare impacts may include such effects as decreased visibility, diminished comfort levels, or other potential injury to the natural or man-made environment, e.g., soiling of materials, damage to vegetation or other economic damage. In contrast to the national AAQS, Hawaii State AAQS are given in terms of a single standard that is designed "to protect public health and welfare and to prevent the significant deterioration of air quality".

Each of the regulated air pollutants has the potential to create or exacerbate some form of adverse health effect or to produce environmental degradation when present in sufficiently high concentration for prolonged periods of time. The AAQS specify a maximum allowable concentration for a given air pollutant for one or more averaging times to prevent harmful effects. Averaging times vary from one hour to one year depending on the pollutant and type of exposure necessary to cause adverse effects. In the case of the short-term (i.e., 1- to 24-hour) AAQS, both national and state standards allow one exceedance per year.

State of Hawaii AAQS are in some cases considerably more stringent than comparable national AAQS. In particular, the State of Hawaii 1-hour AAQS for carbon monoxide is four times more stringent than the comparable national limit.

Under the provisions of the Federal Clean Air Act [1], the U.S. Environmental Protection Agency (EPA) is required to periodically review and re-evaluate national AAQS in light of research findings more recent than those which were available at the time the standards were originally set. Occasionally new standards are created as well. Most recently, the national standard for particulate matter has been revised to include specific limits for particulates 10 microns or less in diameter (PM-10) [2]. The State of Hawaii has not explicitly addressed the question of whether to set limits for this category of air pollutant, but national AAQS prevail where states have not set their own more stringent levels.

Hawaii AAQS for sulfur dioxide were relaxed in 1986 to make them essentially the same as national limits. It has been proposed in various forums that the state also relax its carbon monoxide standards to the national levels, but at present there are no indications that such a change is being considered.

3.0 REGIONAL AND LOCAL CLIMATOLOGY

Regional and local climatology significantly affect the air quality of a given location. Wind, temperature, atmospheric turbulence, mixing height and rainfall all influence air quality. Although the climate of Hawaii is relatively moderate throughout most of the state and most of the year, significant differences in these parameters may occur from one location to another. Most differences in regional and local climates within the state are caused by the mountainous topography.

North Kona, the site of the proposed project, is located near the midpoint of the western coast of the island of Hawaii. The topography of this island is dominated by the great volcanic masses of Mauna Loa (13,653 feet), Mauna Kea (13,796 feet), and of Hualalai, the Kohala Mountains and Kilauea. The island consists entirely of the slopes of these mountains and of the broad saddles between them. Mauna Loa and Kilauea, located on the southern half of the island, are still active volcanoes. The site of the proposed project occupies a portion of the lower western slope of Hualalai extending from near sea level up to an elevation of about 200 feet.

Hawaii lies well within the belt of northeasterly trade winds generated by the semi-permanent Pacific high pressure cell to the north and east. Nearly the entire western coast of the island of Hawaii, however, is sheltered from the trade winds by high mountains, except when unusually strong trade winds sweep through the saddle between the Kohala Mountains and Mauna Kea and reach the areas to the lee. Due to wind shadow effects caused by the terrain, winds in the Kailua-Kona area are predominantly light and variable. Local winds such as land/sea breezes and/or upslope/downslope winds tend to dominate the wind pattern for the area. During the daytime, winds typically move onshore because of seabreeze and/or upslope effects. At night, winds generally are land breezes and/or drainage winds which move downslope and out to sea. Calms occur about 29 percent of the time at nearby Keahole Point.

Air pollution emissions from motor vehicles, the formation of photochemical smog and smoke plume rise all depend in part on air temperature. Colder temperatures tend to result in higher emissions of contaminants from automobiles but lower concentrations of photochemical smog and ground-level concentrations of air pollution from elevated plumes. In Hawaii, the annual and daily variation of temperature depends to a large degree on elevation above sea level, distance inland and exposure to the trade winds. Average temperatures at locations near sea level generally are warmer than those at higher elevations. Areas exposed to the trade wind tend to have the least temperature variation, while inland and leeward areas often have the most. The project site's leeward location and low-level elevation results in a relatively moderate temperature profile compared to windward locations near sea level. At the Old Kona Airport, located a few miles to the south of the project, average daily minimum and maximum temperatures are 67°F and 83°F, respectively. The extreme minimum temperature on record at this location is 47°F, and the extreme maximum is 93°F. Temperatures at the project site are about the same as at the old airport.

Small scale, random motions in the atmosphere (turbulence) cause air pollutants to be dispersed as a function of distance or time from the point of emission. Turbulence is caused by both mechanical and thermal forces in the atmosphere. It is oftentimes measured and described in terms of Pasquill-Gifford stability class. Stability class 1 is the most turbulent and class 6 the least. Thus, air pollution dissipates the best during stability class 1 conditions and the worst when stability class 6 prevails. In the North Kona area, stability class 5 or 6 is generally the highest stability class that occurs, developing during clear, calm nighttime or early morning hours when temperature inversions form either due to radiational cooling or to downslope winds that push warmer air aloft. Stability classes 1 through 4 occur during the daytime, depending mainly on the amount of cloud cover and incoming solar radiation and the onset and extent of the sea breeze.

Mixing height is defined as the height above the surface through which relatively vigorous vertical mixing occurs. Low mixing heights can result in high ground-level air pollution concentrations because contaminants emitted from or near the surface can become trapped within the mixing layer. In Hawaii, minimum mixing heights tend to be high because of mechanical mixing caused by the trade winds and because of the temperature moderating effect of the surrounding ocean. Low mixing heights may sometimes occur, however, at inland locations and even at times along coastal areas early in the morning following a clear, cool, windless night. Coastal areas may also experience low mixing levels during sea breeze conditions when cooler ocean air rushes in over warmer land. Although there is no mixing height data for the Kailua-Kona area, mixing heights elsewhere in the state typically are above 3000 feet (1000 meters). Mixing heights in the North Kona area probably tend to be somewhat lower due to the fact that light winds often prevail and also because sea breeze conditions often develop during the daytime.

Rainfall can have a beneficial effect on the air quality of an area in that it helps to suppress fugitive dust emissions, and it may also "washout" gaseous contaminants that are water soluble. Rainfall in Hawaii is highly variable depending on elevation and on location with respect to the trade wind. The North Kona area being a leeward location experiences a relatively dry climate, especially at lower elevations. Some of the rainfall occurs in conjunction with winter storms, and some occurs during summer afternoons and evenings as a result of the onshore and upslope movement of moisture laden marine air. At the Old Kona Airport, which is reasonably representative of the project site, average annual rainfall amounts to about 24 inches but may vary significantly from one year to the next.

LEGAL AUTHORITY FOR ACCESS CLASSIFICATION:

CODE:			SECTION:
14-1			
14-2			
14-3			
14-4			

RETENTIO

retention code: 16

GENERAL RECORD

information kept in record:

group codes: 18-1 | 18-2 | 18-3

individuals about whom records are maintained:

group codes: 19-1 | 19-2 | 19-3

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4.0 PRESENT AIR QUALITY

Present air quality in the project area is mostly affected by air pollutants from natural, industrial, agricultural and/or vehicular sources. Natural sources of air pollution emissions which may affect the project area but cannot be quantified very accurately include the ocean (sea spray), plants (aero-allergens), wind-blown dust, and volcanoes. Of these natural sources of air pollution, volcanoes are the most significant. Volcanic emissions periodically plague the project area. This is especially so since the latest eruption phase of the Kilauea Volcano began in 1983. Air pollution emissions from the Hawaiian volcanoes consist primarily of sulfur dioxide. After entering the atmosphere, these sulfur dioxide emissions are carried away by the wind and either washed out as acid rain or gradually transformed into particulate sulfates. Although emissions from Kilauea are vented more than 50 miles east of the project site, the prevailing wind patterns eventually carry the emissions into the Kona area. These emissions can be seen in the form of the volcanic haze (vog) which persistently hangs over the area. The American Lung Association is currently studying the character and concentrations of volcanic air pollution in the Kona area, but to date no results of the study are available.

The major industrial sources in the project vicinity include the Keahole Power Plant, operated by Hawaii Electric Light Company, and the Kailua Landfill, operated by the County of Hawaii. Air pollution emissions from Keahole Power Plant consist mostly of sulfur dioxide and oxides of nitrogen. Emissions from the county landfill consist mainly of fugitive dust from heavy equipment operations and noxious fumes from underground fires, the latter of which has been the subject of numerous complaints from people residing and working nearby. The proposed project site is situated far enough away so as probably not to be adversely impacted by emissions from the landfill.

Queen Kaahumanu Highway, which borders the project site on the east, is the region's major arterial roadway. Some contamination from the exhausts of motor vehicles traversing Queen Kaahumanu Highway and other roadways nearby occurs, although elevated concentrations are likely confined to limited areas near intersections where and when traffic congestion occurs during poor dispersion conditions. Emissions from aircraft using Keahole Airport may also have some affect on the present air quality at the site.

The State Department of Health operates a network of air quality monitoring stations at various locations around the state. Unfortunately, very little data are available for the island of Hawaii, and even less are available for the Kona area specifically. As indicated in Table 2, the only existing monitoring data in the vicinity of the project site consist of sulfur dioxide and particulate measurements that were made about 15 miles to the south at Kealakekua during 1985 and 1986. During this two-year period, measurements of 24-hour average sulfur dioxide concentration at this location were consistently low with daily mean values ranging from less than 5 to 12 $\mu g/m^3$. No exceedances of the state/national 24-hour AAQS for sulfur dioxide were recorded. Twenty-four hour average particulate concentrations ranged from 4 to 28 $\mu g/m^3$; no violations of the state AAQS were measured.

At this time, there are no reported measurements of lead, ozone, nitrogen dioxide or carbon monoxide in the project vicinity. These are primarily motor vehicle related air pollutants. Lead, ozone and nitrogen dioxide typically are regional scale problems; concentrations of these contaminants generally have not been found to exceed AAQS elsewhere in the state. Carbon monoxide air pollution, on the other hand, typically is a microscale problem caused by congested motor vehicular traffic. In traffic congested areas such as urban Honolulu, carbon monoxide concentrations have been found to occasionally exceed the state AAQS. Present concentrations of carbon monoxide in the project area are estimated later in this study based on mathematical modeling of motor vehicle emissions.

5.0 SHORT-TERM IMPACTS OF PROJECT

Short-term direct and indirect impacts on air quality could potentially occur due to project construction. For a project of this nature, there are two potential types of air pollution emissions which could directly result in short-term air quality impacts during the construction phase: (1) fugitive dust from vehicle movement and site excavation; and (2) exhaust emissions from on-site construction equipment. Indirectly, there could also be short-term impacts from slow-moving construction equipment traveling to and from the project site and from a temporary increase in local traffic caused by commuting construction workers.

Fugitive dust emissions may arise from the grading and dirt/rock-moving activities associated with site preparation once the area is cleared. The emission rate for fugitive dust emissions from construction activities is difficult to estimate accurately because of its elusive nature of emission and because the potential for its generation varies greatly depending upon the type of soil at the construction site, the amount and type of earth-disturbing activity taking place, the moisture content of exposed soil in work areas, and the wind speed. The EPA [3] has provided a rough estimate for uncontrolled fugitive dust emissions from construction activity of 1.2 tons per acre per month under conditions of "medium" activity, moderate soil silt content (30%), and precipitation/evaporation (P/E) index of 50. Uncontrolled fugitive dust emissions from project construction would probably be somewhere near this level. In any case, State of Hawaii Air Pollution Control Regulations [4] stipulate that emissions of fugitive dust from construction activities cannot be visible beyond the property line. Thus, an effective dust control plan for the project construction phase is essential.

Adequate fugitive dust control can usually be accomplished by the establishment of a frequent watering program to keep bare-earth surfaces in work areas from becoming significant dust generators. In some cases, other control measures such as limiting the area that can be disturbed at any given time, applying chemical soil stabilizers and/or using wind screens may be necessary. Control regulations also require that open-bodied trucks be covered at all times when in motion if they are transporting materials likely to give rise to airborne dust. Paving of parking areas and roads and establishing landscaping as early in the construction process as possible can also lower the potential for fugitive dust emissions.

On-site mobile and stationary construction equipment will also emit some air pollutants in the form of engine exhausts. The largest of this equipment is usually diesel-powered. Nitrogen oxides emissions from diesel engines can be relatively high compared to gasoline-powered equipment, but the standard for nitrogen dioxide is set on an annual basis and is not likely to be violated by short-term construction equipment emissions. Carbon monoxide emissions from diesel engines, on the other hand, are low and should be relatively insignificant compared to vehicular emissions on nearby roadways.

Indirectly, slow-moving construction vehicles on roadways leading to and from the project site could obstruct the normal flow of traffic to such an extent that overall vehicular emissions are increased, but this impact can be mitigated by moving heavy construction equipment during periods of low traffic volume. Likewise, the schedules of commuting construction workers can be adjusted to avoid peak hours in the project vicinity. Thus, most potential short-term air quality impacts from project construction can be mitigated.

6.0 LONG-TERM IMPACTS OF PROJECT

6.1 Roadway Traffic

After construction is completed, use of the proposed facilities will result in increased motor vehicle traffic on nearby roadways, potentially causing long-term impacts on ambient air quality in the project vicinity. Motor vehicles with gasoline-powered engines are significant sources of carbon monoxide. They also emit nitrogen oxides, and those burning leaded gasoline contribute lead to the atmosphere. The use of leaded gasoline in new automobiles is now prohibited. As older vehicles continue to disappear from the numbers of those currently operating on the state's roadways, lead emissions are approaching zero. Nationally, so few vehicles now require leaded gasoline that the EPA is proposing a total ban on leaded gasoline to take effect immediately. Even without such a ban, reported quarterly averages of lead in air samples collected in urban Honolulu have been near zero since early 1986. Thus, lead in the atmosphere is not considered to be a problem anywhere in the state.

Federal air pollution control regulations also call for increased efficiency in removing carbon monoxide and nitrogen oxides from the exhausts of new motor vehicles. By the year 1995 carbon monoxide emissions are expected to be about 30 percent less than the amounts now emitted due to the replacement of older vehicles with newer models. Further reductions in vehicular emissions have recently been proposed by the President for areas of the country which do not currently meet AAQS, mainly through the use of alternative fuels.

To evaluate the potential long-term indirect ambient air quality impact of increased roadway traffic associated with a project such as this, computerized emission and atmospheric dispersion models can be used to estimate ambient carbon monoxide concentrations along roadways leading to and from the project. Carbon monoxide is selected for modeling because it is both the most stable and the most abundant of the pollutants generated by motor vehicles. Furthermore, carbon monoxide air pollution is generally considered to be a microscale problem, whereas nitrogen oxides air pollution most often is a regional issue. This is reflected in the fact that the AAQS for carbon monoxide are specified on a short-term basis (1-hour and 8-hour averaging times) while the AAQS for nitrogen dioxide is set on an annual basis.

For this project, three scenarios were selected for the carbon monoxide modeling study: year 1990 with present conditions, year

1998 without the project, and year 1998 assuming the project is built and complete. To begin the modeling study, critical receptor areas in the vicinity of the project were identified for analysis. Generally speaking, roadway intersections are the primary concern because of traffic congestion and because of the increase in vehicular emissions associated with traffic cycling: decelerating, stopping, queuing and accelerating. For this study, the key intersections identified in the traffic study [5] were also selected for air quality analysis. These include: Queen Kaahumanu Highway at the proposed O'oma Access Road, Queen Kaahumanu Highway at Kaiminani Drive and Queen Kaahumanu Highway at the Keahole Airport Road. Modeling of the present scenario was performed assuming the existing roadway configurations (including the assumption that there is presently through traffic only at the location of the future intersection of Queen Kaahumanu Highway and O'oma Access Road). For the future air quality modeling scenarios, it was assumed that Queen Kaahumanu Highway will be widened to four lanes and that all intersections will be signalized. The project traffic impact assessment report referenced above describes the present and future conditions and configurations of these intersections in more detail.

The main objectives of the modeling study were to estimate both current and projected levels of maximum 1-hour average carbon monoxide concentrations which could then be directly compared to the national and state AAQS. The traffic impact assessment report indicates that traffic volumes generally are or will be higher during the afternoon peak hour than during the morning peak period. Worst-case emission and meteorological dispersion conditions typically occur during the morning hours at many locations. Thus, even though traffic volumes may be higher in the afternoon than in the morning, worst-case air pollution concentrations may occur during the morning. To ensure that worst-case concentrations were identified, both morning and afternoon peak traffic periods were studied.

The EPA computer model MOBILE4 [6] was used to calculate vehicular carbon monoxide emissions for each of the years studied. One of the key inputs to MOBILE4 is vehicle mix. Based on recent vehicle registration figures, the present and projected vehicle mix in the project area is estimated to be 91.9% light-duty gasoline-powered vehicles, 5% light-duty gasoline-powered trucks and vans, 0.5% heavy-duty gasoline-powered vehicles, 0.6% light-duty diesel-powered vehicles, 1% heavy-duty diesel-powered trucks and buses, and 1% motorcycles.

Other key inputs to the MOBILE4 emission model are the cold/hot start fractions. Motor vehicles operating in a cold- or hot-start mode emit excess air pollution. Typically, motor vehicles reach stabilized operating temperatures after about 4 miles of driving. For traffic operating within the immediate project area, it was assumed that about 25 percent of all vehicles would be operating in the cold-start mode and that about 5 percent would be operating in the hot-start mode. These operational mode values were estimated based on a report from the California Department of Transportation [7] and taking into consideration the likely origin of afternoon traffic in the project area. MOBILE4 idle emissions were adjusted to account for excess cold/hot-start emissions per a recent U.S. EPA memorandum [8].

An ambient temperature of 59 degrees F was used for morning peak-hour emission computations while a temperature of 68 degrees F was used for the afternoon case. These are conservative assumptions since morning/afternoon ambient temperatures will generally be warmer than this and emission estimates given by MOBILE4 are inversely proportional to the ambient temperature.

After computing vehicular carbon monoxide emissions through the use of MOBILE4, these data were then input to the latest version of the computer model CALINE4 [9]. CALINE4 was developed by the California Transportation Department to simulate vehicular movement and atmospheric dispersion of vehicular emissions. It is designed to predict 1-hour average pollutant concentrations along roadways based on input traffic and emission data, roadway/receptor geometry and meteorological conditions.

Input peak-hour traffic data were obtained from the traffic study cited previously. The traffic volumes given in the traffic study for the future scenario include project traffic as well as traffic from other growth that is expected to occur in the area by the year 1998. Traffic queuing estimates were made based on the project traffic study, Transportation Research Board procedures [10], U.S. EPA guidelines [11], and traffic observations at the subject intersections. For the 1990 analyses, vehicles using Queen Kaahumanu Highway were assumed to accelerate to 55 mph, while Kaiminani Drive and airport traffic were assumed to move at 25 and 45 mph, respectively. These are the posted speed limits. Deceleration and acceleration times of 25 and 30 seconds, respectively, were assumed for vehicles traveling at 55 mph, whereas values of 20 and 25 seconds were assumed for those traveling at 45 mph. For vehicles moving at 25 mph, deceleration/acceleration times of 10 and 12 seconds were used. For the 1998 scenarios, the posted speed limit on Queen Kaahumanu Highway was assumed to be reduced to 45 mph.

Model roadways were set up to reflect actual roadway geometry, physical dimensions and operating characteristics. Presently, there are no pedestrian walkways along the roadways within the project area and none were assumed to exist when the project is completed in 1998. Thus, model receptor sites were located near the edge of the road right-of-ways at distances of 10 meters from the traveled portions of the roadways near the intersections studied. All receptor heights were placed at 1.5 meters above ground to simulate levels within the normal human breathing zone.

Input meteorological conditions for this study were defined to provide "worst-case" results. One of the key meteorological inputs is atmospheric stability category. For these analyses, atmospheric stability category 6 was assumed for morning scenarios and stability category 4 was assumed for afternoon cases. These are the most conservative stability categories that can be used for estimating pollutant dispersion at suburban or undeveloped locations. A surface roughness length of 100 cm was assumed with a mixing height of 300 meters. Worst-case wind conditions were defined as a wind speed of 1 meter per second with a wind direction resulting in the highest predicted concentration.

Existing background concentrations of carbon monoxide in the project vicinity are believed to be at relatively low levels. Hence, background contributions of carbon monoxide from sources or distant roadways not directly considered in the analysis were accounted for by adding a background concentration of 0.1 ppm to all predicted concentrations for the 1990 scenarios. Due to the expected significant development that is predicted to occur in the Kona area within the next several years, a background value of 0.5 ppm was used for all 1998 scenarios.

Table 3 summarizes the final results of the modeling study in the form of the estimated worst-case 1-hour afternoon ambient carbon monoxide concentrations. These results can be compared directly to the state and the national AAQS. Estimated worst-case carbon monoxide concentrations are presented in the table for three scenarios: year 1990 with existing traffic, year 1998 without project traffic and year 1998 with project traffic. The locations of these estimated worst-case 1-hour concentrations all occurred at or very near the indicated intersections.

As indicated in the table, the estimated present worst-case 1-hour carbon monoxide concentration in the project area, 6.4 mg/m^3, occurred near the intersection of Queen Kaahumanu Highway and Kaiminani Drive. This is mainly due to the long delays experienced by traffic on Kaiminani Drive turning left onto Queen Kaahumanu Highway. The worst-case 1-hour concentration at the other intersection studied, Queen Kaahumanu Highway at Keahole Airport Road, was estimated to be 3.1 mg/m^3 and occur during the afternoon. This is also caused mostly by traffic waiting to turn left onto Queen Kaahumanu Highway from the airport access road. At through locations along Queen Kaahumanu Highway, such as near the location where the proposed project access road will intersect, worst-case 1-hour concentrations were estimated to be about 1 mg/m^3.

In the year 1998 without the proposed project, a worst-case 1-hour concentration of 8.2 mg/m^3 was predicted to occur during the morning near the intersection of Queen Kaahumanu Highway and Kaiminani Drive, the same location and time as the highest concentration for the existing case. At Queen Kaahumanu Highway and Keahole Airport Road, the worst-case concentration was estimated to be 6.3 mg/m^3 during both the morning and the afternoon peak traffic periods. This assumes that Queen Kaahumanu Highway will be widened to four lanes and that both intersections will be at grade and signalized. At through traffic locations along Queen Kaahumanu Highway, peak-hour concentrations were estimated to reach about 1.4 to 1.6 mg/m^3. Compared to present conditions, worst-case concentrations in the year 1998 without the project will be about twice as high at many locations within the project vicinity.

Predicted 1-hour worst-case concentrations for the 1998 with project scenario range from 6.7 mg/m^3 during the afternoon at the intersections of Kaiminani Drive and Keahole Airport Road with Queen Kaahumanu Highway to 11.8 mg/m^3 during the morning at the Queen Kaahumanu Highway and O'oma Access Road intersection. All intersections were assumed to be at grade and signalized. Compared to the without project case, predicted concentrations are considerably higher at the Queen Kaahumanu Highway/O'oma Access Road intersection due to the creation of this intersection and the stop-and-go traffic that will result; concentrations along Queen Kaahumanu Highway at Kaiminani Drive and at Keahole Airport Road will be about 10 to 20 percent higher. Compared to the present case, worst-case concentrations in 1998 with the proposed project will be about two to three times higher at most locations.

All estimated worst-case 1-hour carbon monoxide levels for all scenarios are well within the national AAQS of 40 mg/m^3. It appears likely, however, that future concentrations with the project may exceed the State of Hawaii 1-hour AAQS of 10 mg/m^3 on occasion at the Queen Kaahumanu Highway/project access road intersection.

Worst-case 8-hour carbon monoxide concentrations were estimated by multiplying the worst-case 1-hour values by a persistence factor of 0.5. This accounts for two factors: (1) traffic volumes averaged over eight hours are lower than peak 1-hour values, and (2) meteorological dispersion conditions are more variable (and hence more favorable) over an 8-hour period than they are for a single hour. Based on <u>monitoring</u> data, 1-hour to 8-hour persistence factors for most locations generally vary from 0.4 to 0.8 with 0.6 being the most typical. One recent study based on <u>modeling</u> [12] concluded that 1-hour to 8-hour persistence factors could typically be expected to range from 0.4 to 0.5. EPA guidelines [11] recommend using a value of 0.6 to 0.7 unless a locally derived persistence factor is available. Recent monitoring data for Honolulu reported by the Department of Health [13] suggests that this factor may range between about 0.35 and 0.55 depending on location and traffic variability. Considering the location of the project and the traffic pattern for the area, a 1-hour to 8-hour persistence factor of 0.5 is probably most appropriate for this application.

The resulting estimated worst-case 8-hour concentrations are indicated in Table 4. For the 1990 scenario, the estimated worst-case 8-hour carbon monoxide concentration was 3.2 mg/m^3 at the intersection of Queen Kaahumanu Highway and Kaiminani Drive; other locations studied ranged from 1.6 mg/m^3 near Queen Kaahumanu Highway and Keahole Airport Road to 0.5 mg/m^3 along through sections of Queen Kaahumanu Highway. The predicted maximum value for the year 1998 without project scenario was 4.1 mg/m^3 near Queen Kaahumanu Highway/Kaiminani Drive. In 1998 with the project, the maximum worst-case 8-hour concentration was 5.9 mg/m^3 near Queen

Kaahumanu Highway/O'oma Access Road. Other locations studied for 1998 ranged from 0.8 mg/m^3 without the project along uninterrupted segments of Queen Kaahumanu Highway to 4.5 mg/m^3 with the project at the intersection of Queen Kaahumanu Highway and Kaiminani Drive. Either with or without the project, 1998 concentrations will be higher than existing concentrations at most locations. Comparing the predicted values for the existing case to the AAQS, it appears that both the state and the national 8-hour standards will be met during 1990. The same is true without the project in 1998. With the project, worst-case 8-hour concentrations will meet the national standard but may occasionally exceed the more stringent state standard near the entrance to the development.

The results of this study reflect several assumptions that must be made concerning traffic movement and worst-case meteorological conditions. One such assumption concerning worst-case meteorological conditions is that a wind speed of 1 meter per second with a steady direction for 1 hour will occur. A steady wind of 1 meter per second blowing from a single direction for an hour is not very likely, and it may occur only once a year or less. With wind speeds of 2 meters per second, for example, computed carbon monoxide concentrations would be only about half the values given above.

6.2 Golf Course Pesticide Usage

Once the project is completed and the golf course is in use, it will be necessary to regularly apply various chemical pesticides to maintain grass quality. Herbicides are applied to fairways and roughs, and insecticides and fungicides are used on greens and tees. Herbicide products typically used to treat fairways and roughs include: MSMA, glyphosate, metribuzin and pendimethalin.

Greens and tees may be treated with Sevin to control insects and Dithane M-45, Kocide 101 and/or Subdue to control fungi. The frequency of application for herbicide treatments is typically 2 to 4 times per year for each of the herbicide products mentioned above. Greens and tees are typically treated monthly with Sevin for insect control and semimonthly with one or more of the chemicals listed above for fungi control.

AAQS have not been established for any of the pesticides presently in use, although occupational safety and health standards have been established for some of the chemical ingredients. Most pesticide products carry warning or caution labels on their containers. The primary purpose of these labels is to provide occupational safety and health guidance regarding proper handling and application. The chief risk of using these chemicals is to the applicator rather than to individuals at possible receptor sites downwind, since these individuals should encounter airborne concentrations of these chemical substances only in greatly diluted form if at all. There are, however, certain precautions that must be followed by pesticide applicators in order to prevent significant downwind drift when spraying. Primary among these are the use of a coarse rather than a fine spray and application under low wind speed conditions when the wind direction will not carry any drift towards the clubhouse area or towards nearby residences. If proper safety precautions are followed, the potential for serious air quality degradation from chemical spraying for golf course maintenance can be minimized.

6.3 Electrical Demand

The proposed project will also cause indirect emissions from power generating facilities as a consequence of electrical power usage.

Peak project power demand at full build-out is not expected to exceed about 6 megawatts. Present generating capacity on the Big Island is 161 megawatts with most of this power provided by oil-burning generating units. Island wide, peak power demand is currently about 120 megawatts. Average annual electrical demand of the project when fully developed is not expected to exceed about 32 million kilowatt-hours. This power demand will most probably be provided mainly by oil-fired generating facilities located on the island. In order to meet the electrical power needs of the proposed project, power generating facilities will have to be expanded and/or burn more fuel, and hence more air pollution will be emitted at these facilities. Given in Table 5 are estimates of the indirect air pollution emissions that will result from the project electrical demand assuming all power is provided by burning more fuel oil at Hawaii's oil-fired power plants. Based on the ratio of peak project power demand to total present peak power demand on Hawaii, the project power demand will result in about a 5 percent increase in emissions from the electric utility if all project power is derived from fuel oil.

6.4 Solid Waste Disposal

Solid waste generated by the project when fully completed is expected to amount to about 17 tons of refuse (about three 6-ton truckloads) per day. Presently, the refuse district handles about 100 tons per day. Most if not all project refuse will likely be hauled away and either landfilled or burned at another location. If all refuse is landfilled, the only air pollution emissions associated with solid waste disposal (assuming problems similar to those which currently exist at the Kailua Landfill are avoided) will be due to exhaust fumes and fugitive dust from trucks and heavy equipment used to place the refuse in the landfill. If, on the other hand, all or part of the refuse is burned at a municipal incinerator, disposal of solid waste from the project will also result in emissions of particulate, carbon monoxide and other contaminants from the incineration facility. Table 6 gives emission factors for municipal refuse incinerators (without controls) in terms of pounds of air pollution per ton of refuse material charged. Thus, uncontrolled air pollutant emission rates in terms of pounds per year, for example, can be estimated by multiplying the emission factors given in the table by the number of tons per year of refuse that is burned. Use of emission filtration equipment will substantially reduce emissions of particulate.

7.0 SUMMARY OF IMPACTS AND MITIGATIVE CONSIDERATIONS

7.1 Impacts Summary

The major short-term air quality impact will be the potential emission of significant quantities of fugitive dust during project construction phases. Uncontrolled fugitive dust emissions from construction activities are estimated to amount to about 1.2 tons per acre per month. During construction phases, emissions from engine exhausts (primarily consisting of carbon monoxide and nitrogen oxides) will also occur both from on-site construction equipment and from vehicles used by construction workers and from trucks traveling to and from the project.

The primary long-term air pollution impact from the project will arise from the increased motor vehicle traffic associated with the project. Potential increased levels of carbon monoxide concentrations along roadways leading to and from the proposed development will be the primary concern. Based on mathematical modeling of projected vehicular traffic and on atmospheric dispersion estimates of vehicular emissions, it is predicted that with the proposed project carbon monoxide concentrations in the year 1998 along roadways in the project vicinity will meet the national air quality standards but occasionally may exceed the state standards in the vicinity of the project entrance. The state standards are set so low, however, they are probably exceeded at many intersections in the state that have even moderate traffic volumes. It is worth noting here that, although the national AAQS allow higher levels of carbon monoxide, these standards were developed after extensive research with the objective of defining levels of air quality that would protect the public health with an adequate margin of safety.

Pesticides will be used to maintain golf course grasses. If applied during low wind conditions using proper application techniques, contamination of nearby, downwind areas by airborne drift is not expected be a problem.

Some long-term impacts on air quality also could potentially occur due to indirect emissions from power generating facilities supplying the project with electricity and from the disposal of waste materials generated by the project. Quantitative estimates of these impacts were not made, but it appears likely that any impacts will be small due to the magnitude of the project electrical and solid waste demands compared to the present county demands.

7.2 Mitigative Considerations

Strict compliance with State of Hawaii Air Pollution Control Regulations regarding establishment of a regular dust-watering program and covering of dirt-hauling trucks will be required to effectively mitigate fugitive dust emissions from construction activities. Twice daily watering is estimated to reduce dust emissions by up to 50 percent. Use of wind screens and/or limiting the area that is disturbed at any given time may be required in sensitive or dust-prone areas. Paving of parking areas and establishment of landscaping early in the construction schedule will also help to control dust. Increased vehicular emissions due to disruption of traffic by construction equipment and/or commuting construction workers can be alleviated by moving equipment and personnel to the site during off-peak traffic hours.

Options available to mitigate traffic-related air pollution are to improve roadways, reduce traffic or reduce individual vehicular emissions. Long-term projections of carbon monoxide emissions from vehicular traffic associated with the completed development are based on the traffic impact study findings. It has been assumed that the roadway improvements recommended in the traffic study will be implemented to move traffic efficiently through the project area and adjacent locations. Aside from further improving roadways, air pollution impacts from vehicular emissions can be mitigated by reducing traffic through the use of mass transit and car pooling and/or by adjusting local school and business hours to begin and end during off-peak times. Due to the extended completion date for the project, it is conceivable that the efficiency of motor vehicle engines and/or emission control equipment will be improved or that vehicles will be developed which burn cleaner fuels before the project reaches full build-out. If this occurs, then impacts will be less than predicted. With regard to cleaner burning fuels, vehicles burning methanol or compressed natural gas or powered by electrical motors are some of the possibilities for technological development that are currently being contemplated. Lastly, even without technological breakthroughs, it is also possible that at some point in the future the state may decide to adopt either a motor vehicle inspection and maintenance program, which would ensure that emission control devices are properly maintained and thereby reduce emissions, or more restrictive emission control standards.

Compliance with safety guidelines for the spraying of chemicals for golf course maintenance should mitigate potential air quality impacts from this activity. Safety guidelines for the spraying of chemicals include the use of a coarse rather than a fine spray and application only during periods of light wind conditions.

Indirect emissions from project electrical demand could be reduced somewhat by utilizing solar energy design features to the maximum extent possible. This might include installing solar water heaters, designing homes and building space so that window positions maximize indoor light without unduly increasing indoor heat, and using landscaping where feasible to provide afternoon shade to cut down on the use of air conditioning. Use of wind power generating units, geothermal energy, ocean thermal energy conversion and/or other alternative energy sources by the utility instead of fuel-burning facilities also would lessen indirect emissions from project electrical demand.

Most probably solid waste from the project will be buried at a landfill, and any air pollution impacts will be minimal if the landfill is operated properly. If project refuse is burned instead at a municipal incinerator, air pollution impacts could be reduced substantially if the incinerator is fitted with pollution control equipment, i.e., electrostatic precipitators or fabric filters. Conservation and recycling programs also could reduce solid waste which would reduce any related air pollution emissions proportionately. Lastly, if the new H-Power garbage-to-energy facility located on Oahu proves successful, similar facilities on the other islands may be developed before project completion. Use of solid waste to generate power will offset emissions that would otherwise occur from fossil-fueled power plants if the waste would be simply incinerated instead.

REFERENCES

1. U.S. Congress. Clean Air Act Amendments of 1977 (P.L. 95-95), Section 109, National Ambient Air Quality Standards, August 1977.

2. U.S. Environmental Protection Agency. Revisions to National Ambient Air Quality Standards for Particulate Matter, Federal Register, Vol. 52, p. 2463, July 1, 1987.

3. Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources, Fourth Edition Including Supplements A and B, AP-42, U.S. Environmental Protection Agency, Research Triangle Park, NC, September 1988.

4. State of Hawaii. Hawaii Administrative Rules, Chapter 11-60, Air Pollution Control.

5. The Traffic Management Consultant, Traffic Impact Assessment Report for O'oma II Project, Draft, September 1990.

6. User's Guide to MOBILE4 (Mobile Source Emission Factor Model), EPA-AA-TEB-89-01, U.S. Environmental Protection Agency, Office of Air and Radiation, Office of Mobile Sources, Emission Control Technology Division, Test and Evaluation Branch, Ann Arbor, Michigan, February 1989.

7. Benson, Paul E., "Corrections to Hot and Cold-Start Vehicle Fractions for Microscale Air Quality Modeling", California Department of Transportation, Transportation Laboratory, Sacramento, California.

8. Memorandum from Terry P. Newall, U.S. Environmental Protection Agency, Ann Arbor, Michigan, to MOBILE4 Users concerning "Adjustment of MOBILE4 Idle CO Emission Factors to Non-Standard Operating Conditions", January 4, 1990.

9. CALINE4 - A Dispersion Model for Predicting Air Pollutant Concentrations Near Roadways, FHWA/CA/TL-84/15, California State Department of Transportation, November 1984 with June 1989 Revisions.

10. Highway Capacity Manual, Transportation Research Board, National Research Council, Washington, D.C., Special Report 209, 1985.

11. Guidelines for Air Quality Maintenance Planning and Analysis; Indirect Sources, Volume 9 Revised, U.S. Environmental Protection Agency, September 1978.

12. "Persistence Factors for Mobile Source (Roadway) Carbon Monoxide Modeling", C. David Cooper, Journal of the Air & Waste Management Association, Volume 39, Number 5, May 1989.

13. Hawaii Air Quality Data for the Period of January 1985 to December 1987, State of Hawaii Department of Health.

Table 1

SUMMARY OF STATE OF HAWAII AND NATIONAL AMBIENT AIR QUALITY STANDARDS

Pollutant	Units	Averaging Time	Maximum Allowable Concentration: National Primary	National Secondary	State of Hawaii
Suspended Particulate Matter	$\mu g/m^3$	Annual	-	-	60[a]
		24 Hours	-	-	150[b]
Particulate Matter[c]	$\mu g/m^3$	Annual	50	50	-
		24 Hours	150[b]	150[b]	-
Sulfur Dioxide	$\mu g/m^3$	Annual	80	-	80
		24 Hours	365[b]	-	365[b]
		3 Hours	-	1300[b]	1300[b]
Nitrogen Dioxide	$\mu g/m^3$	Annual	100	100	70
Carbon Monoxide	mg/m^3	8 Hours	10[b]	-	5[b]
		1 Hour	40[b]	-	10[b]
Ozone	$\mu g/m^3$	1 Hour	235[b]	235[b]	100[b]
Lead	$\mu g/m^3$	Calendar Quarter	1.5	1.5	1.5

[a]Geometric mean

[b]Not to be exceeded more than once per year

[c]Particles less than or equal to 10 microns aerodynamic diameter

Table 2

ANNUAL SUMMARY OF AIR QUALITY MEASUREMENTS
FOR MONITORING STATIONS NEAREST O'OMA PROJECT

Parameter / Location	1985	1986
Sulfur Dioxide / Kealakekua, Kona		
Period of Sampling (months)	7	8
No. of 24-Hr Samples	31	40
Range of 24-Hr Values (ug/m3)	<5-8	<5-12
Average Daily Value (ug/m3)	<5	<5
No. of State AAQS Exceedances	0	0
Particulate / Kealakekua, Kona		
Period of Sampling (months)	7	8
No. of 24-Hr Samples	34	40
Range of 24-Hr Values (ug/m3)	6-22	4-28
Average Daily Value (ug/m3)	12	16
No. of State AAQS Exceedances	0	0

Source: State of Hawaii Department of Health, "Hawaii Air Quality Data for the Period of January 1985 to December 1987"

Table 3

ESTIMATED WORST-CASE 1-HOUR CARBON MONOXIDE CONCENTRATIONS ALONG ROADWAYS NEAR O'OMA PROJECT (milligrams per cubic meter)

Roadway Intersection	Year/Scenario[a]					
	1990/ Present		1998/ Without Project		1998/ With Project	
	AM	PM	AM	PM	AM	PM
Queen Kaahumanu Highway at O'oma Access Road	1.0[b]	0.8[b]	1.6[b]	1.4[b]	11.8	9.4
Queen Kaahumanu Highway at Kaiminani Drive	6.4	3.3	8.2	6.1	9.0	6.7
Queen Kaahumanu Highway at Keahole Airport Road	3.0	3.1	6.3	6.3	7.8	6.7

Hawaii State AAQS: 10
National AAQS: 40

[a] 1998 with and without project scenarios assume Queen Kaahumanu Highway widened to four lanes and all intersections signalized.

[b] Assumes through traffic only on Queen Kaahumanu Highway.

Table 4

ESTIMATED WORST-CASE 8-HOUR CARBON MONOXIDE CONCENTRATIONS ALONG ROADWAYS NEAR O'OMA PROJECT (milligrams per cubic meter)

Roadway Intersection	Year/Scenario[a] 1990/ Present	1998/ Without Project	1998/ With Project
Queen Kaahumanu Highway at O'oma Access Road	0.5[b]	0.8[b]	5.9
Queen Kaahumanu Highway at Kaiminani Drive	3.2	4.1	4.5
Queen Kaahumanu Highway at Keahole Airport Road	1.6	3.2	3.9

Hawaii State AAQS: 5
National AAQS: 10

[a] 1998 with and without project scenarios assume Queen Kaahumanu Highway widened to four lanes and all intersections signalized.

[b] Assumes through traffic only on Queen Kaahumanu Highway.

Table 5

ESTIMATED INDIRECT AIR POLLUTION EMISSIONS FROM O'OMA PROJECT ELECTRICAL DEMAND[a]

Air Pollutant	Emission Rate (tons/year)
Particulate	6
Sulfur Dioxide	80
Carbon Monoxide	17
Volatile Organics	6
Nitrogen Oxides	77

[a]Based on U.S. EPA emission factors for utility gas turbines [3]. Assumes net electrical demand of 32 million kw-hrs per year and low sulfur oil used to generate power.

Table 6

UNCONTROLLED AIR POLLUTION EMISSION FACTORS FOR MUNICIPAL REFUSE INCINERATORS (lb/ton)[a]

Air Pollutant	Emission Factor
Particulate	14[b]
Sulfur Oxides	2.5
Carbon Monoxide	35
Organics	1.5
Nitrogen Oxides	3

[a]Emission factors are given in terms of weight of material emitted per unit weight of refuse material charged.
[b]Assumes incinerator equipped with settling chamber and water spray.

Source: U.S. Environmental Protection Agency [3]

APPENDIX N

ARCHAEOLOGICAL SURVEY

Paul H. Rosendahl, Ph.D., Inc.

PAUL H. ROSENDAHL, Ph.D., Inc.
Consulting Archaeologist

Report 254-081286

ARCHAEOLOGICAL SURVEY AND TESTING OOMA II RESORT PROJECT AREA

Land of Ooma II

North Kona, Island of Hawaii

April 1987

305 Mohouli Street • Hilo, Hawaii 96720 • (808) 969-1763 or 966-8038

PAUL H. ROSENDAHL, Ph.D., Inc.
Consulting Archaeologist

Report 254-081286

ARCHAEOLOGICAL SURVEY AND TESTING
OOMA II RESORT PROJECT AREA

Land of Ooma II
North Kona, Island of Hawaii
(TMK:3-7-3-09:4)

by

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Submitted to

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April 1987

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SUMMARY

An archaeological survey and testing program was conducted by Paul H. Rosendahl, Ph.D., Inc. at the Ooma II Resort project area during the period July 16-23, 1986, under agreement with Helber, Hastert, Van Horn & Kimura. The area surveyed consists of a 314-acre parcel located between the shoreline and the Mamalahoa Trail within the Land of Ooma II, North Kona District, Island of Hawaii (TMK:3-7-3-09:4).

The survey and testing program consisted of a high intensity level pedestrian reconnaissance survey of the coastal zone within the project area (shoreline to 300 m from shoreline) and an intensive survey with testing of sites previously located in the inland portion of the project area. Subsurface testing or controlled surface collection was conducted at ten inland sites during this study. A total of 27 new sites with 130 features was located during the reconnaissance phase, and 54 new features were located at previously recorded sites. These new findings result in a cumulative total of 74 archaeological sites with 279 component features located within the project area to date.

Fifteen permanent habitation complexes have been identified within the coastal area of Ooma II. Nine of these sites were previously tested by Cordy (1981), and temporal as well as functional interpretations of the sites have been offered. Thirty-four temporary habitation or shelter sites have been identified within the project area, in addition to four footpath segments, five burial sites, two shrines, and a high-walled enclosure. A total of 69 hydration rind age determinations has been completed for 15 sites within the project area. The calendric ranges of these determinations are within AD 1430 to 1855. Ranges determined from temporary sites fall within a much narrower span of AD 1550 to 1755.

Additional archaeological work is recommended at this time for 24 sites which contain information of significant research value.

Preservation with interpretive development is recommended for five sites, and preservation with protection is recommended for 10 sites. Sufficient research information was collected to permit a recommendation of no further work at 50 of the 74 archaeological sites.

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INTRODUCTION

An archaeological survey and testing program was conducted at the Ooma II Resort project area by Paul H. Rosendahl, Ph.D. Inc. (PHRI), under agreement with Helber, Hastert, Van Horn & Kimura. The purpose of this program was to provide technical information and preliminary site assessment statements that can be used in the preparation of a Draft Environmental Impact Statement (DEIS). This information will also be used for any zoning requests or Special Management Area (SMA) permit applications that might be made to the Hawaii County Planning Department.

The 314-acre project area includes the seaward portion of the Land of Ooma II, North Kona, Island of Hawaii (TMK:3-7-3-09:4). Field investigations were conducted July 16-23, 1986, under the direction of Principal Archaeologist Dr. Paul H. Rosendahl and Project Director Theresa K. Donham.

Prior to the present investigation, 47 archaeological sites with 95 component features had been recorded within the project area. Twenty-seven new sites with 130 features, and 54 new features at previously recorded sites, were located and identified during the present investigation. These new findings result in a cumulative total of 74 archaeological sites with 279 component features located within the project area to date. Subsurface testing or controlled surface collection was conducted at ten sites during this study. Detailed recording was conducted at all previously recorded and newly identified sites, and scaled plan maps were compiled for 26 sites. A summary and evaluation assessment of all sites is presented in this report, which represents a final report of findings and recommendations.

SCOPE OF WORK

The scope of work for this program was designed through consultations between Dr. Ross Cordy--staff archaeologist in the Historic Sites Section of the Hawaii State Department of Land and Natural Resources; Mark Hastert--principal with Helber, Hastert, Van Horn & Kimura; Dr. Paul H. Rosendahl--PHRI principal archaeologist; and Dr. Alan E. Haun--PHRI senior archaeologist. The original scope of work was designed following a field inspection of the project area by Dr. Cordy (1986a, b), who found a number of deficiencies in a recently completed reconnaissance survey conducted by William J. Barrera, Jr. (1985). Cordy indicated that the inland portion of the survey area had been adequately surveyed and that no additional reconnaissance was needed for the purpose of locating new sites (Cordy 1986a:5).

Barrera's survey was found to be deficient in the coastal portion of the project area, which includes all land within a minimum of 1,000 ft from the shoreline (Cordy 1986a:5). Cordy indicated that the area seaward (west) of the coastal jeep road is within the affected project area and should be included within the archaeological survey area. He also stated that all small coastal sites observed but not recorded by Barrera should be inventoried and located. In addition, Cordy noted that Barrera failed to incorporate existing data that had been collected from Ooma II sites during prior surveys of the area by Martin (State Inventory) in 1971 and by Cordy in 1975.

The specific tasks outlined by Cordy (1986b) in his work for Helber, Hastert, Van Horn & Kimura, were designed to supplement existing archaeological data collected by Barrera (1985) and Cordy (1981), and to permit fulfillment of historic preservation concerns identified by the Department of Land and Natural Resources. These concerns were to be addressed in the DEIS prepared for the Ooma II Resort project area and are as follows:

1. Identify all historic sites;
2. Collect enough information to evaluate the significance of each site;
3. Determine the significance of each site;
4. Establish the nature of impacts on significant sites; and
5. Provide a general mitigation plan which attempts to reduce impacts on significant sites (Cordy 1986b:1).

Concerns 1, 2, 3, and 5 are directly relevant to this study. The fourth concern involves management decisions to be made by the developer, which are based on a number of factors that are beyond the scope of archaeological consultant involvement at this time.

The specific tasks of the scope of work were outlined as follows:

1. Intensive survey of the coastal area lying between the shoreline and a line of low aa bluffs that are situated 900 to 1,200 ft inland and;
2. Intensive survey of all previously identified sites, with the exception of previously recorded features at 12 coastal sites (D15-1 thru -8, and -16 thru -19; Bishop Museum site numbers) for which Dr. Cordy considers his previous recording of them to be sufficient. This work would include identification of component features and appropriate detailed recording (written descriptions, measurements, scaled plan maps, photographs and representative surface midden and artifact collections) at the following specific sites:

Coastal Area Sites T-14 thru -18, -33, -37, -39, and -40, plus any additional new sites identified during the coastal intensive survey; and

Inland Area Sites T-1 thru -13, -19 thru -28, and -41 thru -46 (29 sites);

3. Testing by excavation at Site T-16 to determine the type and nature of the buried feature. At all other sites containing subsurface deposits, testing by probe or auger sufficient to determine the general nature, depth, and content of stratigraphic deposits. No testing to be conducted at suspected burial features at Sites T-20, -21, and -33 (scope limitations per telephone conversation with Mr. Hastert, July 3, 1986);

4. Check caves c. 400 ft west of Site T-1, and record if evidence of cultural use is present;

5. Laboratory analysis of data recovered from the archaeological survey and test excavations, including dating of "a few volcanic glass samples," if available from surface collections or test excavations; and

6. Preparation of written reports (preliminary and final). In addition to a final descriptive account of project findings, the final report will provide site-specific interpretations of site functions and ages, a general interpretation of past land use patterns in Ooma II, site-specific significance assessments, and recommendations for appropriate further treatment of significant sites.

Minor discrepancies were found in the specific sites listed in Tasks 2 and 3; Sites T-18, T-37, and T-40 are actually Sites D15-8, D15-7, and D15-4, which had been previously tested by Cordy. Additional excavation was not conducted at these sites; however, scaled plan maps were compiled which included numerous new features not previously recorded by Cordy or Barrera. Site T-33 is listed as a site to be tested; it is also included in the list of burial features not to be disturbed at this stage of study (Task 3). It is within the boundaries of Site D15-3, which was previously tested, and therefore it was not disassembled.

Vegetation clearing and examination of the wall feature at Site T-16 indicated that small test excavation units, as described in Task 3, would not provide new information about this feature. Erosion from wave action had created an undercut which exposed a 3.0-m-long section of the western wall; this exposure confirmed that the remaining stones were the base of the wall and that no additional subsurface stones were present. The southern wall was sufficiently exposed to permit description and measurement (further discussed in the site description).

The significance of the archaeological resources identified and tested during this survey is evaluated in terms of potential scientific research, interpretive, and/or cultural values. <u>Research value</u> refers to the potential of archaeological resources for producing information useful in the understanding of culture history, past lifeways, and cultural processes at the local, regional, and interregional levels of organization. The research value of individual sites is best explicated when a formal research design has been prepared for the project area, outlining specific problems, prior hypotheses, and newly collected data.

A research design has been formulated for the Ooma II Resort project area, based on previous archaeological work, newly collected data, and general research priorities identified for North Kona (cf. Draft Hawaii County Historic Preservation Plan 1986). This design is briefly outlined below and will be further discussed in the conclusion.

<u>Interpretive value</u> refers to the potential of archaeological resources for public education and recreation. Sites with high interpretive value are generally recommended for preservation, with possible limited reconstruction and/or stablization. Three sites within the Ooma II project area have been previously recommended by Dr. Cordy for interpretive preservation (1985:45). These and other sites with high interpretive value are discussed below.

<u>Cultural value</u>, 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 or traditional values. Three sites within the Ooma II project area have been previously recommended by Dr. Cordy for preservation for cultural significance reasons (1985:45). These and other sites with potentially high cultural value are discussed below.

PROJECT AREA DESCRIPTION

The Ooma II Resort project area is a single parcel of c. 314 acres, bordered on the west by the Pacific Ocean, on the south by the Land of Kohana-Iki, and on the north by the Land of Ooma I. The southernmost portion of the eastern boundary follows the Mamalahoa Trail for a short distance and then diverges northwestward at an angle of c. 12 degrees (Figure 1). The property boundaries were not marked in the field, and there is some confusion as to exactly where the boundary between Ooma II and Kohana-Iki is located. A recent reconnaissance survey base map provided to PHRI by Helber, Hastert, Van Horn & Kimura indicates that the eastern Ooma boundary is aligned with an access road to the coast. The Ooma II base map indicates that the boundary is 80 ft south of the road. If the latter boundary is correct, approximately six sites previously located in Kohana-Iki (Donham 1986a) are actually within the Ooma II project area. Two of these boundary sites (T-14 and T-15), recorded by Barrera as Sites T-175 and T-176 in Kohana-Iki, were recorded as being in the Ooma II area.

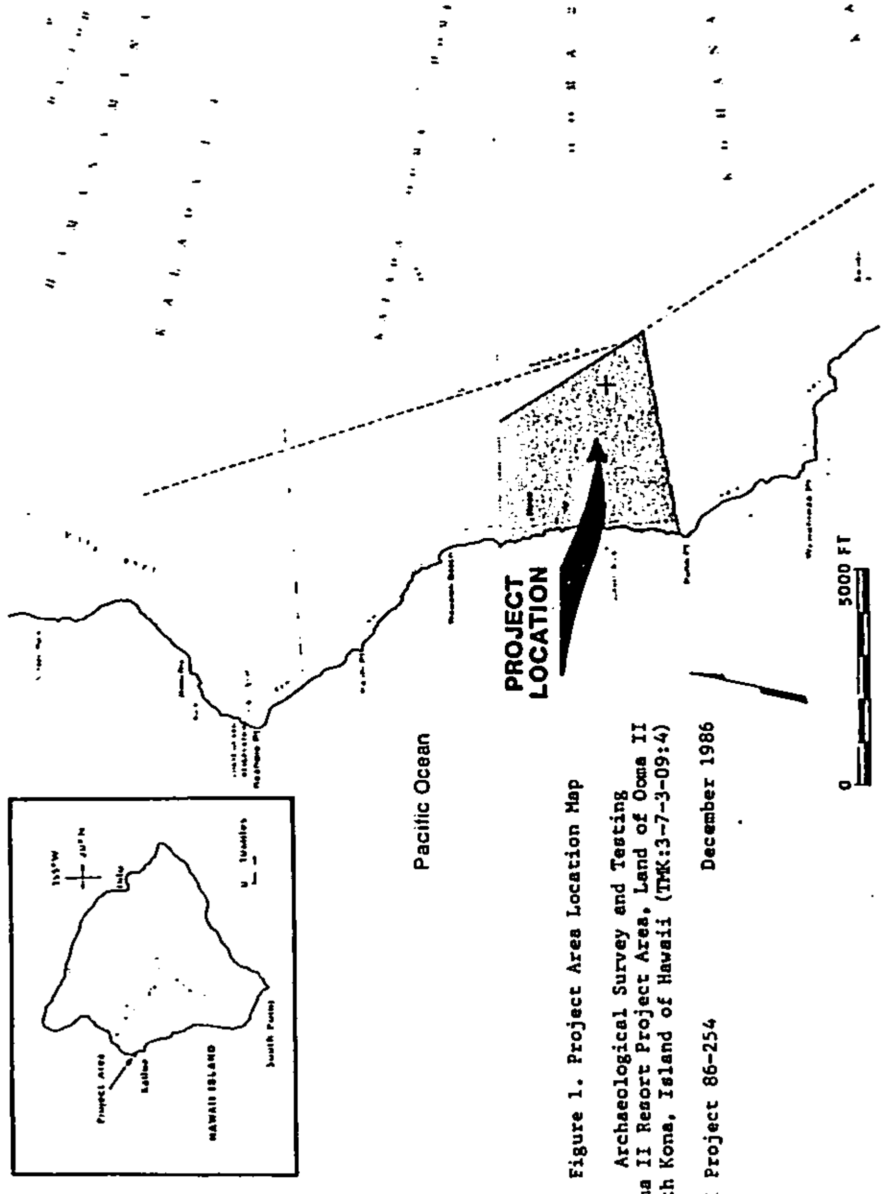

Figure 1. Project Area Location Map

Archaeological Survey and Testing
Ooma II Resort Project Area, Land of Ooma II
North Kona, Island of Hawaii (TMK:3-7-3-09:4)

PHRI Project 86-254 December 1986

The Land of Ooma II is situated on the lower southwestern slope of Hualalai Volcano, in the region of Kekaha, which includes those lands from Honokohau north to Puuanahulu (Springer 1985:87). The principal environmental features of Kekaha are the dry, hot climate of the region and the extensive lava fields, which have little to no soil accumulation. Local climatic patterns are affected by the mountains, which block moisture-laden northeast trade winds. Average annual rainfall ranges between 10 and 20 inches, with a slightly lower average along the coastal zone (Armstrong 1973:57). Mean temperatures range from 70 to 76 degrees F (DLNR 1970:81).

The current ground surface of the project area consists of prehistoric pahoehoe and aa lava flows derived from Hualalai Volcano (Macdonald et al. 1983:353). Relatively level, weathered, smooth pahoehoe occurs along c. 50% of the coastal zone and is the locus of most of the vegetation within the project area. Smooth pahoehoe forms most of the rocky points along the shoreline that extend beyond the band of coral beach wash. With the exception of a narrow band of coral beach deposits, no soil zones are recorded within the project area by the Soil Conservation Service (Sato et al. 1973:Sheet 66). Soil accumulation observed in the rocklands during field investigations was limited to cave or overhang shelters that also had dense midden deposits.

A more recent deposit of mixed aa and rough to broken pahoehoe occurs in discontinuous patches across the project area. This more recent flow forms a definite topographic feature that curves inland from the southern coastal zone and roughly correlates with the inland/coastal zone boundary in the northern half of the project area. Archaeological sites tend to be clustered along the west-facing crest of this flow ridge, where topographic relief is most pronounced. Nearly all located footpath segments were over the aa and rough pahoehoe of this overlying flow; paths became extremely difficult or impossible to distinguish once the smooth, weathered pahoehoe was encountered. The aa/rough pahoehoe flow extends to the shoreline in two disconnected deposits within the project area. Major coastal sites are concentrated either along the periphery or on prominent landforms within these two deposits, which cover approximately 50% of the immediate coastal area.

Two general environmental zones are distinguishable within the project area; the coastal and the inland, or barren, zones. The coastal zone has an average width of 1,000 ft (305 m) from the shoreline and varies in elevation from sea level to 35 ft. The coastal zone survey stratum was defined prior to this study and was based on Barrera's definition of the coastal zone (1985:1). The inland boundary of this zone is an imaginary line connecting selected sites, and it ranges from 900 ft (207 m) inland at the southern boundary to 1,200 ft (366 m) inland at the northern boundary.

Characteristic coastal vegetation includes tree heliotrope (Messerschmidia argentea [L.f.] Johnston), naupaka (Scaevola sericea Vahl), Christmas-berry (Schinus terebinthifolius Raddi), and beach morning glory (pohuehue, Ipomoea pes-caprae L.). Particularly dense stands of naupaka and Christmas-berry occur in the southern portion of the coastal zone, which is generally lower than the northern portion. On smooth pahoehoe immediately inland of the naupaka stands are relatively dense stands of fountain grass (Pennisetum setaceum [Forsk.] Chiov.), with scattered Christmas-berry, noni (Morinda citrifolia L.), and kiawe (Prosopis pallida [Humb. and Bonpl. ex Willd.] HBK.). Lantana (Lantana camara L.) and 'ilima (Sida fallax Walp.) occur throughout the coastal zone and in lesser quantities in the barren inland zone. Most of the aa and rough pahoehoe areas are devoid of vegetation, or they support small patches of fountain grass in low, protected pockets. A few isolated kiawe trees also occur in the barren inland zone.

PREVIOUS ARCHAEOLOGICAL WORK

The earliest recorded field work recorded for Ooma II was conducted for the Bernice P. Bishop Museum (BPBM) in 1930 by John E. Reinecke (1930), who located major coastal sites in the Districts of North Kona and South Kohala. Reinecke recorded ten sites along the Ooma II coast (Sites 66- 75), seven of which have been correlated with BPBM sites later recorded by Cordy (1986a:27). Two additional Reinecke sites have been correlated with newly recorded sites, and only one site (Site 67, a "dry well on the crest of the beach") has not been identified to date. Despite the fact that Reinecke's site descriptions are very brief and that no site maps were compiled, his data provide a historical perspective on the condition of some sites as they were 56 years ago (Reinecke 1930:15-16). For example, Reinecke's Site 66, which consisted of several house platforms and a high-walled enclosure, is represented today by only a few wall remnants (Site T-16 and T-48). Reinecke's observations likewise suggest that a number of shoreline structures have been totally washed away by storm waves. He observed "sand-covered platforms" along the beach at Site 66, which were interpreted as the site of "6-10 homes" (1930:15). He also observed that "(t)here are many faint traces of sites along this strip of coast" (1930:16).

In 1971-72, the Hawaii Department of Land and Natural Resources began an inventory of known archaeological sites and revisited a number of sites located by Reinecke. State inventory numbers were assigned to seven coastal sites at this time by B.J. Martin, who completed Hawaii Register of Historic Places (HRHP) forms. Sketch maps were compiled, and features were given letter designations at four of these seven sites. Four coastal sites (1911 thru 1915*) were subsequently grouped as the Ooma II Complex (4165). These four sites were later subdivided by Cordy and were designated as nine sites (D15-3 thru 6, 8, 16 thru 19#).

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*Hawaii Register of Historic Places (HRHP) site designation system: all four-digit site numbers prefixed by 50-10-27- (50=State of Hawaii, 10=Island of Hawaii, 27=USGS 7.5' series quad map [Keahole Point, Hawaii])

#B.P. Bishop Museum (BPBM) site designation system: all site numbers prefixed by 50-Ha-D15- (50=State of Hawaii, Ha=Island of Hawaii, D=District of North Kona, 15=Lands of Ooma [I and II]).

The most intensive prior archaeological work conducted within the project area was done in late 1975 by Ross H. Cordy, who conducted a coastal survey and site testing program in selected areas of West Hawaii. Cordy identified features of inferred permanent habitation function (platforms and terraces within a given size range), assigned Bishop Museum numbers, compiled sketch plan maps, and excavated one-meter-square units into the structures for the purpose of obtaining volcanic glass for dating. Twelve sites were recorded and nine were tested within the Ooma II project area (Table 1). Sites not tested include a large animal enclosure (D15-16) and adjacent platform (D15-17), and a heiau (D15-18).

Table 1.

SUMMARY OF EXCAVATIONS AND VOLCANIC GLASS DATES DETERMINED DURING CORDY'S 1975 DISSERTATION WORK IN OOMA II

Site No.	Features Recorded	Test Units	Dated Glass Specimens	Range of Dates Determined (AD)
D15-1	4	4	15	1490-1832
D15-2	2	3	1	1550-1660
D15-3	5	4	8	1560-1760
D15-4	2	1	1	1750-1821
D15-5	4	1	6	1430-1720
D15-6	1	1	2	1540-1650
D15-7	2	2	5	1590-1779
D15-8	2	1	7	1480-1857
D15-16	1	-	-	---
D15-17	1	-	-	---
D15-18	1	-	-	---
D15-19	1	2	4	1590-1720

Source: Cordy 1981.

Data collected at Ooma II were incorporated with data from seven other North Kona ahupua'a and were synthesized as part of Cordy's doctoral dissertation research (Cordy 1981). Cordy's research is primarily from a settlement pattern analysis approach and is based on ethnohistoric resources and on archaeological data. The goals of his study are to re-examine archaeological correlates generally used to predict various categories of political evolution (i.e., tribal, chiefdom and state) and to present a Hawaiian-specific model that measures social complexity. The variables of population size, territory size and number of social eschelons or ranks are hypothesized to be covariant and to be accurate predictors of social evolution on a scale of simple to complex. A number of his hypotheses are directly relevant to this study and are further examined in the following section.

Between 1975 and 1985, a number of survey projects were conducted in the vicinity of the Keahole Airport and Agricultural Park Area, north of the project area. These surveys are summarized in an overview study of the Ooma and Kalaoa ahupua'a prepared by Cordy (1985).

Cordy's overview was compiled as a working paper, from the Historic Sites Section of the Hawaii Department of Land and Natural Resources, for use by researchers and contractors working within the focal area. The paper is designed for use in cultural resource management and contains information on local environment, prior archaeological work, site patterning, chronological data, and an interpretive overview. Cordy also lists specific sites known to him that have high potential for preservation as interpretive or religious structures.

Additional field work was conducted at Ooma II in 1985 by William J. Barrera, Jr., who undertook a reconnaissance-level survey of the Ooma II Resort project area for Helber, Hastert, Van Horn & Kimura (Barrera 1985). Barrera divided the project area into coastal and inland zones and conducted different intensities of reconnaissance in each zone. In the inland zone, all features--with the exception of pahoehoe clearings--were located, given temporary site numbers, photographed, and briefly described (many in a single sentence). In the coastal zone, only the "larger and more substantial features" were located and described (Barrera 1985:1).

Apparently having neglected to review available reports and records on prior work within the project area, Barrera recorded 40 temporary site numbers, 11 of which corresponded with features previously recorded by Cordy as BPBM sites. The Barrera survey therefore recorded 29 new sites with 56 new features. Recommendations are not given for specific sites, and Barrera concluded--without apparent justification--that "[f]rom the archaeological perspective, none of the sites found are of such significance that preservation should be required" (1985:46).

Due to problems with Barrera's report and level of work, Helber, Hastert, Van Horn & Kimura requested a review and field check of the Barrera work by Dr. Cordy of the Historic Sites Section-DLNR. Cordy returned to Ooma II and examined the northern one-third of the inland survey area, as well as a small section of the northern coastal survey area (Cordy 1986b). Six new sites with seven features were located in the inland area by Cordy during this field check (Sites T-41 thru T-46). Cordy's assessment of the inland survey was that Barrera's survey was "fairly accurate," with additional necessary work limited to gathering more complete data on recorded sites. Cordy apparently had problems relocating some of Barrera's sites (1986a:5). The PHRI survey team was able to locate all of Barrera's inland sites, most of which were still labeled with a site number and which were accurately plotted on Barrera's project area map.

In his field check report, Cordy includes field notes and age determination data for the sites which he tested in 1975 at Ooma II. A table correlating BPBM site numbers and Barrera's temporary site numbers is included; however, there are a number of errors in this table. All correlations between the various survey designations were confirmed by PHRI in the field, using Barrera's site markers and photographs, and maps

accompanying Martin's and Cordy's site forms. A revised site correlation table is presented here (Table 2). Many of Cordy's statements refer to erroneous feature measurements by Barrera or to Barrera's confusion between vandalism and former test units, due to Cordy's confusion between correlated Bishop Museum sites and Barrera's temporary site numbers (Cordy 1986a:11-12). The recommendations and scope of work resulting from Cordy's field check have been discussed in a preceding section.

Table 2.

CORRELATION OF ASSIGNED SITE NUMBERS, OOMA II COASTAL ZONE

Bishop Museum (1975)	State Inventory (1971-72)	Reinecke (1930)	Barrera (1985)	Comments
D15-1	1910	68	-	-
D15-2	1910	68	29, 30	-
D15-3	1912	69	33	Barrera's number corresponds with a stone mound on the site
D15-4	1914	71	40	-
D15-5	1916(?)	72	-	-
D15-6	1916(?)	-	-	-
D15-7	1916	75	37, 38	Barrera's 37 is Cordy's Fea. 2; 38 is Fea. 1
D15-8	1914	71	18	-
D15-16	1911	69	32	-
D15-17	1911	69	34	-
D15-18	1913	70	35	Barrera's number corresponds with an associated platform directly across the coastal jeep road from the heiau (D15-18)
D15-19	1915	73	36	-

RESEARCH PROBLEMS AND APPROACH

A number of research issues of importance to this investigation and to further archaeological work at Ooma II are discussed here, in order to provide an explicit context for the assessment of research significance. These issues cannot be substantively addressed at this stage of analysis; however, a number of hypotheses can be offered, based on the information available at this time.

The various approaches to archaeological interpretation--culture history, settlement pattern analysis, human ecology, culture process, and the reconstruction of past lifeways--each require specific data sets, but can often be pursued conjunctively in order to provide a more complete interpretive analysis. When analysis is focused on a single approach, it often becomes difficult to identify or explain the array of variation that is present within archaeological data. The interrelationship of the above approaches, as they may be applied within the context of this project, is briefly considered here. Also considered are specific research problems, many of which are derived from previous work.

The development of a local culture history is often seen as a necessary first step in the pursuit of the remaining approaches. In the absence of reliable temporal control, settlement patterns are uninterpretable, and processual studies are too generalized to be of consequence. A primary goal in developing a culture history is to obtain the smallest temporal units permitted by available data and to group these units into meaningful cultural-temporal periods.

Previous work by Cordy at Ooma II has resulted in a general culture history and a chronological framework for the prehistoric period, using 50-year temporal units. The derivation of cultural-temporal periods from this framework was based directly on age determinations from collected volcanic glass. Briefly, Cordy's chronology begins c. AD 1430, with the initiation of coastal settlement at Ooma II. Population increased from one household to five within the next century, and it peaked at seven households c. 1550. The next century represents the peak population period, when seven households were maintained thoughout. After c. 1650, the population gradually declined to five households at the time of contact (Cordy 1981:168).

A number of problems relating to the culture history of Ooma II remain to be addressed through further work. A major goal is to expand the chronology to include post-contact population estimates. Secondly, the assumptions upon which the prehistoric chronology is based need further examination, particularly the assumptions concerning volcanic glass dates and their implications (these are specifically discussed in the Age Determinations section). Thirdly, the existing chronology is focused on changes in population size and regional political organization; this focus should ideally be expanded to include changes in other aspects of the cultural system, such as subsistence, transportation, and upland and coastal settlement patterning within the <u>ahupua'a</u>.

Settlement pattern analysis is generally an integral component of archaeological studies; it requires the development and application of an accurate functional typology of sites and features, as well as reliable temporal control. All functional categories must be identified and accounted for, in order to obtain an accurate settlement model. Prior to this investigation, only certain types of sites within the project area were selectively tested or selectively recorded. Cordy's investigations were focused on permanent habitation, so all data collection was confined to sites that fit his functional definition of permanency. A permanent site as defined by Cordy consists of one or more platforms, pavings, and/or low enclosures that are of substantial construction (stone fill, bifaced walls) and greater than 16 m^2; smaller, special-purpose structures should be nearby, and the site is expected to occur along the coast (1981:66). This definition was not specifically tested during field investigations, and no alternative functional interpretations of individual features were examined (i.e., burial rather than habitation).

More complex functional types are identifed by Cordy, including a distinction between sleeping houses and men's houses, which are larger than the former. An examination of the specific functional types assigned to features at Ooma II, in conjunction with the proposed chronology, raises some questions that should be addressed through further work.

According to Cordy's model, the coastal area of Ooma II was initially settled c. AD 1430 at Site D15-5, where about six persons resided (1981:166-170). Site D15-5 was thereafter occupied until c. AD 1730, which represents the latest range of six hydration dates determined from this site. The low enclosure at Site D15-5 is interpreted by Cordy as the largest men's house (180 sq m) within his North Kona study area (eight <u>ahupua'a</u>). No sleeping houses were identified at this site, despite Cordy's criteria for permanent habitations which specifies that "(a)t least one structure must be a sleeping house" (1981:84). It is very unclear how an extremely large men's house would have appeared at Ooma II prior to the establishment of a local population, particularly if the men's house represents what Cordy describes as a local residence group of commoners. A group of six people would include a maximum of three individuals who would utilize a men's house.

By AD 1480, three additional sites had been occupied (Sites D15-1, D15-7, and D15-8); Cordy's population estimate for AD 1450-1500 is 30 persons (1981:170). These sites are located inland from Site D15-5, but they are still within the coastal zone. A large number of hydration dates were determined from Site D15-1 (N=15), which includes the second-largest men's house within the project area (103 sq m). This site is interpreted as having been occupied continuously until contact, with all structures contemporaneous. Again, it is unclear how a local population of only four or five households (all within a radius of less than 1 km) could maintain two very large men's houses.

It is suggested here that the functional definitions offered by Cordy are perhaps too generalized and are not substantiated with data other than the architectural parameters that form the basis of the definitions. In addition, the historic components present at sites such as D15-5 are not considered in the functional interpretation of architectural features. Clearly, additional work is needed in developing a more rigorous functional typology.

An ecological approach to archaeological interpretation attempts to identify and account for various aspects of the interrelationships between human populations and their environment. Very little research has been conducted within the project area from this perspective, and ecofactual remains were disregarded by Cordy in his settlement pattern analysis. Ecofacts not only provide evidence of subsistence strategies; they are important tools for the reconstruction of effective environments. Environmental conditions cannot be expected to have remained static at Ooma II during the entire span of human occupation, and changes in human settlement patterns and subsistence systems may have coincided with, or may even have been related to, these environmental changes.

Examination of ecofactual data as indicators of the effective environment c. AD 1550-1650 at Ooma II may help explain why the coastal population stopped expanding and began to decline by AD 1650, well before contact-related demographic factors would have begun to operate. The depletion of coastal resources, as a primary effect of overpopulation and as a subsequent cause for depopulation, has been dismissed by Hommon, who argues that populations would have controlled themselves by more effective means (1976:257). Coastal habitats are, however, subject to occasional severe ecological disruption, and regardless of a population's skill in controlling its numbers, a significant storm can cause periods of extreme stress and can permanently affect a coastal settlement pattern (cf. Donham 1986b). For this reason, coastal areas might also be expected to exhibit periods of occupation and abandonment, rather than long, uninterrupted histories of constant occupation.

The culture process approach examines the mechanisms and causes of change in cultural systems. This approach is largely synthetic and requires a reliable culture history, an understanding of environmental and social constraints, and proper application of ethnohistorical sources. The development of social stratification within and between local populations is a problem domain that is often examined through processual perspectives. This topic is addressed in Cordy's research, and he offers hypotheses concerning the degree of stratification, within Ooma II as well as the specific material correlates of stratfication as they are expected to affect residential architecture and the spatial patterning of features within permanent sites.

Cordy determined that no chiefly residencies were located at Ooma II, and he designates all habitation sites as commoner households, based on two models: one predicts a difference in levels of energy expended in the construction of features, and one is based on the number of structures expected to occur on commoner versus chiefly or priestly habitation sites, as suggested in historic sources (commoner households include no more than three permanent structures, and chiefly households include five or more

structures surrounded by a palisade; Cordy 1981;84). The application of the first model to Ooma II data has been generally subjective, and no explicit parameters for differentiating energy expenditure levels have been developed. There are obvious differences in the energy used in the construction of the heiau (Site D15-18) and the large platform at D15-1, as compared with other platforms at Ooma II. These differences might be expected to have attendant implications for social organization within the ahupua'a. Differences in the degree of structural elaboration within and between other sites at Ooma II are also expected to reflect temporal variation in architectural styles.

The second model, which predicts a given number of associated structures for commoner vs. chiefly households, is sufficiently general so as to permit considerable latitude in fitting archaeological data to the definition of a commoner household. This model is highly dependent upon where site boundaries are established and how features are defined. If, for example, site boundaries as established by Martin in 1971 are followed, at least two chiefly households could be identified at Ooma II.

A procedural step that should help in addressing this problem is to attempt independent dating of each feature, rather than assume that all features within an arbitrarily defined area are contemporaneous. Comparisons of portable remains recovered from platform and pavement fill should also provide a more complete picture of potential differences reflective of social stratification within the local population.

Additional research issues are raised in the discussion of age determinations and in the conclusion of this report. The topics discussed here have been used as an aid in evaluating the research potential of specific sites as well as in underlining the research value of the project area as a whole. It is expected that further work will result in redevelopment of the research design and in refinement of hypotheses and test implications.

FIELD PROCEDURES

Field work at the Ooma II Resort project area began July 17, 1986, with two field teams of three persons each. An inland team concentrated on relocating all previously recorded sites east of Barrera's coastal/inland boundary line. Relocation efforts were begun at the northern end of the project area and moved southward. Upon relocation, all sites were tagged with an aluminum strip which included the temporary site number assigned by Barrera, the PHRI project number (86-254), and the date. Site designation information was written on a strip of pink flagging tape which was then wrapped around a cobble-sized stone in order to insure longer preservation of the tag. The stone was placed in a protected but conspicuous place on the site.

The location of each site was checked, using a 1"=400' scale aerial photograph (R.M. Towill, 1980: Photo No.7895-16), and was replotted if necessary. A standard PHRI site survey form was completed, and 35 mm black-and-white photographs were taken. If surface midden was sparse, with no soil deposit, all represented species of faunal remains were listed on the site form. When definable horizontal features such as hearths or concentrations of midden were observed, a scaled plan map of the site was compiled, and the surface material was collected by feature provenience. All surface artifacts were collected and plotted on site plan maps.

Excavation was conducted when a sufficient amount of soil and midden had accumulated at the site. These accumulations were extremely limited in the inland survey area, and excavations were conducted at only six sites. Test units were small (0.5 by 0.5 m), reflecting the small area of deposits with any depth. No units could be extended beyond 10 cm deep, and most were terminated at bedrock between 2 to 5 cm below surface. All soil removed during excavation was screened through 1/8" mesh, and material was bagged for laboratory analysis. Soil samples were collected from test units, and a single bulk sample for radiometric dating was collected. Relatively large pieces of charcoal were separated in the field prior to screening and were wrapped in foil, in order to protect them from further damage. All charcoal is sorted in the laboratory, and samples of sufficient size from the inland sites are considered for radiometric age determination.

As specified in Task 4 of the scope of work, additional work conducted in the inland zone included the location of a series of caves c. 400 ft west of Site T-1. Previous descriptions of these caves by biologists suggested they might contain cultural debris. The caves were located and examined, but no evidence of use by humans was indicated; however, the caves did exhibit evidence of occupation by feral goats.

The coastal field team began by conducting a systematic pedestrian survey of the coastal area, between the shoreline and Barrera's coastal/inland boundary. A series of 25 sweeps (three transects each) were walked, beginning at the southern project area boundary and moving northward in east-west lines. All sites encountered were located, tagged, and recorded as described above. Sites previously recorded by Cordy were tagged with BPBM site numbers, while those previously recorded by Barrera were tagged with his assigned temporary site numbers (T-1 thru -40). Sites more recently identified by Cordy were tagged with his assigned temporary site numbers (T-41 thru -46). All newly identified sites were tagged with a temporary site number, beginning with T-47. Sites with BPBM and Barrera numbers were tagged with BPBM site numbers, since these had been assigned prior to Barrera's survey.

Test excavations were conducted at the previously recorded sites listed in the scope of work; however, it was impossible to conduct excavations at all newly located features with substantial midden deposits. The complexity and large number of newly located features in the coastal area was not expected, given Cordy's remarks in his field check report that the larger sites had "already been recorded at the intensive survey level" (1986a:5). Scaled plan maps were compiled for four of the previously recorded and mapped sites, illustrating the extensiveness of associated features that had not been mentioned by either Cordy or Barrera. Additional scaled plan maps were compiled for the extensive complexes that consisted of small shelters, cairns, rubble piles, and pahoehoe clearings. These sites had no surface midden and will probably need no further recordation.

In summary, test excavations or controlled surface collections were conducted at ten sites; these include Sites T-4, T-6, T-12, T-13, T-17, T-22, T-24, T-39, T-41, and T-45. Surface artifacts were collected and plotted at the above sites and at an additional seven sites: T-5, T-15, T-27, T-61, T-67, D15-7 and D15-8. Laboratory analysis of midden collections consisted of sorting all midden collections into 1/4-inch and 1/8-inch size grades, with a complete sorting of 1/4-inch material and a thorough examination of all 1/8-inch material for artifacts and any faunal materials not represented in the 1/4-inch size grade.

All shellfish remains were sorted by genera and species, and weights were recorded by provenience. Vegetal materials were identified to the degree possible, and vertebrate remains were subdivided by class or species when possible. These remains generally require specialist examination for specific identification, which should be conducted as part of the mitigation phase. Twenty volcanic glass specimens from six Ooma II sites have been submitted to Mohlab for age determination; five of these specimens are also being analyzed for source affinity.

FINDINGS

A total of 279 archaeological features at 74 sites has been recorded to date within the Ooma II Resort project area (Figure 2; Tables 3, 4, and 5, at end). Over half of these features (N=184, 66%) were recorded during the current PHRI survey and testing program. Fifty-four of these newly recorded features represent new data for previously recorded sites, while the remaining 130 features were located at 27 newly identified sites.

The breakdown of the cumulative site and feature count is as follows:

Cordy (1975) coastal survey	12 sites	32 features
Barrera (1985) survey	29 new sites	56 new features
Cordy (1986) field check	6 new sites	7 new features
PHRI (1986) survey & testing	27 new sites	130 new features
Cordy (1975) sites	-	43 new features
Barrera (1985) sites	-	6 new features
Cordy (1986) sites	-	5 new features
Totals	74 sites	279 features

The following site descriptions are arranged in three groups; sites that have Barrera and Cordy temporary numbers, those that have PHRI temporary numbers, followed by those with Bishop Museum numbers. The volcanic glass hydration rind age determinations for all sites are discussed following the site descriptions. All portable remains recovered to date are then described; recovered and observed ecofactual remains are considered in this section as well. Interpretive discussion of findings is presented in the conclusion.

SITE DESCRIPTIONS--BARRERA AND CORDY TEMPORARY SITES

T-1 Complex

This site consists of a single cairn and three pahoehoe clearings, located within a 128 sq m area. It occurs in open pahoehoe rocklands at an elevation of 87 ft, which is the maximum elevation within the project area. Site T-1 was recorded by Barrera, who identified the four features described here. The cairn (Feature A) is located 17.0 m from the Hamalahoa Trail, just inside the project area boundary. The base of this feature is 1.0 m in diameter, and it is 0.50 m high. The cairn is constructed from loosely piled pahoehoe boulders, three to four courses high, and is unfaced.

Feature B, a pahoehoe clearing, is located 16.4 m at 305 degrees Az from Feature A. The cleared area, an amorphous-shaped crevice, is 2.5 m long and 1.25 m wide. Loose pieces of bedrock have been removed from the crevice and piled adjacent to the opening to a maximum height of 0.5 m.

Feature C is similar to Feature B, measuring 1.25 by 0.7 m, with an adjacent 0.3-m-high pile of loose stones. It is located 16.4 m at 305 degrees Az from Feature A and is 2.6 m from Feature B.

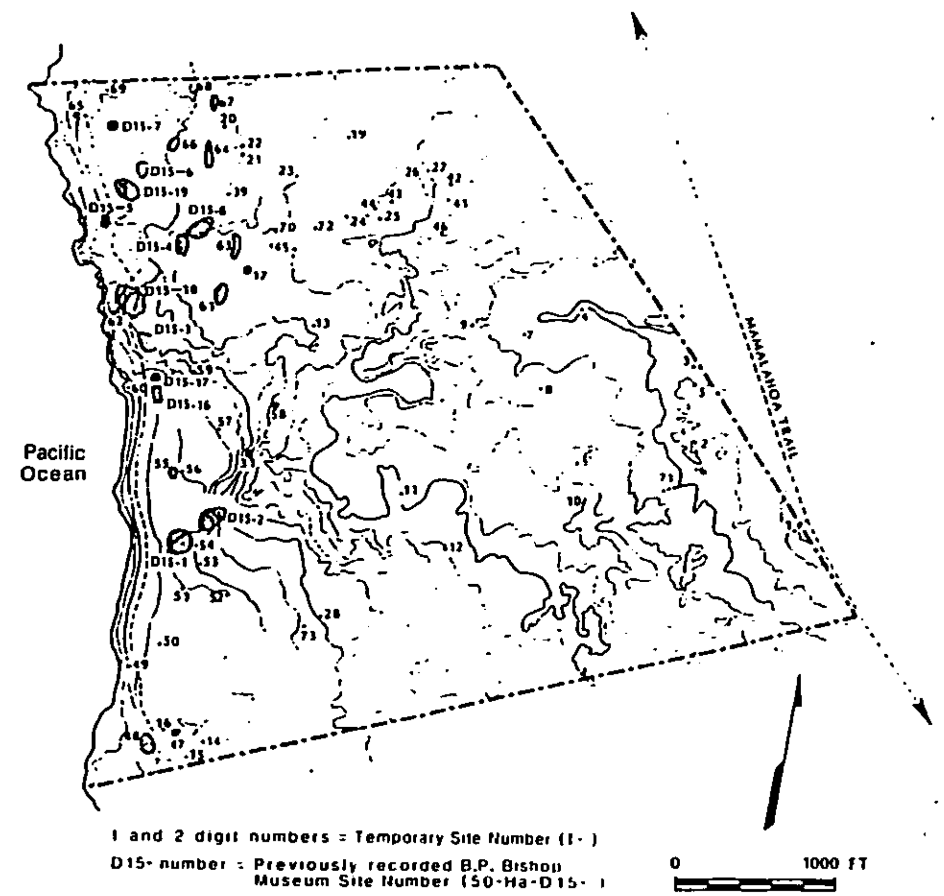

FIGURE 2. Site Location Map

Feature D, a cleared linear crevice, is 3.0 m long and 0.7 m wide. Stones are loosely piled to a height of 0.6 m along one side of the crevice. This feature is 13.3 m at 230 degrees Az from Feature A and is 18.2 m from Feature C.

T-2 Pahoehoe Clearing

This isolated feature consists of a bedrock crevice from which loose stones have been pulled and placed in an adjacent jumbled pile. It was first recorded by Barrera, who located and photographed the single feature. The cleared area is 3.0 by 2.0 m, and the pile of stones is 0.7 m high. There is no structure to the pile of loose stones, which are darker in coloration and less weathered than the surrounding bedrock. No portable remains were associated with the feature, and the specific function is unknown.

T-3 Cairns

These two small cairns are located at the eastern boundary of the project area, 536 m from the southeast corner. Both are crudely constructed from pahoehoe boulders piled two to three courses high. Feature A cairn is 0.8 by 0.9 m at the base and 0.4 m high. Feature B is 0.6 by 0.9 m at the base and has a maximum height of 0.5 m, with an average height of 0.3 m. Feature B is 2.5 m from Feature A, at 55 degrees Az. These cairns, recorded by Barrera, may represent surveyor's markers.

T-4 Complex

This temporary habitation complex is located in a major ravine that is edged with rough pahoehoe and patches of aa. It is somewhat isolated, 122 m east of the nearest site (T-7). The complex consists of a cave shelter, a walled shelter, and two cairns. Feature A, a cave shelter, is located in a large lava tube that is accessed through a collapsed opening in the southwest side of the tube. The opening is 4.6 m wide and 1.1 m high. The main chamber of the shelter is oriented east-west and has an average width of 12.0 m (Figure 3). The tube is accessible for a total length of 45.0 m; however, the inhabited area is 30.0 m long, with most surface material within an area 18.0 m long. Two large piles of rockfall occur within the main habitation area; these stones do not appear to have been moved from their original location. The remaining floor space is flat and level; the ceiling height averages 1.3 m.

Shell midden is scattered in moderate quantities over the bedrock floor within the 192 sq m area of the main chamber. A single soil and midden deposit is located along the northeast side of a large rockfall pile; it covers an area 3.5 m long and 0.5 m wide. This deposit has a maximum thickness of 3.0 cm; however, most of the deposit is less than 2.0 cm thick.

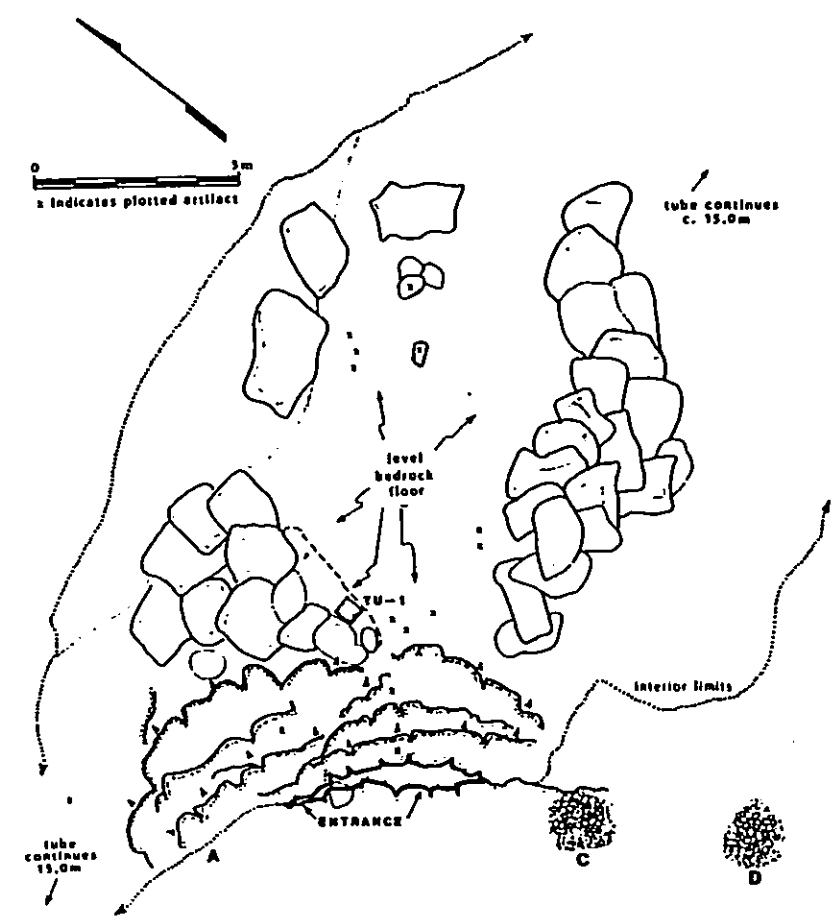

FIGURE 3. Site T-4, Features A, C, and D

An unusually high number of artifacts were observed on the cave floor. These items were plotted on the plan map and collected. They include 11 abraders (four coral, four Echinoidea spine, and three scoria), two volcanic glass flakes, a bird bone pick, a bone awl, a piece of polished basalt (adze flake), a basalt hammerstone, a Cypraeidae shell octopus lure, and two pieces of cut (whittled) wood. These items are discussed with all other recovered artifacts in a following section. One volcanic glass flake (PHRI VG-517) was submitted to Mohlab for hydration rind age determination and for source affinity analysis; it yielded a calendric date range of AD 1662-1754 (two sigmas).

A 0.5 by 0.5 m test unit (TU-1) was excavated in the soil and midden concentration described above. It was located in an area of maximum thickness where the deposit was slightly mounded (3.0 cm total thickness). Eight shellfish families were collected from this sample, which had a total weight of 1,505.9 g. Families represented include Conidae, Cypraeidae, Isognomonidae, Littorinidae, Mytilidae, Neritidae, Patellidae, and Thaididae. At least 458 individual shellfish are represented; these are predominantly Nerita picea (N=327) and Thaididae (N=76). The shell midden is further discussed and compared with other collections below.

Additional material observed in the cave, other than collected artifacts and shellfish remains, include kukui nut shell, Echinoidea, Crustacea, fish bone, mammal bone, and a few pieces of coral.

Feature B is a walled shelter that was also identified by Barrera during his survey. It is located 25.5 northeast (70 degrees Az) of the entrance to Feature A. The shelter consists of an oval-shaped rough wall constructed on relatively flat pahoehoe. It has a maximum length of 4.0 m (northwest-southeast) and a maximum width of 3.0 m. The wall is in very poor preservation and is collapsed to a height of 0.1 to 0.3 m. No portable remains were located in or around this feature.

Features C and D are two cairns that are located outside the entrance to Feature A, 3.0 and 7.0 m to the east, respectively. These cairns are roughly rectangular in plan and are similarly constructed from piled, unfaced pahoehoe slabs. Feature C is 1.4 by 1.1 m at the base and is 0.3 to 0.4 m high. Feature D is 1.5 by 1.0 m at the base and is 0.3 to 0.45 m high.

T-5 Overhang Shelter

Located in open pahoehoe rocklands at an elevation of 80 ft, this site is 24.0 m southwest of Site T-3. The shelter was formed from a collapsed lava tube and has a north-facing opening 8.0 m long. The shelter is 3.0 m deep and has a maximum ceiling height of 2.5 m at the dripline. A small filled area that has been artificially leveled occurs at the entrance to the overhang.

A very sparse surface scattering of shellfish remains occurs in the shelter, including Cypraeidae, Thaididae and Nerita picea. A single echinoid fragment (Heterocentrotus mammillatus) and a single volcanic glass flake were also observed. The volcanic glass flake was collected and submitted to Mohlab for age determination as well as source affinity analysis (PHRI VG-518); it yielded a calendric date range of AD 1713-1749 (two sigmas).

T-6 Cave Shelter

This cave is located in the southeast corner of the project area, at the eastern edge of a broad zone of disturbed pahoehoe. It is 49.0 m southwest of Site T-2 and directly aligns with a trail segment, Site T-71, which was identified 61.0 m to the west. The shelter is in a lava tube and is entered via a collapsed hole in the ceiling of the tube (Figure 4). The entrance is 3.0 by 1.7 m and is 1.6 m above the floor of the cave; it has a northerly exposure. The cave floor around the entrance is covered with rockfall, none of which appears to have been modified or cleared. No other modifications occur within the shelter. The habitable space is nearly circular, with an east-west axis of 12.0 m and a north-south axis of 11.0 m. Ceiling heights vary from 1.6 to 2.5 m.

Nine very small concentrations of ash and shell midden are scattered about the cave; these appear to be hearth areas. One hearth is roughly defined by three small boulders; all others are on bare bedrock. This former hearth and two additional areas of ash were collected as possible samples for radiometric age determination (ash concentrations 1, 2 and 3).

A Cypraeidae shell octopus lure fragment and the point of a two-piece fish hook were collected from the floor of the cave. The fish hook fragment was adjacent to an ash concentration at the south end of the cave. Subsistence remains are sparsely scattered over the shelter floor, with no concentrations. Shellfish families represented include Conidae, Cypraeidae, Neritidae, Patellidae, and Thaididae. Also present is kukui nut shell, Echinoidea, mammal bone, fish bone, and bird bone.

This cave is interpreted as a temporary habitation site that was occupied at a low intensity level.

T-7 Cave Shelter

This cave is located at the head of a major ravine in open rocklands, at an elevation of 72 ft. It is 120 m directly west of Site T-4, a more intensively utilized cave shelter. The cave opening is 8.0 m wide and is oriented eastward along the side of a partially collapsed lava tube. The cave is 16.0 m deep and has a ceiling height range of 1.0 to 1.85 m. A very sparse amount of subsistence material and scattered coral was observed inside crevices in the cave floor. Shellfish fragments present include Cypraeidae, Thaididae, Patellidae and Conidae; a few pieces of Echinoidea, kukui nut shell and bird bone were also observed. The deposit

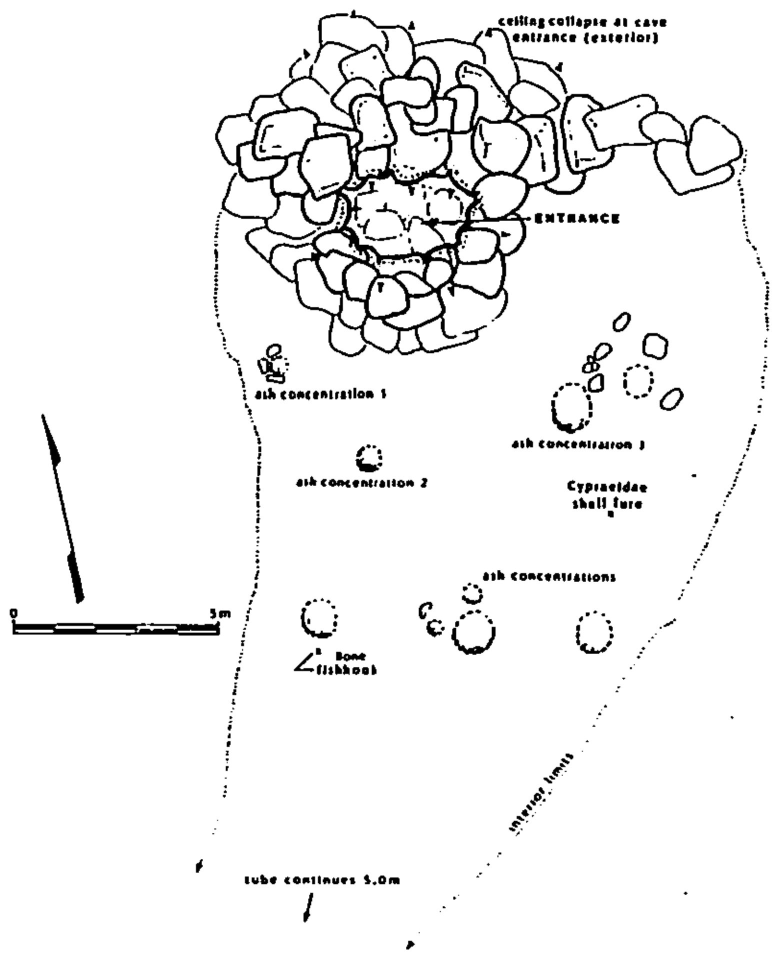

FIGURE 4. Site T-6

is less than 1.0 cm deep in all areas of the cave, and there is no indication of hearths or other internal features. This site apparently functioned as a temporary habitation shelter.

T-8 Cairns

This site, described by Barrera as "four crude stone mounds" (1985: 11), has an overall surface area of 27.0 sq m. It is located in open rocklands, 98.0 m from the nearest site (Site T-7). Feature A, a small cairn, is oval in plan view and constructed from pahoehoe slabs piled three to four courses high. Major axis of the base is oriented east-west and is 1.2 m long; minor axis is 0.6 m long. Maximum height is 0.45 m.

Feature B is located 1.0 m northeast of Feature A. It is circular in plan view, with a basal diameter of 1.1 m. Pahoehoe slabs are piled five to six courses to a height of 0.45 m.

The largest cairn, Feature C, is located 3.0 m southeast of Feature A. It is oval in plan view, with basal axes of 1.8 m east-west by 1.7 m north-south. Pahoehoe slabs are piled five courses to a height of 0.55 m.

Feature D, an irregularly shaped rubble pile (0.3 m high), is located 9.0 m west of Feature A. Stones are scattered in an area 0.8 m east-west by 0.7 m north-south.

No portable remains were located in the vicinity of these features, and no definitive functional interpretation can be offered at this time. The features possibly mark a now obscure footpath.

T-9 Cairns

This site was identified by Barrera, who grouped two cairns spaced 32.0 m apart. The cairns are located on minor pressure ridges in open rocklands, at an elevation of 65 ft. Feature A, the northernmost cairn, is 1.0 m in diameter at the base and is 0.8 m high. It is constructed from blocky pahoehoe stones piled to seven courses, and it has a relatively well-structured appearance.

Feature B is smaller and less structured than Feature A; it is 0.75 m in diameter at its base and is 0.6 m high. No portable remains were observed near or between the two features, and a definitive functional interpretation cannot be offered at this time.

T-10 Cairns

This relatively isolated site is located in open rocklands at an elevation of 60 ft. It consists of three small cairns spread across an east-west linear distance of c. 45.0 m. The nearest site, a section of a footpath (Site T-71), is located 150 m directly to the east.

Feature A, a cairn, is three to four courses of piled pahoehoe slabs measuring 0.5 by 0.6 m at the base and 0.45 m high.

Feature B is of similar construction and is the largest of the three cairns. It measures 0.7 m in diameter at its base and has a height of 0.7 m, with six to seven courses of stone present.

Feature C is located c. 40.0 m southwest of Feature B. It has basal dimensions of 0.6 by 0.7 m and is 0.5 m high, with three courses of stone present. No portable remains were observed near or between the cairns, and there was no indication that the footpath located to the east at Site T-71 continues to this site. Continuation of the footpath could explain the presence of these cairns.

T-11 Cave Shelter

This unmodified lava tube cave is located in open rocklands at an elevation of 50 ft. The entrance to the shelter is through a 5.0 m long, 1.5 m wide fault in the lava tube ceiling, which opens to the north. The interior of the cave is naturally divided into two chambers by a deposit of roof fall that is located below the entrance. The chamber to the north of the entrance has an area of 28.5 sq m (7.7 by 3.7 m) and an average ceiling height of 1.3 m. A small tube extends northward from this chamber for a distance of 14.0 m.

The second chamber of the cave has an area of 132 sq m (14.2 by 9.3 m) and an average ceiling height of 1.0 m. No deposit occurs in either chamber of the cave; however, sparse amounts of portable remains are scattered about on the bedrock floor.

Shellfish remains from Conidae, Cypraeidae, Neritidae, Patellidae, Tellinidae, and Thaididae families were observed, in addition to Echinoidea, kukui nut shell, and bird bone. One waterworn boulder was observed, as well as feral goat bones. No internal modifications or hearth areas were observed in the shelter, which represents a temporary habitation site.

T-12 Cave Shelter

This lava tube cave is located 573 m inland from the shoreline, in an area of naturally disturbed pahoehoe. It is 134 m south of Site T-11, which is the nearest site. The major axis of the tube is oriented northwest-southeast, and it is entered via a collapsed section of the northeastern side wall. A crevice immediately outside the entrance has been filled and leveled in order to permit easier access to the shelter. The entrance is 5.2 m wide and has a ceiling height of 0.9 to 1.0 m. Ceiling height inside the shelter varies from 0.4 to 1.9 m; the habitable area has an average ceiling height of 1.5 m. The main chamber extends north from the entrance for a distance of 12.0 m. A smaller tube continues 5.0 m beyond this point; however, it is a crawlspace that has been partially blocked by cleared rockfall. The average width of the tube is 6.3 m (Figure 5).

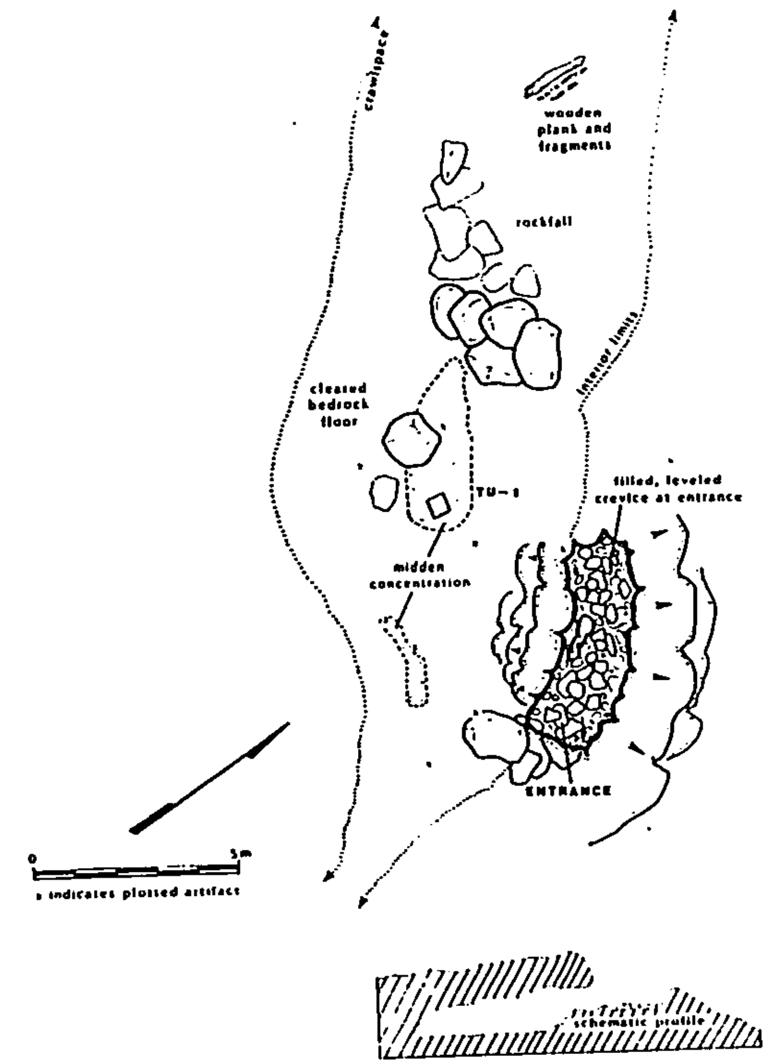

FIGURE 5. Site T-12

Two areas of concentrated surface midden occur on the shelter floor. The largest concentration, in the center of the habitable area of the tube, is a linear deposit 4.2 m long, 1.5 m wide, and 2.0 to 7.0 cm thick. A moderate deposit occurs in other areas of the shelter that are not covered with rockfall, and a number of artifacts were scattered on the shelter floor, with no patterning or concentration.

All surface artifacts were collected and were plotted on the site plan map. The nine artifacts include six abraders (two coral, three Echinoidea spine, and one scoria), a basalt hammerstone, cut and perforated wood, and modified mammal bone. These artifacts are further discussed below.

A 0.5 by 0.5 m test unit (TU-1) was excavated into the thickest portion of the midden concentration, in order to obtain subsistence and dating samples. No datable materials were recovered from this excavation, and none could be located in other areas of the shelter. The deposit was found to have an average depth of 2.0 cm and included a limited amount of very fine, grey silty loam. Ten different shellfish families were recovered from the area sampled, including Conidae, Cypraeidae, Isognomonidae, Littorinidae, Mytilidae, Neritidae, Patellidae, Strombidae, Thaididae, and Trochidae.

The number of species represented in this midden sample is relatively high; however, the total weights and minimum numbers of individuals per species is rather small, and it is likely that fewer than 300 individuals are represented in the entire shellfish collection. The majority of the individuals represented (N=207) are Nerita picea (see discussion below).

Other portable remains present in the shelter include kukui nut shell, Echinoidea, Crustacea (crab), and small amounts of coral. This site is interpreted as a temporary habitation shelter.

T-13 Rock Mound

This isolated rock mound is located in open rocklands, 152 m from the nearest site (T-17). It is oval in shape, with a major axis of 2.8 m, oriented east-west. The minor axis is 2.3 m, and average mound height is 0.6 m. The mound is constructed from pahoehoe slabs and boulders that are stacked to form somewhat vertical, unfaced sides and a roughly level mound surface. This feature was tentatively interpreted by Barrera as a possible grave (1985:16).

A 1.0 by 0.5 m excavation unit was established over a portion of the mound, and the stones were removed in order to determine if it was in fact a burial. The unit bisected the mound on a north-south axis. A natural bedrock crevice, which was found at the base of the mound, had been filled with cobble-sized stones and capped with two large pahoehoe slabs (Figure 6). After removal of these stones, skeletal remains were visible in the crevice, 0.75 m below bedrock surface. The remains were extremely weathered and deteriorated and were not removed from the crevice. The crevice was covered, and a portion of the original mound was reconstructed over the burial.

Figure 6. SITE T-13, AFTER EXCAVATION. View to north. (PHRI Neg.496-37)

T-14 Complex

This site consists of two coral pavements, three rubble-filled depressions, and a cairn. It is located along the southern boundary of the project area and has been previously recorded as Site T-175 within the Kohana-Iki Resort Development project area (Donham 1986a:58). Since the final property line boundary between these two project areas has not been demarcated in the field, it is impossible to determine which project area will contain the site. Its assignment to one land division must await boundary demarcation.

The five features within this complex are arranged in a linear pattern, c. 20.0 m long, that is oriented north-south. Barrera identified three of these features in his description of the site (1985:17).

Feature A, a small sinkhole, is 8.0 m in diameter and has been filled with pahoehoe rubble to within 1.0 m of the rim. The rubble deposit has an average depth of 0.5 m and contains three small cleared holes which extend to bedrock. In the center of the rubble fill is a depression 0.6 m in diameter that is ringed with upright pahoehoe slabs. Exterior diameter of the ring of slabs is 1.6 m. The base of this depression is 0.7 m below the rubble fill level and appears to have been deeper at one time.

Feature B is a roughly rectangular (5.5 by 3.5 m) coral pavement that is partially surrounded by pahoehoe boulders. It is described by Barrera as an enclosure and is located c. 18.0 m south of Feature A. Immediately to the north is a circular area of rubble fill (c. 4.0 m in diameter) that had been deposited in a crevice in order to level the ground surface. Several small waterworn pebbles and a large boulder grinding stone are located on the coral pavement.

Feature C, a small rectangular (1.2 by 1.5 m) coral pavement, is situated in a slight depression at the northern edge of the Feature A sinkhole. The southern side of this pavement is defined by a low, faced wall that serves to isolate the pavement from the rubble fill in the sinkhole. Waterworn pebbles are present on this pavement.

Feature D, a small area of rubble fill, is located 3.0 m west of Feature B. This 1.5 sq m area of rubble was apparently deposited to level the surface of a depression. The surface is somewhat rough, and there are no indications that it was paved with smaller pebbles or cobbles.

Feature E, a cairn, is located near the center of the site. This feature is in very poor preservation, and stones are scattered in an area 6.0 m in diameter. The original structure was 1.25 m in diameter at the base; it is presently 0.35 m high. This cairn is situated very close to the Kohana-Iki/Ooma II boundary, and its relationship to the other features on the site is unclear. It may have been erected at a later date, or it may be part of a cairn alignment that surrounds the anchialine ponds in Kohana-Iki.

An area of surface midden (c. 1.5 m in diameter) is located 2.0 m southeast of Feature E. This midden consists primarily of Cypraeidae and Neritidae shell fragments. Other shell observed on paved areas is weathered and appears to have been deposited with the coral. Functional interpretation of this complex is difficult without more detailed investigations of specific features. The site probably had a ceremonial function, and burials may occur in the filled crevices or in the filled sinkhole.

T-15 Complex

This habitation complex consists of an extensively modified sinkhole, a rubble-filled terrace, and a large cairn. It is located near the southern boundary of the project area and was previously recorded as Site T-176 within the Kohana-Iki Development project area (Donham 1986a:59). As with the preceding site, the exact location of this site, in relation to the project area boundary, must await demarcation in the field.

A sinkhole, which contains four of the seven features within this complex, is 15.0 m long (east-west) and 11.25 m wide. It has an average depth of 2.5 m, and the western portion extends beneath the opening to form two overhang shelters (Figure 7). The shelters were not located by Barrera, who recorded the well and stone wall only.

Feature A, a well, is constructed around an anchialine spring at the western end of the sinkhole. It consists of faced walls, 1.8 m high, that partially enclose a small (1.0 sq m) spring pool. The northern portion of this feature consists of two straight walls, nine courses high, that face an access to the small pool. The southern portion is a circular wall, four courses high, that encircles the pool. This latter wall is built under a low natural overhang. Water level at the time of survey was 1.62 m below the top of the straight wall; a high water mark occurs 0.65 m above present water level. Boulders used in this structure are regularly sized and are squared; the construction technique appears to be historic.

Feature B is a cobble paving that occurs in the floor of the sinkhole. This feature covers an area 30.5 sq m and apparently was deposited in order to raise and level any irregularities in the sink floor. Areas of bedrock are exposed in the paving. A ramp extends off the north side of the paving and leads into Feature D, an overhang shelter.

Feature C, also an overhang shelter, is situated at the eastern end of the sinkhole. It is 2.5 m deep and 3.75 m wide. A faced wall section which serves to separate it from Feature D is located at the northern end of this shelter. A soil deposit is present in this shelter, as well as a number of late nineteenth/early twentieth century bottles.

Feature D, an overhang shelter, is located along the northern edge of the sinkhole; it is 7.5 m wide and 1.75 m deep. The western 3.0 m of this shelter opening has been closed off with a faced wall, six courses high. The exterior side of the wall is built up with rubble fill; the interior

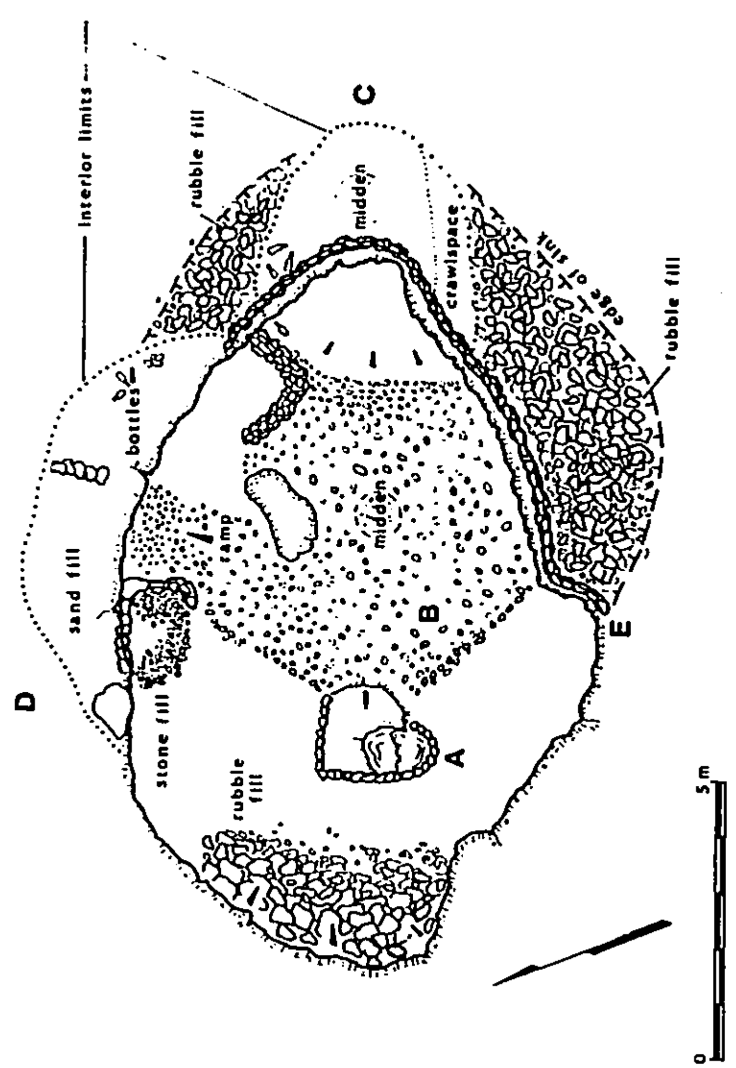

FIGURE 7. Site T-15, Features A-E

side is faced to the dripline of the shelter. A short north-south wall, four to six courses high, extends out from the dripline at the eastern end of the former wall. The floor of Feature D has a beach sand deposit, and historic bottles are scattered about. It is divided into two compartments by a low (two course) wall which extends 1.25 m from the back of the shelter.

Feature E, a wall, is constructed around the outer edges of the sinkhole opening on the eastern side. It is a stacked wall, five courses high, that is faced on the interior and is built up with rubble fill on the exterior side. The fill extends as much as 3.0 m away from the wall and serves to fill in the sloping ground surface between the outer rim of the sink (at ground surface) and the actual opening, which is lower than the outer rim.

Feature F, a large cairn, is located c. 7.0 m south of the modified sinkhole. It is constructed of stacked pahoehoe slabs with a core fill of smaller cobbles and coral. The cairn is partially dismantled, and stones are scattered over an area 2.2 m in diameter. Original dimensions were 1.5 by 1.7 m at the base. The present structure is 0.75 m high, and the central fill has been removed to below this level. Coral, shell midden, and historic bottles are scattered on the surface around the cairn. A recent aluminum can has been placed inside the feature. This cairn is northernmost of an alignment of similar, but somewhat larger, features which define a boundary around the anchialine ponds of Kohana-Iki.

Feature G, a low, faced terrace, is located c. 10.0 m south of the modified sinkhole. The terrace is odd-shaped, with overall dimensions of 3.0 by 3.0 m. A stone-lined depression, 2.0 by 1.0 m, occurs in the center of the terrace. The western side of the terrace is paved with small pahoehoe cobbles and is more level than the eastern portion. Artifacts scattered over this feature include bottle glass, coral and sponge-stamped whiteware. It is possible that this latter feature is within the Kohana-Iki project area and that all other features are within the Ooma II project area.

Two artifacts were collected from the site surface, near the access path to the sinkhole; these include a metal spike and a basalt adze that was apparently broken and re-used as a hammerstone. No excavations were conducted at the site, since its location within the project area could not be substantiated.

<u>T-16</u> <u>Wall</u>

This feature is located 73.0 m north of Site T-15 and is immediately east of the coastal jeep road, at an elevation of 5 ft. It was described by Barrera as a core-filled stone wall, 25 m long and 0.6 m high. Barrera suggested that remaining portions of a structure may be buried under coral storm wash, as indicated by a "square outline" shown on a 1981 aerial photograph of this location (1985:19). Such an outline is not indicated on the 1980 aerial photograph of this location provided to PHRI by Helber.

Hastert, Van Horn and Kimura (R.M. Towill, Photo No.7895-16). Subsurface testing at this site was recommended by Cordy in the scope of work for the intensive survey, in order to determine if, in fact, portions of the structure were buried under storm wash.

Following vegetation clearing at the site, an associated stone alignment was located to the north, oriented perpendicular to the western end of the major wall (Figure 8). This alignment was severely undercut by a wash channel on the east side, and it was evident that there were no additional stones beneath the exposed boulders. These stones are large waterworn boulders up to 0.8 m long, and they appear to be the basal stones of a former wall.

The main wall remnant was cleared and mapped; it is oriented on a line 41 degrees Az and is intact for a distance of 21.0 m. The original width was 0.9 to 1.0 m, and existing height ranges from a maximum of 0.7 to 0.3 m. The wall is constructed from waterworn basalt boulders and is double-faced, with core fill. The entire surface on the interior of the wall formation is a deep deposit of rounded coral, limestone pebbles, and basalt cobbles. Two broad wash channels have cut through the storm deposit, 14.0 m to the north of the wall remnant and at the center of the wall formation. These channels are below the basal depth of existing stones along the north wall, and they occur in areas most likely to have been former wall or platform locations.

Given the length and width of the existing wall segments, it appears that the feature represents an enclosure. Since wall height and internal features are indeterminate due to erosion, identification of the enclosure as a habitation site or animal pen cannot be established. It is unlikely that any additional remnants of structures are buried beneath the coral storm wash, since existing basal stones (not directly in the path of the wash channels) are nearly washed away.

This feature may correlate with an "old, large animal pen" described by Reinecke (1930:15) as one of the features at his Site 66. Reinecke's plotted location of the pen corresponds very well with the location of these wall remnants. Site 66 includes habitation platforms, which probably correlate with Site T-48, located 13.0 m to the west of Site T-16 (see Site T-48 discussion).

T-17 Complex

This site is located at the coastal/inland interface, in an area of flat pahoehoe with collapsed blisters and tubes. Site T-63, a large complex of cairns, shelters, and rubble piles, is located c. 20.0 m to the west of this complex. Site T-17 was originally described as including five stone mounds, a platform, an enclosure, a walled shelter, and three cave shelters (Barrera 1985:20). Several of the features described by Barrera have been included here as part of Site T-63 rather than of Site T-17. This determination was necessary in order to provide a clear definition between the two sites. As defined here, Site T-17 is more

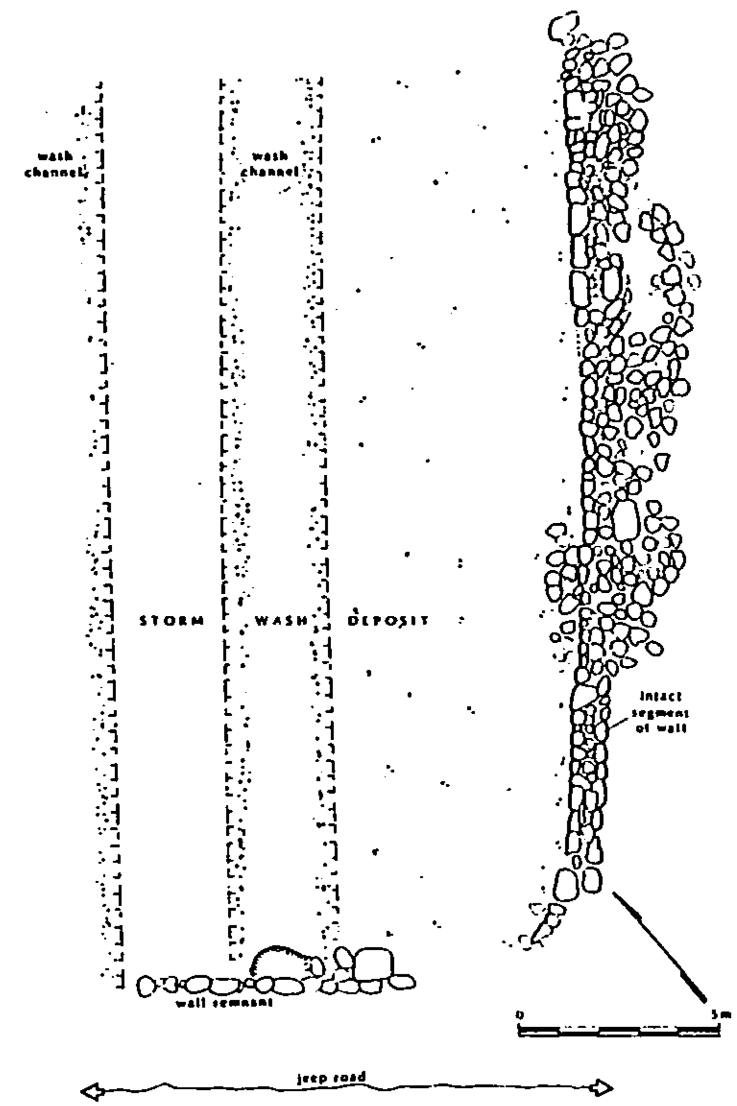

FIGURE 8. Site T-16

compact than the 10,125 sq m area defined by Barrera, and it includes features that reflect a more permanent habitation than do the features grouped as part of Site T-63. These features include an intensively utilized walled sinkhole, four cave shelters, a platform and a surface midden deposit.

Feature A, an oval sinkhole, is surrounded by a network of tube caves. The major axis of the sinkhole is oriented east-west and is 9.5 m long; minor axis is 6.5 m. The floor of this feature is 1.3 to 1.75 m below the rim of the sink and is scattered with rockfall, some of which has been piled inside the rim along the northern edge, possibly for improved access. Areas with low vertical relief around the edge of the rim have been bordered with a stacked stone wall, in order to provide a more consistent rim level. The wall occurs primarily along southern portions of the rim, where sections are 4.0, 2.5, and 1.3 m long. The wall has an average height of 0.5 m and is 0.3 to 0.5 m wide.

The entrances to two cave shelters and an overhang shelter are located around the rim of the sinkhole (Figure 9). The largest of these caves extends eastward for a distance of 10.5 m and has a variable width of 9.5 to 4.0 m. Ceiling height varies from 1.10 m at the entrance to 0.7 m at the back, with an average height of 1.15 m. A deposit of soil and midden occurs across the entire floor of this cave, and it has been piled up in five areas where relic hunters have been working. Fifteen artifacts were observed and collected from the cave surface; they include five coral abraders, seven Echinoidea spine abraders, one scoria abrader, a piece of polished basalt, and a piece of cut shell. These artifacts are localized in four areas that are dispersed within the cave.

Five surface artifacts, located on ground level above the caves, were plotted and collected; these include two volcanic glass flakes, a coral abrader, a scoria abrader, and a Cypraeidae shell octopus lure. The volcanic glass flakes were submitted to Mohlab for hydration rind age determination (PHRI VG-520, -521); they yielded calendric date ranges of AD 1688-1744 and 1717-1737 (two sigmas), respectively.

The second cave extends from the north end of the sinkhole and consists of two connected tubes; one is oriented northward, and one is oriented to the northwest. The cave entrance is 9.0 m wide and has a ceiling height of 1.2 m. The northern tube is 10.0 m long and has an average width of 2.5 m, with an average ceiling height of 0.75 m. The northwestern tube is 10.6 m long and has an average width of 5.0 m, with an average ceiling height of 1.0 m. These tubes are connected in a chamber that is 9.5 m wide and 2.6 m deep.

Surface deposits are dense in this cave, and a large backdirt pile, 2.0 m in diameter and 0.5 m high, is located just outside the entrance. This pile appears to have been removed from the cave by relic hunters, who have caused considerable disturbance to the deposit.

Artifacts observed and collected inside the cave include six coral abraders, one Echinoidea spine abrader, and a piece of modified shell.

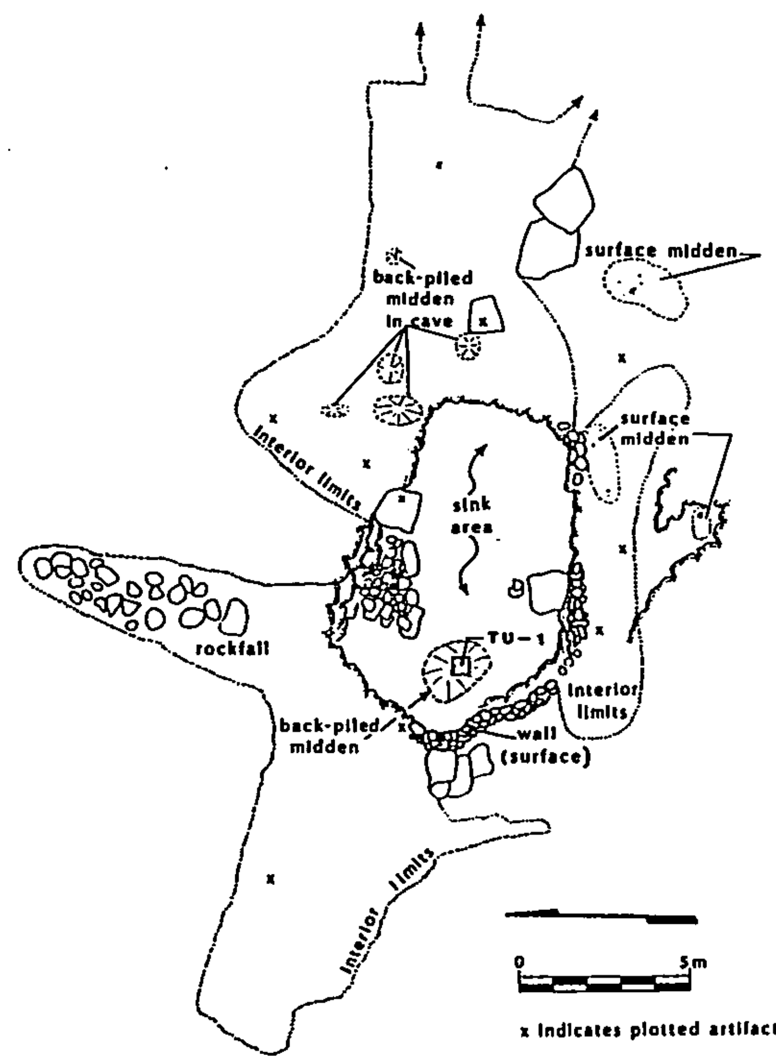

FIGURE 9. Site T-17, Feature A

A 0.5 by 0.5 m test unit was excavated into the backdirt pile in order to obtain a sample of midden and dating materials. An extremely rich and varied midden deposit is indicated in this sample, including Echinoidea, Crustacea, fish bone, 17 families of shellfish, and kukui nut shell. This midden collection is further discussed below.

In total, 28 artifacts were recovered from the test unit (TU-1). These include two Echinoidea spine abraders, two coral abraders, three modified shells, a basalt flake, a Patellidae shell scraper, a historic glass sherd, and 18 volcanic glass flakes. Eight of the volcanic glass flakes were submitted to Hoblab for hydration rind age determination (PHRI VG-519, -524 thru -530); one of these was also submitted for source affinity analysis (PHRI VG-528). Collectively, the samples yielded calendric dates that ranged from AD 1526-1766 (see Table 6 for individual breakdown). The artifacts are further discussed below.

An overhang shelter is located at the southern side of the sinkhole. This shelter is wide (9.0 m) at the opening and is generally shallow (2.0 to 3.0 m), with the exception of a narrow tube extension to the southeast. The tube has a maximum length of 5.0 m and an average width of 1.9 m. Ceiling height within the cave ranges from 1.05 to 0.90 m.

Three artifacts were collected from this shelter; an Echinoidea spine abrader, a coral abrader, and a Patellidae shell scraper. Surface midden is less dense in this overhang, and no appreciable soil accumulation was observed.

Feature B, a cave shelter, is located 10.5 m northeast of Feature A. It is a large blister cave that is accessed through a nearly vertical opening at the southern end. The opening is 3.5 m long and 0.75 to 1.8 m wide; it has a variable ceiling height of 0.20 m at the southern end to 1.5 m at the northern end. Rockfall has been piled along the length of this entrance so as to create a sloping access route down into the cave. The main chamber of the cave is somewhat amorphous in plan and has a major east-west axis of 8.5 m; minor axis is 6.5 m (Figure 10). Two small tube extensions lead from the southern and eastern edges of the main chamber; both of these tubes are partially blocked with piled rockfall and are inaccessible.

Modifications within the cave include a number of rubble piles around the perimeter of the main chamber, a stone alignment, and a filled depression. Midden and soil covers all floor areas that are clear of rockfall or rubble. The general deposit varies in thickness from 1.0 to 3.0 cm, with scattered occurrences of small piles. Five midden concentrations were identified; these are scattered in various locations within the cave and are designated as horizontal features (HF-1 thru -5) on the plan map.

HF-2 was collected and HF-3 was sampled in order to determine the range of subsistence material present in the cave. These features exhibit slightly different compositions in the proportions of shellfish and vertebrate species; however, they are more similar to one another than to the Feature A midden sample (discussed below).

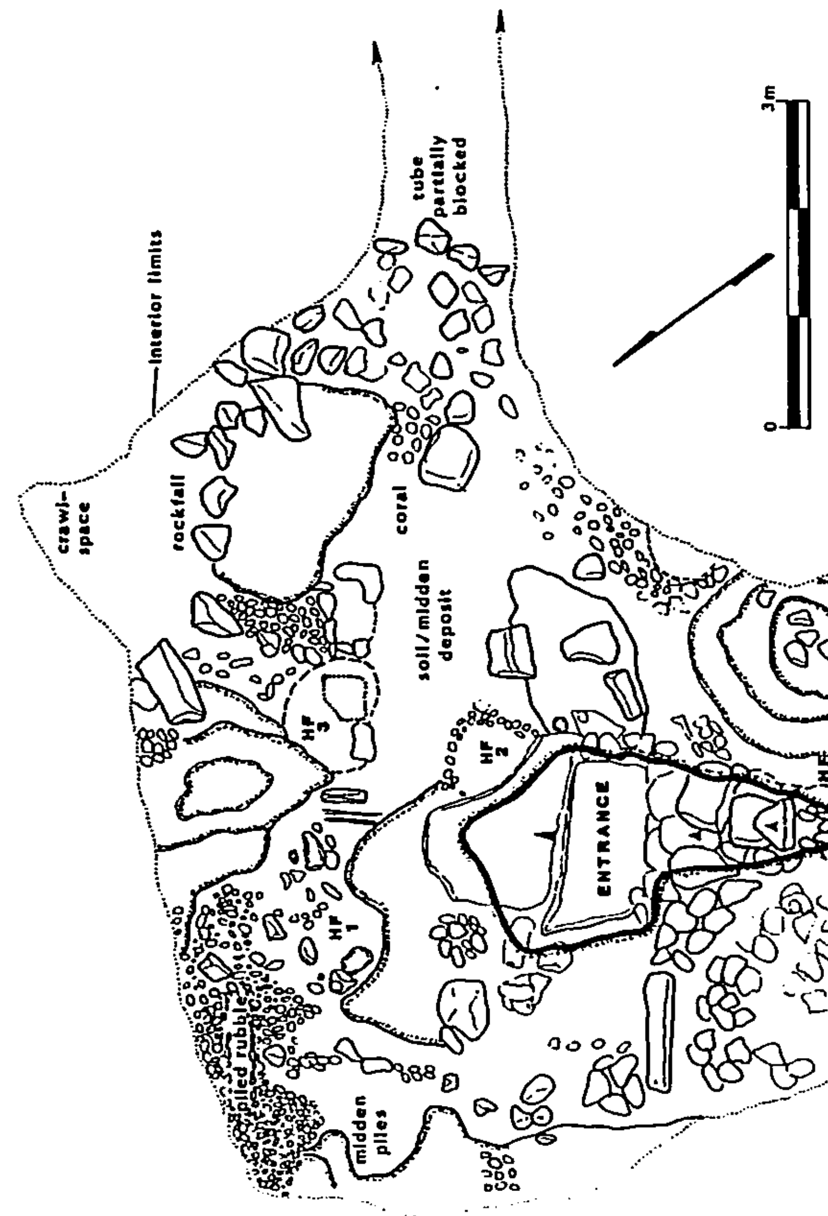

FIGURE 10. Site T-17, Feature B

Artifacts recovered from Feature B include a drilled coral abrader and two volcanic glass flakes. The two volcanic glass specimens (PHRI VG-522, -523) were submitted to Mohlab for hydration rind analysis and yielded calendric date ranges of AD 1571-1715 and 1663-1727 (two sigmas), respectively.

Feature C, a partially collapsed platform, is located 3.8 m southeast from the southern rim of Feature A (sinkhole). The area between this platform and the rim of Feature A is scattered with shell midden and is a peripheral area of Feature D. The platform is D-shaped in plan, with a major north-south axis of 3.5 m and a maximum center width of 2.6 m; width at the ends is 2.3 to 2.5 m. Its current maximum height is 0.4 m at the southeastern corner, and minimum height is 0.15 m at the northwestern corner. All of the corners have collapsed, and the overall shape of the platform is probably the result of this collapse. The perimeter of the platform is defined with large chunks of pahoehoe and fill consisting of pahoehoe that has been broken into cobble- to pebble-sized pieces. A concentration of beach coral and shell midden occurs at the northeastern corner of the platform and covers an area c. 1.0 m sq.

Feature D is surface midden and artifact deposit that covers a 30.0 sq m area adjacent to the east side of Feature A. Midden was not collected from Feature D.

Sufficient work was conducted at Site T-17 to determine that more extensive data recovery will be necessary at this site. It contains the most extensive cultural deposit among all cave sites examined within the project area. It appears there are undisturbed areas in all caves, despite the presence of numerous relic hunters' dirt piles. These piles are extremely rich in subsistence remains and will be of considerable interpretive value, particularly if additional dated materials indicate a narrow time span for site occupation.

T-18 Complex

This complex was previously recorded as Site 50-Ha-D15-8; it is discussed below.

T-19 Footpath

This site is located on the northernmost aa flow, 487 m from the shoreline. It consists of a narrow (0.7 m) path of crushed and worn aa, discernable for a distance of 24.0 m. The path (Feature A) is oriented northwest-southeast (325 degrees Az) and is associated with three small cairns which mark its course.

Two cairns (Features B and C) are at the northwest end of the trail section and are of very similar construction; both are 0.8 m high and have base dimensions of 0.6 by 0.5 m and 0.8 by 0.4 m, respectively. These cairns are constructed from crudely stacked pahoehoe slabs and aa boulders; they have somewhat vertical, unfaced sides.

Feature D, a cairn, is located at the southeast end of the trail section. It is partially collapsed and is scattered over an area 1.4 by 1.2 m; it has a maximum height of 1.0 m.

The path is not visible on the pahoehoe at either end of the narrow aa finger, although it is likely that it would have continued beyond the length of this particular identifiable segment. A single small piece of mammal bone was observed on the path; no other portable remains were present.

T-20 Platform

This isolated feature is located 80.0 m south of the northern project area boundary, on a prominent pahoehoe ridge at the west end of a narrow aa flow. It is located 326 m from the shoreline; however, it is quite visible from the coast, due to the topographic setting and to the morphology of the platform. It is roughly rectangular, with a major axis of 5.0 m and with minor axes of 3.5 and 4.4 m. The height of the platform varies from 1.4 to 1.6 m, with the exterior walls being slightly higher than the interior cobble fill. The platform is constructed from pahoehoe slabs and boulders, stacked 8 to 12 courses high, with vertical and faced sides.

Two small pits have been excavated into the cobble fill, probably by recent looters. The southernmost pit is 0.4 m deep and is roughly rectangular (0.4 by 0.45 m) in plan. The second pit, located 1.0 m to the north, is 0.2 to 0.55 m deep; the opening is 0.7 by 0.8 m. This excavation tunnels beneath the platform surface for a distance of 0.5 m.

No cultural deposit is visible on or around the platform; however, waterworn coral boulders and cobbles are present, along with two waterworn basalt boulders.

This feature was interpreted by Barrera as a possible burial (1985: 25). This interpretation is probably correct, as indicated by the morphology and construction of the platform.

T-21 Rock Mound

This feature is located 73.0 m south of Site T-20, in a similar topographic setting of an interface between coastal and inland zones. It presently has a mound-like appearance and a rounded surface, but it may actually represent a collapsed platform. The feature is square in plan, 2.0 m along each side, and 1.2 m high. It is constructed from stacked pahoehoe slabs and boulders, with cobble fill. The north and west sides of the feature are faced, and the other two side have collapsed; they were probably also faced.

Portable remains scattered on the ground surface around Site T-21 include a piece of coral and three mammal bone fragments.

This feature is located just 8.0 m from Site T-22 and should be considered as part of the same complex, which includes a cave shelter and petroglyphs (Figure 11). Site T-21 was interpreted by Barrera as a possible burial (1985:26). This feature is morphologically very similar to the Site T-13 burial, and the interpretation is likely to be correct.

T-22 Complex

Originally described as a cave shelter by Barrera, this site complex consists of a cave, an L-shaped wall and five petroglyphs, within an area of c. 90.0 sq m (Figure 11). Feature A is a cave formed from a lava bubble, with 32.5 sq m of habitable space (9.3 east-west by 3.5 m). A small portion of the bubble roof has collapsed, permitting vertical access to the cave from the ceiling. The entrance is 1.2 m sq and is 0.8 m above the floor of the cave. Maximum ceiling height inside the cave is 1.2 m. A small skylight occurs at the western end of the cavo.

Subsistence remains are concentrated in two locations inside the shelter and include five shellfish families (Cypraeidae, Littorinidae, Neritidae, Patellidae and Thaididae), Echinoidea, gourd, mammal and bird bone, and waterworn basalt cobbles and boulders. There is no substantial accumulation of midden and no soil inside the cave.

Feature B, a group of five anthropomorphic petroglyphs incised in smooth pahoehoe, is located midway between Feature A and Site T-21. The petroglyphs are within a relatively small area (2.0 by 0.6 m) and are stylistically similar (Figure 12). Four of the human forms are complete, and one is represented by the upper torso only. The petroglyphs represent the only location of this site type within the project area.

Feature C, an L-shaped wall, is located 21.4 m northeast of the Feature A entrance. The long section of the wall is oriented east-west (270 degrees Az) and is 3.0 m long. The short section is 2.0 m long and is oriented north-south. The wall is 0.3 m high and 0.5 m wide and is constructed from piled pahoehoe slabs and boulders. No portable remains were observed near the wall, which apparently functioned as part of a temporary shelter.

T-23 Walled Shelter

This relatively isolated feature is located on a narrow pahoehoe flat between two aa fingers, in open rocklands, at an elevation of 40 ft. It is a small, low-walled enclosure that has a narrow opening in the west side (oriented 260 degrees Az). The enclosure is oval in plan, with a major axis of 3.6 m and a minor axis of 3.0 m. The wall height varies from 0.45 to 0.1 m. Walls are constructed from loosely stacked pahoehoe slabs and cobbles, three to four courses high.

No deposit was observed inside or outside of the enclosure; portable remains are limited to two pieces of shellfish (Cypraeidae and Thaididae) and a piece of weathered coral, all located outside the shelter.

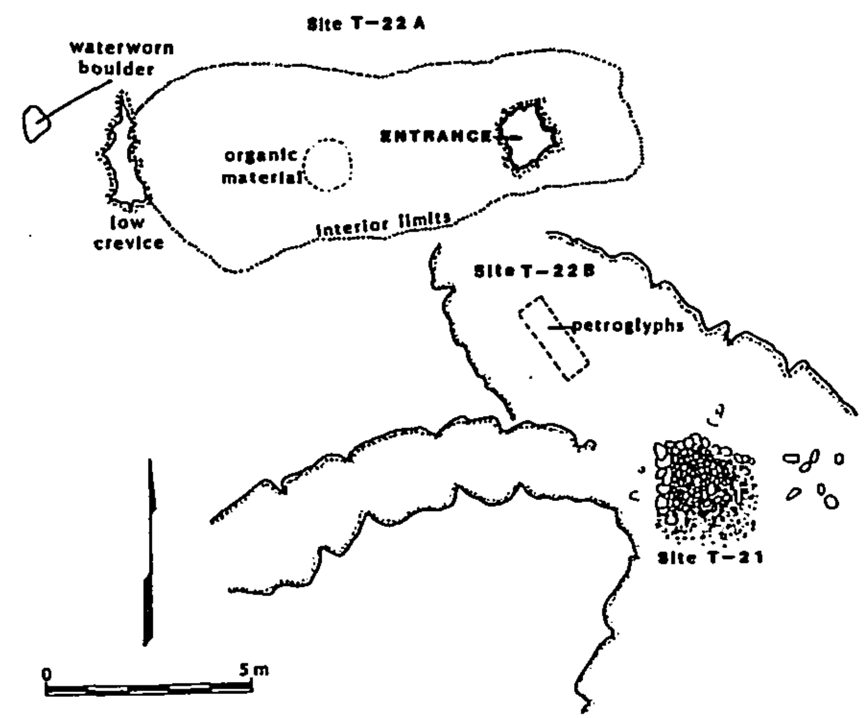

FIGURE 11. Site T-21 and T-22, Features A and B

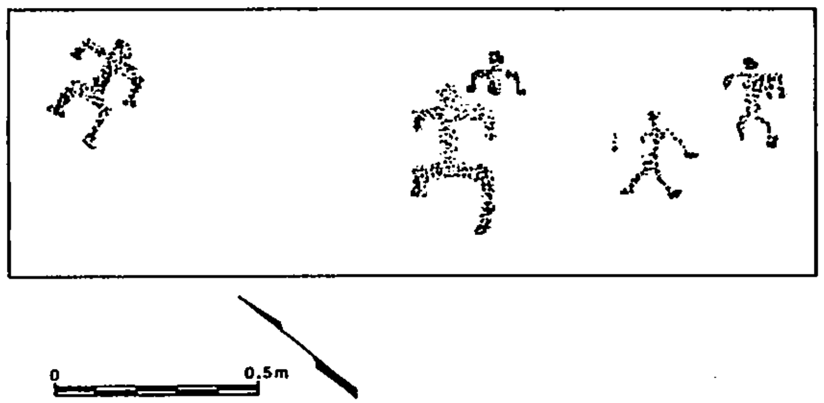

FIGURE 12. Site T-22, Feature B Petroglyphs

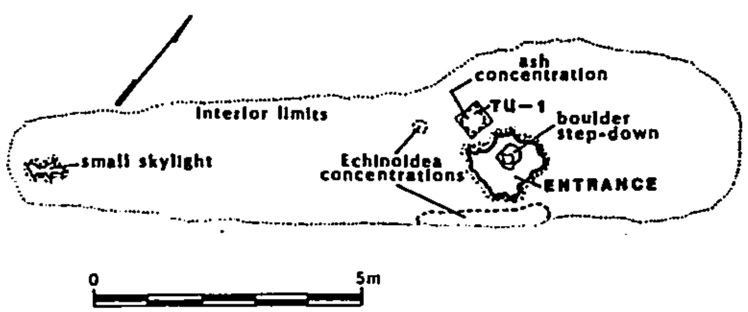

FIGURE 13. Site T-24

This feature is interpreted as a temporary habitation site. A scaled plan map was compiled at the time of survey.

T-24 Cave Shelter

This lava tube cave shelter is located 12.2 m west of Site T-25, along the southern edge of a pahoehoe disturbance caused by a more recent nearby aa flow. The tube is oriented northeast-southwest, with a major axis of 13.7 m and a variable width of 2.2 to 3.2 m (Figure 13). It is accessed through a small collapsed area in the ceiling, which is 1.3 m above the cave floor. The entrance is nearly square (1.15 by 1.05 m), and a boulder step has been positioned directly beneath the opening, for easier entry and exit. A very small skylight occurs at the western end of the tube, 7.5 m from the entrance. There are no internal modifications to the cave, which is generally free of rockfall. A scattering of feral goat bones occurs at the northeastern end, and two small concentrations of Echinoidea remains are present. A single ash concentration, which appears to be a hearth area, was located just west of the entrance. This 1.0 cm deep deposit was collected and screened. Also collected from the cave surface was a charcoal sample for possible radiometric age determination. A single coral abrader was recovered from the general site surface.

Subsistence remains collected from the single hearth area include seven shellfish families, Echinoidea, Crustacea, and a small amount of charcoal. A second coral abrader was also recovered from the screened matrix (discussed below).

The information content of this site is limited, due primarily to the nature of the occupation.

T-25 C-Shaped Shelter

This small shelter is located 12.2 m east of Site T-24, on a level and smooth pahoehoe flat. It consists of a low, loosely stacked, curved wall that opens to the west. The wall encompasses a 5.1 sq m area (3.0 by 1.7 m) and ranges in height from 0.3 to 0.4 m. Average wall width is 0.5 m; it is in poor condition, and most portions are collapsed.

An extremely sparse scatter of Conidae, Cypraeidae, and Neritidae shell fragments was observed on the pahoehoe bedrock surface to the west of the wall. This feature probably represents a temporary habitation site.

T-26 Footpath

This segment of a footpath is located across a narrow finger of aa in the inland rocklands, at an elevation of 45 ft. It consists of a 0.8 to 0.9 m wide path of crushed and slightly worn aa cobbles that extends for a distance of 9.5 m. The path is not identifiable once it leaves the aa; no worn, cleared, or marked areas were observed on either side of the aa ridge. No portable remains or cairns are associated with this path.

T-27 Cave Shelter

This cave is located in rough pahoehoe, 18.0 m north of the Site T-26 trail segment. It was formed in a lava bubble and has a habitable area of 33.2 sq m (9.5 by 3.5 m). The entrance to the cave is vertical; it is 0.7 m above the cave floor and provides an access area 1.8 by 1.0 m. Maximum ceiling height of the cave is 0.7 m.

Subsistence remains observed in the cave are concentrated in bedrock crevices and do not exceed 1.0 cm in depth. A small range of shellfish families is represented by a few fragments each. These include Cypraeidae, Littorinidae, Neritidae, Patellidae and Thaididae. A few Echinoidea fragments and coral pieces were observed, as well as two volcanic glass flakes. These latter artifacts (PHRI VG-531, -532) were collected and were submitted to Hohlab for age determination. The volcanic glass samples yielded calendric date ranges of AD 1640-1716 and 1670-1746 (two sigmas), respectively.

The site has been interpreted as a temporary habitation shelter.

T-28 Cairn

This solitary cairn is located on relatively smooth pahoehoe, 415 m from the coast. It is one of the southernmost features located by Barrera in the inland area. The cairn is in a collapsed condition and may have originally been roughly square (1.8 by 1.8 m). Maximum height of the cairn is 0.5 m; it is constructed from piled pahoehoe slabs and boulders.

During the relocation of this feature, two additional cairns (Site T-73) were located 24.0 m to the southwest. These three cairns are 183 m from the nearest recorded site.

T-29, T-30 Complex

These sites were previously recorded as Site 50-Ha-D15-2 and are discussed below.

T-31 Complex

The principal feature at this site is a coral paved terrace that has been constructed at the base of a pahoehoe pressure ridge, on a narrow ledge that overlooks a steep ravine. It is situated at the western edge of an aa flow, 232 m from the shoreline, and has a western exposure. The terrace is amorphous in shape, conforming to the available space of the ledge. Portions of the sides are faced to a height of 0.5 m, in order to extend the leveled surface along the slope of the ledge (Figure 14).

A rectangular looter's hole (1.2 by 1.4 m) has been excavated into the southern half of the terrace, revealing pahoehoe slab fill to a depth of

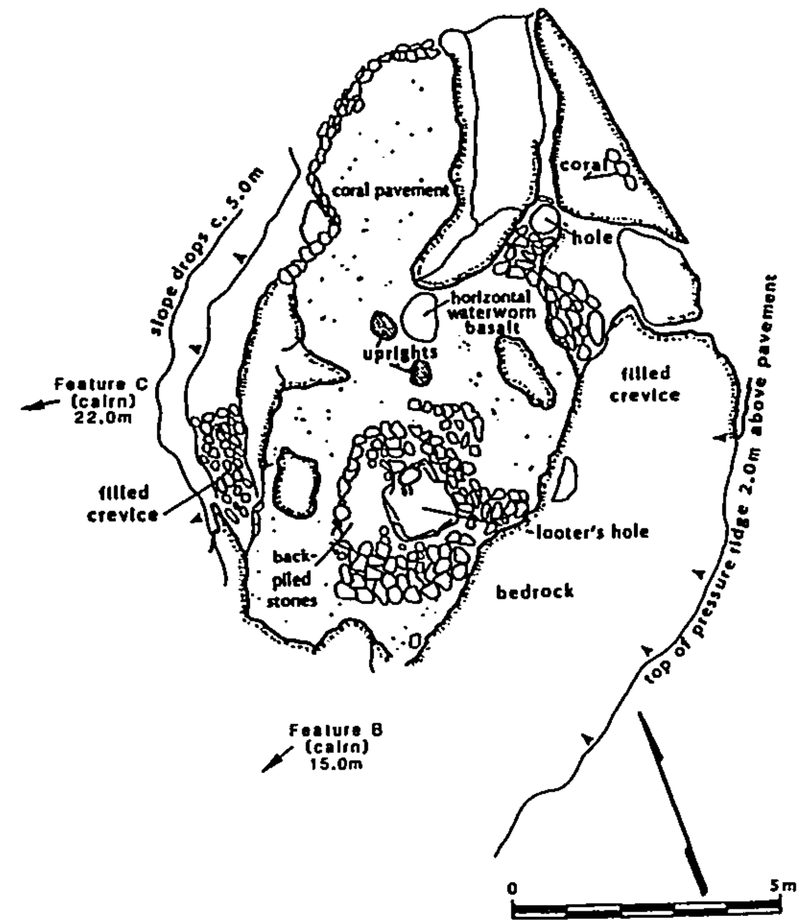

FIGURE 14. Site T-31, Feature A

at least 0.75 m. Other portions of the feature appear to have a shallow deposit of fill stone underlying a leveled and compacted surface of fine coral paving. All loose stone on the feature originated from the looter's hole, with the exception of three large waterworn basalt boulders. Two of the basalt boulders are oval uprights (0.45 and 0.56 m long); the third stone is horizontal and relatively flat (0.9 by 0.75 m). These stones are clustered near the center of the terrace. Two small rubble-filled crevices are located around the periphery of the terrace, which has a maximum length of 11.0 m and a maximum width of 6.0 m.

The largest filled crevice is located at the eastern edge of the coral paving, against the bedrock slope of the pressure ridge. An area 2.5 m long and 1.0 m wide has been filled with cobble- and boulder-sized pahoehoe stones. Two small holes around the edges of the fill suggest that the crevice may have been quite deep.

The second filled crevice is on the west side of the terrace, 0.5 m below the surface of the pavement, along the slope of the ravine. An area 2.0 m long and 1.0 m wide has been filled with cobble-sized pieces of pahoehoe. Original depth of the crevice is indeterminate.

No midden or other portable artifacts were observed on or near the terrace or in the looter's backpile of stones. This feature is tentatively interpreted as a shrine, with possible burial(s) either located under the pavement or in the filled crevices.

Features B and C, two cairns, are located to the west of the terrace, along the edges of the ravine. Feature B is located 15.0 m to the southwest (225 degrees Az). It is roughly circular in plan and is 0.74 by 0.71 m at its base and 0.55 m high. Feature C is located 22.0 m to the northwest (305 degrees Az). It measures 0.61 by 0.75 m at its base and is 0.33 m high. Both cairns are simple constructions of stacked pahoehoe slabs and chunks.

T-32 Complex

This complex was previously recorded as Site 50-Ha-D15-16; it is discussed below.

T-33 Rock Mound

This feature is within the boundaries of previously recorded Site 50-Ha-D15-3; it is discussed below.

T-34 Platform

This platform was previously recorded as Site 50-Ha-D15-17; it is discussed below.

T-35 Platform

This platform is within the boundaries of previously recorded Site 50-Ha-D15-18; it is discussed below.

T-36 Platform

This platform was previously recorded as Site 50-Ha-D15-19; it is discussed below.

T-37, T-38 Platforms

These features were previously recorded as part of Site 50-Ha-D15-7; they are discussed below.

T-39 Collapsed Tube

This temporary habitation shelter is located at the coastal/inland interface, in an area of extremely rough pahoehoe. It is 36.5 m south of Site T-64, an extensive temporary habitation complex. The principal feature of the site is a collapsed tube section, 4.4 m long (east-west) and 2.8 m wide, which has low overhang shelters and a small tube cave extending from the periphery (Figure 15). The floor of the collapsed area is of variable depth and has been modified by clearing large stones away from the center and by filling low areas with small pieces of rubble. Floor depth varies from 0.45 to 0.95 m below the surface of the rim.

Overhang shelters occur along the north and south sides of the collapsed tube. These shelters are shallow, with maximum depths of 1.0 to 1.3 m. A narrow crawlspace tube extends north from the northern overhang for a distance of 4.0 m; it is nearly inaccessible and contains no evidence of use. A second narrow tube cave extends westward from the west end of the collapsed area of the tube. This tube was measurable for a distance of 4.0 m and is 1.3 m wide at the entrance. The front portion of this tube was utilized, and a scatter of midden and artifacts extends a distance of 1.5 m from the entrance.

Shell midden is sparsely scattered over the entire surface of the collapsed tube floor and around the perimeters of the rim. Five distinct concentrations (HF-1 thru -5) were mapped and collected. HF-1 is a circular scatter of shell midden (1.5 m in diameter) located on a disjointed pahoehoe slab adjacent to the rim of the collapsed tube. Nine shellfish families are represented in the 905.83 g invertebrate collection from this area, as well as a few pieces of fish bone and kukui nut shell.

HF-2 is a concentration of soil, charcoal, shell midden, and fish bone located in the lowest spot of the collapsed tube floor. It covers an area 1.6 by 1.3 m and extends to a depth of 17.0 cm in a small crevice; the majority of the deposit is less than 2.0 cm deep. This horizontal feature

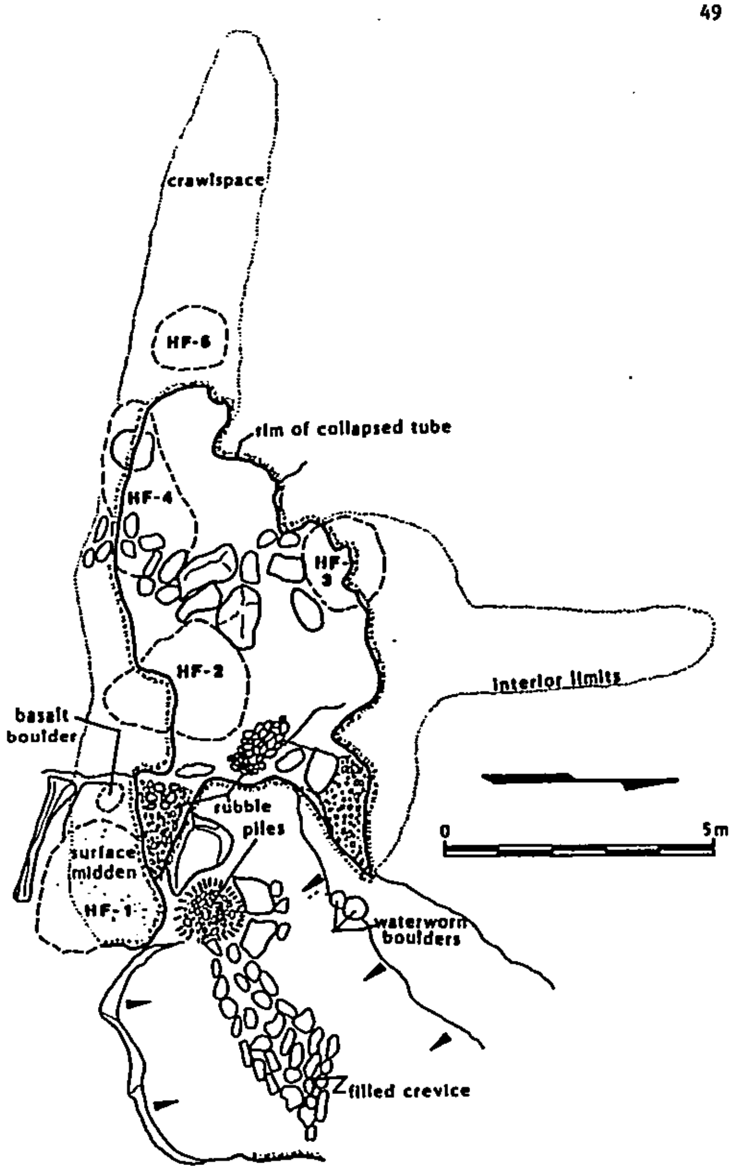

FIGURE 15. Site T-39

appears to represent a hearth area; 1,420 g of invertebrate remains were collected, in addition to 7.04 g of vertebrate remains. Fourteen shellfish families are represented in this small collection, which is an unusually high number when compared to other excavation samples collected to date. This collection is further discussed below.

Two volcanic glass flakes were recovered from HF-2 matrix and were submitted to Mohlab for hydration rind age determination (PHRI VG-533, -534). They yielded calendric date ranges of AD 1607-1675 and 1573-1657 (two sigmas), respectively. Other artifacts recovered from this area include eight Echinoidea spine abraders, two coral abraders, and a piece of modified bone.

The remaining three horizontal features (HF-3 thru -5) are small hearth areas, all of which were collected as distinct proveniences. These hearths contained fewer artifacts (a single Patellidae shell scraper from HF-4) and less varied shellfish remains than did HF-2.

T-40 Complex

This complex was previously recorded as Site 50-Ha-D15-4; it is discussed below.

T-41 Complex

This site consists of a modified depression in aa, located at the western end of a broad aa flow that also contains rough and highly disturbed pahoehoe. It was newly identified by Cordy during his field check of Barrera's survey. All features are located within a 37.7-sq-m area and are confined to a small depression that has a circular opening 6.8 m long (northeast-southwest) and 5.6 m wide (Figure 16).

Feature A, a cave, extends west from the southwestern end of the depression. It is 5.5 m wide at the dripline and has an average width of 2.0 m, with a narrow, tube-like extension at the back of the cave. Ceiling height within the cave averages 1.25 m. The cave has no internal modifications; however, a number of artifacts were present, and a small midden concentration occurs along the western wall of the cave. All artifacts were plotted on the site plan map and were collected; these include six coral abraders, an Echinoidea spine abrader, and two perforated Cellana sp. shells. A waterworn basalt boulder is also present within the cave.

Feature B is an artificially leveled rectangular area on the floor of the depression. It is located on a low bedrock shelf and covers the southern half of the blister floor. Maximum length of this feature is 3.5 m; maximum width is 2.25 m. It is constructed from aa boulders and cobbles, with boulders defining the outer edges. A 2.5 sq m concentration of pebble-sized aa occurs in the eastern portion of this pavement. A small faced excavation (Feature D), 0.5 by 0.4 m at the opening, is located in the center of the western half of the pavement. This excavation is 0.4 m deep and appears to be part of the structure; it may represent a posthole.

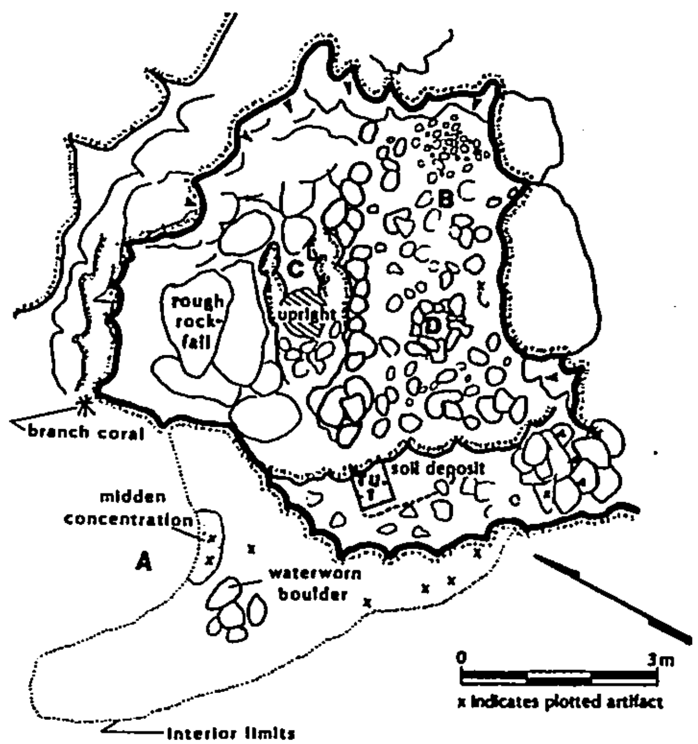

FIGURE 16. Site T-41, Features A-D

Feature C, a cupboard, is located at the northern end of the depression. It is constructed from large pahoehoe slabs and encloses a rectangular area 0.6 by 0.5 m, with a ceiling height of 0.6 m. A complete Cypraeidae shell and a Cellana sp. shell were observed in the cupboard, in addition to a few small, unidentifiable fragments.

A relatively deep soil and midden deposit occurs in a low area of the depression, just outside of the entrance to the cave (Feature A) and immediately west of the leveled surface. The deposit covers an area 1.5 by 0.7 m and has a variable thickness of 10.0 to 25.0 cm. A 0.5 by 0.5 m sq test unit was excavated into this deposit at its point of maximum depth.

Artifacts recovered from the test unit include two Echinoidea spine abraders, a coral abrader, and a broken fishhook. Cordy collected a poi pounder fragment from this location during his survey. Twelve shellfish families are represented in the screened midden collection, in addition to Echinoidea and Crustacea remains. A small amount of fish bone and kukui nut shell is also present in the collection (discussed below). The test unit excavation removed over half of the deposit present at the site, and it is assumed that the range of materials present and their relative proportions are adequately represented.

T-42 Walled Shelter

This site was newly identified by Cordy during his field check of Barrera's survey findings. It consists of a low wall of piled pahoehoe slabs constructed around the opening of a collapsed lava blister. The site is located at the northern edge of an aa flow, 24.0 m north of the more intensively occupied Site T-41.

The blister opening is oriented northwest-southeast, with a major axis of 2.7 m and a width of 1.0 m. The floor is 0.3 to 0.4 m below the surface of the bedrock. The wall is likewise 2.7 m along its major axis and has an average height of 0.3 m. Width of the piled slabs varies from 0.4 to 0.6 m.

A small cave located at the western end of the blister has a habitable space of 10.0 m (5.0 by 2.0 m). Maximum ceiling height inside the cave is 1.75 m; however, the entrance is 1.0 m high and is partially blocked by a rock shelf, which makes access difficult. The cave floor is sloping and steep, and there is no evidence of human activity inside.

No portable remains were observed in the cave or walled blister, which functioned either as a temporary shelter or as a storage facility.

T-43 Complex

This site was newly identified by Cordy during his field check and was described as a "small cave with slight deposits" that was "just briefly glanced at" (Cordy 1986a:37). The site described here consists of two caves and may include the feature observed by Cordy. The location of this site is at variance with Cordy's plotted location; however, no caves were located in the area of Site T-43, as plotted by Cordy. Due to the variance in descriptions and locations between the sites, the features described here were tagged PHRI-2 in the field.

Feature A may be the feature identified by Cordy; it is a small cave with 15.6 sq m of habitable space (6.0 m north-south by 2.6 m east-west). The cave opens to the east through an access, 1.7 by 0.9 m. Average ceiling height is 1.1 m.

Portable remains inside the cave are sparse and generally occur in bedrock crevices. Shellfish families represented include Cypraeidae, Isognomonidae, Neritidae, Patellidae, and Thaididae. A few Echinoidea fragments were observed, and a single artifact was collected--a small adze flake. This specimen is of fine-grained basalt and exhibits polish on three faces, including a small portion of the dorsal side.

Feature B is a cave shelter with 42.0 sq m of habitable floor space. The cave is accessed through a vertical entrance 1.4 by 0.9 m, and has a very low average ceiling height (0.5 m). This cave has no subsistence remains, and a single artifact was recovered--a well-used Echinoidea spine abrader (discussed below). Other material present in the cave includes feral goat bones.

Feature C is a small cairn consisting of three boulders stacked on top of one another. The cairn measures 0.5 by 0.4 m at the base and is 0.5 m high.

T-44 C-Shaped Shelter

This site was newly identified by Cordy, who suggested that it may correlate with Barrera's Site T-25. Barrera's site was confirmed to be a different feature, and the C-shape located and described here is assumed to be Cordy's Site T-44, even though it is not located where plotted by Cordy. Because of the variance in locations, the site was tagged PHRI-1.

This C-shaped shelter is located 12.0 m northeast of Site T-25, a very similarly constructed shelter. It consists of a stacked pahoehoe slab wall which partially encloses an 8.8-sq-m area (4.0 by 2.2 m). The wall is partially collapsed and has an average width of 0.6 m; height varies from 0.35 to 0.5 m.

No portable remains were observed in or near the shelter, which apparently functioned as a temporary habitation site.

T-45 Overhang Shelter

This single feature is located in open pahoehoe rocklands, 378 m from the coast. It consists of a collapsed lava tube which has an overhang

shelter at the west end of the tube. The overhang is 4.5 m wide at the entrance and extends to a maximum width of 6.0 m. It has a maximum depth of 2.0 m and a ceiling height of 0.9 m. The shelter has a northwestern exposure, and the floor space along the walls is covered with rockfall from the tube ceiling.

A very sparse scatter of shellfish remains is present in the cave, including Conidae (one piece), Cypraeidae (four pieces), Littorinidae (one piece), Neritidae (c. 50 pieces) and Thaididae (two pieces). Also present are three pieces of Echinoidea.

No artifacts or internal features are present within this shelter, which is interpreted as a temporary shelter site.

T-46 Cairns

These cairns were newly identified by Cordy, who described them as being 1.0 m in diameter at their base, 1.0 m high, and "perhaps 10 m apart" (1986a:38). The only cairns located in the vicinity of Cordy's plotted location for this site were two wider and shorter cairns spaced 1.0 m apart. Due to the variance in site descriptions, the features located during the survey were tagged PHRI-3. Since no additional cairns could be located subsequent to the location of this site, it is assumed that PHRI-3 and T-46 are the same site.

Feature A, a cairn, is roughly circular in plan, with a basal diameter of 2.0 m and a maximum height of 0.45 m. Feature B is of similar diameter, but is slightly taller (0.5 m).

SITE DESCRIPTIONS—PHRI TEMPORARY SITES

T-47 Complex

This site consists of a broad, shallow, collapsed blister that has a limited amount of modification, and a partially walled cave shelter that extends from the western perimeter of the blister. It was newly identified during the intensive survey of the coastal zone and is 36.6 m north of Site T-15, at the southern end of the project area.

The collapsed blister has a major axis of 28.0 m, oriented roughly northeast-southwest (65 degrees Az). The blister is oval in plan, with a minor axis of 10.0 m. The north and south walls of the blister gradually slope inward, whereas the east and west walls are vertical, with an average height of 1.0 m. Small overhang crawlspaces occur around the inside of the east and west walls; these have extremely low ceilings (0.3 m) and are not habitable. Recent trash is present within these crawlspaces.

Modifications inside the blister include a filled crevice along the southern slope and across the central, lowest portion of the blister floor. An area 8.4 m long and 2.4 m wide was filled with cobble-sized pieces of pahoehoe, apparently to level a low area. The major axis of the fill is oriented 25 degrees Az. The fill does not appear to be over 0.2 m deep.

A considerable amount of recent and historic material is scattered inside the blister. The most frequent material class is beverage bottle glass, some of which dates to the early twentieth century. Modern glass jars and beverage bottles are also present, in addition to wire and recently deposited Patellidae (opihi) shells. A few large waterworn beach boulders have been deposited near the center of the blister, which appears to have been recently used for a campsite. The surface of the blister is scattered with storm wash, including weathered coral cobbles and coral sand.

Feature B, a low ceiling cave at the west end of the blister, is entered from an opening 0.6 m below the floor of the blister. The entrance is 2.6 m wide, and the cave opens up to a width of 6.0 m. Maximum ceiling height is 0.78 m. The cave has a maximum depth westward of 9.0 m. Two small tubes extend from the north and south sides of the cave and follow the perimeter of the blister for a short distance. These tubes are inaccessible. Rockfall was cleared from a crevice in the ceiling of the southern tube extension, creating a small opening 0.3 m high, perhaps for ventilation.

Portable remains inside the cave are limited to glass bottle sherds and a few scattered shell fragments (Cypraeidae, Neritidae, and Patellidae). Early twentieth-century bottle glass is concentrated in and at the entrance to this cave; deep kickup bases of dark olive glass and panel bottle sherds were observed.

This site appears to have functioned as a temporary shelter site; it has no accumulation of subsistence remains. Portable artifacts suggest that its most intensive use was during the twentieth century, probably after 1950.

T-48 Complex

This site is located on a coral beach, near the southern edge of the project area, less than 10.0 m west of the coastal jeep road. The complex consists of three platforms, retaining walls, and a salt pan stone. These features occur within an area of c. 450 sq m.

Feature A, a roughly rectangular platform, is constructed from large weathered, porous lava stones and beach cobbles. It is 3.1 m long, 2.14 m wide, and has a maximum height of 0.36 m. The exterior sides of the platform are outlined with a single course of large stones, and the interior is filled with smaller beach boulders and weathered coral, much of which appears naturally deposited. The corners of the platform are rounded; the

surface is currently slightly mounded and appears to have had minor disturbances.

Feature B, a large basalt stone with an abraded depression in its surface, is located c. 8.0 m west of Feature A. The stone is positioned horizontally, with the abraded surface up (Figure 17). The abraded surface is oval in plan and is worn to a maximum depth of 5.0 cm. The stone is 0.96 m long by 0.77 m wide and is 0.24 m thick. It is movable, but only with considerable effort by more than one person. Two upright basalt stones are adjacent to the salt pan stone.

Feature C, a partially buried platform, is located adjacent to Feature A. It is similar in construction to Feature A; however, it is smaller and is square in plan, with sides of 1.93 and 1.95 m. The east wall of the platform is 0.34 m high and consists of a single course of large boulders. The west wall is partially buried in storm wash, and its height is indeterminate. This feature has been exposed to more erosion than has Feature A, suggesting that it may be of somewhat earlier construction.

A partially buried retaining wall extends southward from this platform for a distance of 13.0 m. The wall is constructed from large waterworn boulders and is quite jumbled; it may be the remnant of a large platform.

Feature D consists of badly eroded wall segments that appear to represent a house foundation. The walls are constructed from unusually large waterworn basalt boulders; they are double-faced, with most of the core filling washed away. A rectangular area, 7.0 by 6.1 m, is defined by the segments; however, no corners are clearly defined. An internal wall is oriented north-south within the enclosed area, defining an eastern compartment, 6.1 by 2.7 m. An additional alignment of what appear to be the basal stones of a former wall occurs directly west of this feature.

Site T-48 appears to have been considerably more extensive than is indicated by the features that are still intact. Its location correlates with Site 66, identified by Reinecke in 1930 (1930:11). Site 66 is plotted on Reinecke's map at Puhili Point, very near the border between Kohana-Iki and Ooma II; it is described as follows:

> Very doubtful dwelling site. Then a row of sand-covered platforms at the border of the sand and the beach lava, enough for 6-10 homes. Remains of an old, large pen (Reinecke 1930:15).

It is uncertain which of the features described by Reinecke may correlate with the features at Site T-48. The pen has been tentatively associated with Site T-16, located 13.0 m to the northeast. The "row of sand-covered platforms" appears to best fit what is currently visible at the site. Features A and C are morphologically more similar to burial platforms than to house platforms; however, Feature D and the longer feature identified as a retaining wall could easily be house platform remnants.

Figure 17. SITE T-48, FEATURE B, SALT PAN STONE. View to south. (PHRI Neg.497-4)

T-49 Platform

This badly eroded platform is located on a coral beach, 109 m north of Site T-48 and c. 20.0 m from the tidal shoreline. It is identifiable as a raised area (7.7 by 5.10 m) enclosed by aligned stones that are partially buried in the coral storm wash. The surface of the platform is covered with disturbed, waterworn boulders and weathered coral. No associated features could be identified in the area.

It is probable that this platform was among those described by Reinecke in his Site 66 designation, which identified enough platforms for 6-10 houses (see above).

It is unlikely that any portable remains associated with the feature are still present at the site, or that useful descriptive data on the structure are present.

T-50 Pahoehoe Clearing

This feature is located at the eastern edge of the storm beach deposit, along the upper, east-facing slope of a pahoehoe bubble. It consists of a vertical fissure in the pahoehoe that has been partially cleared of rockfall. The fissure is 1.5 m long, 0.88 m wide, and varies in depth from 0.78 to 0.90 m. The removed stones have been spread over an area 3.5 m long, in a rough alignment to the south side of the fissure. Some of the stones have been stacked in a low area along the opening of the clearing. There is a shallow deposit of coral sand in the cleared fissure, which appears to have been naturally deposited. No portable remains, other than the broken rims of modern sunglasses, were observed in or around the clearing.

The cleared area is conceivably large enough for a small shelter; however, it is difficult to assign a specific function to this feature, based on available evidence. No additional information appears to be obtainable from the site itself, which was mapped and measured.

T-51 Complex

This site consists of two substantial walled shelters and leveled aa areas. It is located at the southern edge of the broad aa flow that extends westward to the beach. The site is c. 30 m east of the most inland extent of the storm wash.

Feature A, a C-shaped shelter, is constructed from flat pieces of rough pahoehoe and from small pieces of aa. The shelter opens to the west (230 degrees Az) and has a maximum width of 3.37 m, measured from the exterior sides of the wall. The east-facing portion of the wall is most substantial and has a width of 1.32 m. The interior area of the shelter (5.7 sq m; 2.04 m north-south by 2.8 m east-west) is leveled and paved with small, crushed pieces of aa. Interior wall height is 0.5 m; exterior w a l l height is 0.84 m. The exterior side of the east portion of the wall is faced with five courses of neatly stacked slabs. No portable remains were observed inside or around the shelter, with the exception of a modern aluminum beverage can.

Feature B is located 7.9 m south (358 degrees Az) of Feature A and is a similarly constructed shelter with a U-shaped wall. This shelter opens to the west (260 degrees Az) and is constructed from similar lava materials. Maximum length of the shelter is 3.7 m east-west, measuring from exterior sides of the wall. Exterior width is 3.1 m. The interior area (3.8 sq m) is partially leveled with crushed aa, which extends a short distance westward beyond the limits of the shelter wall. The eastern wall is faced on the interior side and has a very level surface, which looks as if it has been used as a walkway. This wall is 0.9 m wide and rises 0.6 m above the interior floor.

An additional area of filled and leveled aa is located immediately east of the Feature B wall. Small pieces of aa cover a 1.5 by 1.9 m area and appear to have been placed over a depression in order to facilitate access to the shelters, which are in extremely rough aa. No portable remains were located in the vicinity of these features.

T-52 Modified Outcrop

This site is located 73.0 m west of Site T-51, along the southern edge of the broad aa flow. It is situated in a low natural depression in aa, against the base of a vertical slope that forms a natural windbreak shelter, exposed only to the west. The aa within the protected area (c. 9.0 sq m) of the natural windbreak has been modified either by leveling and filling or by excavation.

Loose aa cobbles were removed from a small area at the foot of the rock slope in order to form a deep (0.96 m), narrow hole. The opening of the hole is outlined with three courses of stacked stone. The excavation is 0.66 by 0.89 m at its opening and narrows to 0.5 by 0.56 m at its base. No portable remains were located within this excavation.

An area 2.26 m from the hole, against the rock outcrop, has been filled and leveled with small pieces of aa. This area is 1.52 by 1.8 m east-west. A second, small, filled and leveled area is located to the southeast, beyond the sheltered portion of the site. This patch of small aa gravel is 1.0 m long and 0.5 m wide; it may represent a footpath segment and appears to be aligned with a third small patch of fill located 6.0 m to the east.

Additional indications of a footpath could not be located, and no portable remains were observed in the vicinity of this temporary shelter site.

T-53 Marked Footpath

This footpath is located in the broad aa flow, 82.0 m north of Site T-52. It is oriented northeast-southwest and appears to lead to the Site D15-2 complex, located 85.0 m to the north. The western continuation of the path from its identified segment in the aa could not be determined; however, it is possible that the path continued to the beach, 70.0 m directly west. The width of the path is extremely varied, and little to no modifications were made along its surface. It is observable primarily through the aid of small cairns, three of which were located. These cairns are simple stacks of three to four rough slabs, placed on high points along the path. Average height of the cairns is 0.25 to 0.40 m, and the stones used for construction are under 0.5 m in diameter.

T-54 Faced Excavation

This single feature is located in aa, 24.0 m north of the westernmost Site T-53 cairn. It is very similar in form and construction to the excavation found at Site T-52. The feature was constructed by excavating a deep (0.90 m), narrow hole in the aa and by outlining the opening with stacked, slab-like pieces of lava. This hole is roughly circular (0.32 m in diameter), and it contains no portable materials. Its function is indeterminate; possible functions include use for storage or use as a posthole.

T-55 Complex

This rather extensive (c. 3,679 sq m) complex of pahoehoe excavations and a walled shelter is located in an area of weathered pahoehoe, to the north of the broad aa flow, just east of the zone of coral storm wash. The pahoehoe in this area is considerably lighter in surface color than is that in adjacent areas beyond the site boundaries. The ground surface has been subjected to natural disturbances, and a number of crevices are open in the pahoehoe. The upper pahoehoe stratum forms a thin (0.2 to 0.3 m) rock cap that is separated from an extremely porous stratum by a gas pocket. In some areas of the site, this extremely porous stratum is separated from a lower rock stratum by a second gas pocket.

The upper pahoehoe has been broken away in chunks along the crevices, creating holes of various sizes and shapes. The stratum of porous lava has also been broken away in excavations where it is delineated by an underlying gas pocket. Where this second gas pocket occurs, the porous lava stratum is 0.2 m thick. At least 12 excavations occur within the area of Sites T-55 and T-56, which are continuous segments of the same complex.

There is considerable variability in the amount of quarried stone present around the openings of the excavations, and it appears that less of the porous lava has been left around the excavations from which it was removed.

The shelter (Feature A), a roughly C-shaped wall which abuts a bedrock outcrop, is located at the western edge of the site. The shelter opens to the west and incorporates a 1.09 m section of bedrock which forms the southern wall. The stacked pahoehoe slab wall has an average height of 0.28 m. Its overall length is 3.36 m, with sections 0.97, 1.21 and 1.18 m long. No portable remains occur in or around this temporary shelter site.

Two additional modified outcrops occur at the western edge of the site. These features are three-sided walls of stacked pahoehoe slabs built at the bases of steeply sloping collapsed blisters. The walls function(ed) as foundations for a movable plywood lua that is currently positioned over one of the walls (Feature B). The recently abandoned lua foundation (Feature C) is filled with modern rubbish. This feature has an interior area of 1.5 sq m (1.2 by 1.25 m) and a wall height of 0.5 m. The base of the wall is in a depression 1.2 m below ground surface. The currently utilized wall is of very similar size and construction.

T-56 Complex

This site is a continuation of the same pahoehoe quarry complex described for Site T-55, and it has been included in the total complex area given above. Also present at the east end of this site is a cairn, constructed on a prominent lava projection. The cairn is roughly circular, with basal axes of 1.9 and 1.6 m. It was constructed from large blocky boulders and was filled with smaller pahoehoe stones; original height is indeterminate due to poor preservation. Current height is 1.0 m.

T-57 Complex

This site consists of two C-shaped shelters and a cairn. It is located on broken pahoehoe in the coastal zone, 85.0 m east of the coral storm wash. All features are within an area of c. 40.0 sq m.

Feature A, a collapsed blister, has been walled around the north, east, and south portions of its opening. Maximum diameter is along the north-south axis and is 6.0 m, measured from exterior sides of the wall. Maximum depth of the blister is 1.0 m at the center; average depth is 0.75 m. Average wall width is 1.2 m, and average height is 0.4 m. The walls are jumbled, and a number of stones have fallen inward from their original location.

A few fragments of shellfish are scattered on the floor of the blister; these include Cypraeidae, Neritidae and Thaididae. A few pieces of Echinoidea and coral are also present.

Feature B is located directly to the north and adjoins the north wall of Feature A. This C-shaped wall opens to the west, with a 3.0 m wide break in the wall. Maximum north-south diameter of this wall is 4.0 m, measured from the exterior sides. The northern portion of this wall is 1.0 m wide, and its average height is 0.3 m. No subsistence remains were observed within this smaller shelter; however, coral fragments are more numerous.

Feature C, a cairn, is located on a naturally uplifted pahoehoe shelf at the southern edge of Feature A. It is constructed from pahoehoe boulders and is filled with smaller pieces of pahoehoe. The cairn is roughly rectangular, with basal sides of 2.8 and 1.9 m. Height is 1.0 m.

This site is interpreted as a temporary habitation locale.

T-58 Complex

This site is located along the coastal/inland interface, on a relatively high ridge of broken and extremely disturbed pahoehoe. It consists of a small excavation in rockfall, a small cairn, and a small, walled shelter.

Feature A, a relatively deep excavation in loose rockfall, is located beneath an overhang along the upper west-facing slope of the ridge. The overhang shelters an area 1.79 m wide and 1.32 m deep, which consists of an irregular surface of rockfall. A circular, vertical-walled hole (0.95 by 0.81 m) has been excavated into the rockfall to a depth of 0.97 m beneath this overhang, in order to create what appears to be a storage facility.

Feature B, a low cairn, is located 1.88 m southeast of Feature A, on a prominent, outjutting rock along the ridge. The cairn is roughly rectangular in plan, with basal sides of 1.7 and 0.98 m. It is constructed from large, blocky chunks of pahoehoe that are stacked only two courses high (0.46 m) on the outer wall. The center of the cairn is core-filled and is lower than the outer walls.

Feature C is located slightly lower along the ridge slope, immediately below Feature A. It consists of a short wall erected across a low fissure and an adjoining area of fill, which extends beneath a low overhang. The wall is 1.15 m long, 0.61 m wide, and 0.91 m high. It is constructed from small pahoehoe slabs piled four courses high and two stones wide. Both ends of the wall abut bedrock, and a crevice to the west of the wall has been filled with cobble-sized stones in order to create a level surface. The western end of the filled surface extends under a projecting boulder which shelters an area 1.5 m wide by 0.83 m deep. Ceiling height under this stone is 0.83 m.

No subsistence remains were observed at this site; however, a large basalt tool was located 7.6 m south of Feature A. This relatively fine-grained, weathered basalt has been flaked to form a wedge-like tool, 0.34 m long, 0.14 m wide and 0.13 m thick. The bit end of the stone is beveled, and the butt end has been extensively battered. The tool is considerably larger than most adze preforms and has been utilized with very little formal modification. The extensiveness of wear on both the bit and butt ends suggests use with other heavy tools on a relatively hard medium. This artifact is possibly a quarrying tool, used as a wedge to force open small crevices and break off chunks of pahoehoe. The extensive quarry site (T-55) is located c. 170 m west of this site.

T-59 Walled Shelter

This collapsed blister with a small, walled section is located in the coastal zone, 61.0 m northeast (70 degrees Az) of Site D15-16. The blister has a maximum east-west axis of 4.5 m and a north-south axis of 2.6 m. Depth varies from 0.8 to 1.20 m. A 1.0 m long wall has been constructed at the northeastern end, across a low section of the blister rim. The wall is constructed of loosely piled pahoehoe slabs, one to three courses high (0.15 to 0.40 m high).

A small overhang shelter (2.2 m wide and 1.0 m deep) extends off the south end of the blister; this shelter is devoid of any portable materials. A very small scatter of Nerita picea (seven pieces) and Echinoidea (one piece) occurs near the center of the blister. Six pieces of waterworn coral are scattered about, with no concentration.

This site is interpreted as a temporary habitation shelter; a scaled plan map has been complied.

T-60 Complex

This site is located on a coral beach, directly west of the coastal jeep road. It consists of a permanent hearth (constructed from waterworn boulders and coral cement) and a mound of structural remains with a stone alignment. Feature A has been tentatively identified as a hearth; it is constructed with four oblong stones of uniform size that were laid on their sides to form a roughly square area (0.46 by 0.50 m), and it has been filled with coral cement to within 0.15 m of the top of the stones. The cement is relatively soft, and no recent refuse or ashes are present in the feature.

Located northeast of and adjacent to the hearth is a low, mounded formation of rock and coral (6.3 m in diameter). A number of large, partially buried boulders form an alignment 4.5 m long, which extends eastward from the northeast edge of the mound. This feature appears to be the remnant of a severely disturbed structural platform. The surface has been totally covered with storm wash, and there is no indication that original dimensions or formal attributes of the feature are obtainable from what currently remains.

T-61 Complex

This site consists of nine features within an area of 1,672 sq m. Two cave shelters, four overhang shelters, two rubble piles and a cairn are present. Feature A, a cave shelter, is entered through a vertical opening in smooth pahoehoe, 1.3 m long and 1.0 m wide. The entrance is 0.9 m

above the cave floor, which is covered with decomposing basalt crumbs and thin organic deposits. The cave has a habitable area of c. 75.0 sq m, with a major axis of 10.0 m. Two bedrock pillars near the center of the cave divide it into three distinguishable chambers, all of which have low ceilings (0.9 m and less).

Portable remains are scattered over the cave floor, with no definite concentrations. Shellfish species present include Conidae, Cypraeidae, Neritidae, and Thaididae. Echinoidea, mammal bone, and coral cobbles are also present.

Feature B is located 8.2 m northwest (328 degrees Az) of Feature A. It is an intensively utilized cave shelter with internal modifications. The cave is small (c. 18.0 sq m habitable space), amorphous in shape, and has a generally low ceiling (0.85 to 1.3 m high). There are two cave openings, both of which are small and vertical. The westernmost (entrance) is 0.9 m long and 0.47 m wide; the eastern opening is 1.26 m long and 0.23 m wide.

Loose rockfall has been piled near the entrance to form a mound, 1.17 by 1.78 m and 0.25 m high. Three tube extensions from the main chamber have been walled off with stacked rockfall, and a stone alignment has been constructed to the south of the rubble mound. Large, waterworn boulders are positioned at either end of this short alignment.

The midden deposit is dense in this small cave, and it has been disturbed by relic hunters. Shellfish families observed include Conidae, Cypraeidae, Isognomonidae, Littorinidae, Neritidae, Patellidae, Spondylidae, and Thaididae. Other portable remains include kukui nut shell, fish and mammal bone, gourd, Echinoidea, charcoal, modified wood, modified mammal bone and volcanic glass. Two volcanic glass flakes were collected and were submitted to Mohlab for hydration rind age determination (PHRI VG-535, -536). The samples yielded calendric date ranges of AD 1653-1713 and 1648-1704 (two sigmas), respectively.

Feature C, an overhang shelter and cleared blister, is located 3.8 m northeast (45 degrees Az) of Feature B. This low-ceilinged (0.5 m high) overhang opens to the south and is located along the perimeter of a collapsed blister. The opening is 3.10 m wide, and the sheltered area has a maximum depth of 1.6 m. The sheltered area is triangular in shape and has an interior area of 2.5 m. Pahoehoe cobbles have been deposited at the entrance of this overhang, in order to level the ground surface. A linear pile of boulders is located to the north, along the floor of the blister. This pile is 7.0 m long and has a maximum height of 0.20 m. Additional stones are piled along the rim of the blister, above a small adjucent shelf along the blister rim. Conidae, Cypraeidae, Neritidae and Thaididae shellfish families were observed in low numbers at the entrance to the overhang.

Feature D, an overhang shelter in a cleared blister, is located 16.4 m southwest (220 degrees Az) of Feature B. The overhang shelters an area 3.2 m wide and 2.5 m deep. Average ceiling height is 0.6 m. A crevice in the shelter floor has been filled with boulders and large waterworn stones, and loose rockfall has been cleared from the collapsed blister.

Portable remains observed include Conidae, Cypraeidae, Thaididae, and Brachidontes sp., all in sparse amounts.

Feature E is a dismantled cairn that is presently scattered over an area 3.4 m in diameter. It has a present height of 1.2 m. A portion of the disturbed scatter may represent the remnants of a small platform. An area 1.7 m long, to the south of the cairn, is relatively level and has a uniform height of 0.3 m. A single piece of coral was observed on the rubble adjacent to the cairn. This feature is 34.5 m southwest (222 degrees Az) of Feature B.

Features F and G are rubble piles that may be dismantled cairns. They are located 34.5 and 33.9 m southwest of Feature B. Stones from Feature F are scattered over an area 1.9 by 1.8 m. A portion of the feature is still intact, indicating an original circular shape with a diameter of 1.1 m. This remnant is constructed from thin pahoehoe slabs stacked five courses high (0.65 m).

Feature G is a small rubble pile on top of a filled crevice. It is 1.6 by 1.8 m at its base and is 0.4 m high. A shallow crevice has been filled with small cobbles, over which have been piled large, chunky pahoehoe boulders. There is no indication of former structure to this pile of stone.

Feature H consists of two adjacent overhang shelters located along the east-facing wall of a collapsed lava tube. The northernmost overhang is 2.2 m wide at the opening, 1.6 m deep, and has a maximum ceiling height of 95 m. The floor of the shelter is rough and sloping, and the east half is covered with roof fall; minimal use is suggested by a few pieces of Cypraeidae shell and coral. The adjacent shelter is 1.46 m wide at the opening, 0.9 m deep, and has a ceiling height of 0.95 m. A few small pieces of weathered coral are scattered outside the entrance and on the roof of this small overhang.

T-62 Platform

This feature is located along an exposed pahoehoe shoreline, on the seaward side of the coral storm beach, in a low area that is exposed to considerable wave action. The northern edge of the platform is still intact; however, all other sides are badly eroded and ill-defined. That feature has an east-west axis of 6.0 m and a north-south axis of 3.5 to 5.5 m. Its original width appears to have been 3.5 m. The present height of the feature varies from 0.15 to 0.25 m. It is constructed of pahoehoe boulders and cobbles and has natural deposit of coral over its surface, which is still relatively level. This platform is located 25.9 m south (170 degrees Az) of Site D15-18, which has been interpreted as a heiau.

T-63 Complex

This site consists of 13 features within an area 95.0 m north-south by 30.0 m east-west (Figure 18). It is located at the coastal/inland interface in an area of relatively flat, broken pahoehoe and is one of five extensive complexes that occur in this interface zone. All of these complexes (T-61, T-63, T-64, T-66, and T-67) include a number of minimally used shelters, small cairns, and rubble piles. Site T-63 includes four cairns, four rubble piles, a cave shelter, an enclosure, two modified outcrops, an alignment, and a rubble pavement.

Feature A is the largest cairn on the site. It is located at the southern end of a loose cluster of five cairns and/or rubble piles. It is roughly circular at its base, with axes of 4.2 and 4.8 m and a height of 1.41 m. It is constructed from loosely piled pahoehoe slabs and has no faced or vertical sides. A portion of the cairn surface is flat; however, the overall shape is mounded. A few pieces of Conidae shell and coral are situated near the cairn.

Feature B, a smaller cairn, is located 8.2 m north (360 degrees Az) of Feature A. It is circular in plan, with base axes of 3.2 and 3.35 m; height is 0.39 m. Construction is very similar to that of Feature A, and the overall form is mounded rather than vertically stacked. No portable remains were observed near this feature.

Feature C is a rubble pile with a central depression possibly created by relic hunters. This feature is located 3.0 m northeast of Feature B and is very similar in overall size and shape. Base axes are 3.3 and 2.7 m; height is 0.38 m. The central depression penetrates to 0.2 m below the top of the feature. A few pieces of waterworn coral are present in the central depression.

Feature D is located 4.0 m east of Feature C. This small rubble pile is scattered over an area 2.2 by 2.0 m and has a maximum height of 0.52 m. The east side of this pile is defined with upright slabs that have a height of 0.42 m. No portable remains occur near this feature.

Feature E is a single layer of small pahoehoe cobbles placed in an area 3.3 m long and 2.4 m wide. There is no indication of a filled crevice beneath this pavement, which is located 9.0 m northwest of Feature B. Small coral fragments and a single piece of Cypraeidae shell are scattered on the paved area.

Feature F is the most substantial structure on the site. It is a small habitation enclosure with a 0.9-m-wide opening in the northern wall. It is rectangular in shape, with squared corners and walls 4.5 by 4.0 m long. The walls are constructed from thin pahoehoe slabs stacked up to eight courses high (0.8 m) and three stones wide, and they are faced on both sides. Average wall width is 0.7 m, and the corners are 1.0 m wide. Interior space within the enclosure is 2.3 by 2.4 m. No midden or portable remains were observed inside or outside this structure. It is located near the center of the complex and is somewhat isolated, with the nearest feature (G) located 12.0 m to the northeast.

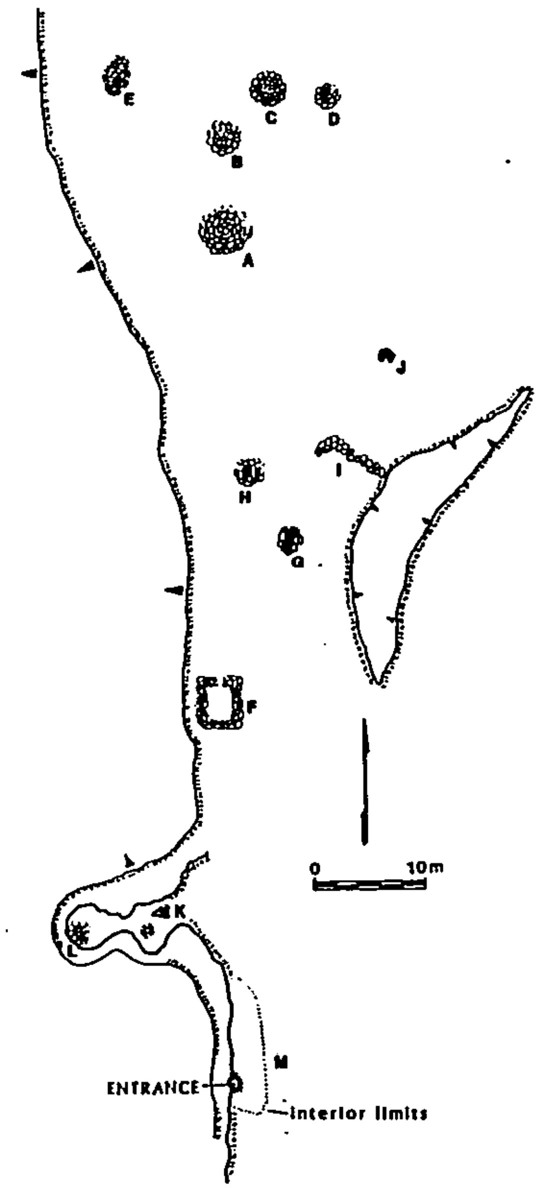

FIGURE 18. Site T-63, Features A-M

Features G, H, I, and J form a second loose cluster, the center of which is 20.0 m south of Feature A. Features G and H are rubble piles spaced 6.0 m apart. Both appear to be dismantled cairns, particularly Feature G, which has remnants of a square shape, 1.1 m on a side. Stones are presently scattered over an area 2.1 by 2.4 m and 0.4 m high. The center of the feature has been excavated, and there is one piece of Cypraeidae shell nearby.

Feature H is a rubble pile that is currently scattered over an area 2.7 by 2.8 m. The original shape appears to have been square, 1.5 m on a side. Maximum height is currently 0.4 m. Features G and H may have functioned as shelter post supports.

Feature I is an L-shaped alignment that incorporates a naturally uplifted pahoehoe shelf. The longest portion of the alignment is oriented northwest-southeast and is 6.0 m long. It curves southward at the western end and continues for 1.3 m. The bedrock portion of the alignment occurs at the curved section and is 0.8 m long. The alignment consists of large, blocky pahoehoe boulders positioned two to three stones wide and a single stone high. No portable remains were observed in the area of the alignment, which is 5.0 m northeast of Feature H.

Feature J, a small modified outcrop, may have functioned as a storage facility. It consists of a small, cleared overhang, with stones piled around the entrance to create a smaller opening. Overall size of the overhang is 1.4 m wide and 0.7 m deep. An artificial opening, 0.40 sq m, was left in the positioned stones, creating a small sheltered area 0.24 m deep, with a ceiling height of 0.47 m. A few pieces of weathered coral were observed near this feature, which is located 7.0 m northeast of Feature I.

Features K, L, and M form the southernmost cluster of the complex. They are located on a prominent extension of the pahoehoe ridge, 20.0 to 30.0 m south of Feature F. Feature K is a cairn and recent memorial shrine. The cairn is in much better condition than are the other features to the north, and it is probably of recent construction. It is constructed from large pahoehoe slabs piled eight courses high, with two pieces of weathered coral positioned on top. The base is roughly circular (1.1 m in diameter), and the cairn is conical in shape.

At the base of the Feature K cairn are two large slabs that lean upright against a fault line, forming a type of backdrop for several pieces of weathered coral and a glass vase with dried flowers (ginger?). The vase is modern, and the condition of the flowers indicates quite recent placement.

Feature L, a large cairn, is located 5.0 m west of Feature K. It is situated on a high uplift, which gives the feature the appearance of being larger than its actual constructed size. The cairn is constructed from stacked pahoehoe slabs and is roughly circular (2.0 by 1.67 m). It incorporates bedrock into the form, so that six courses are stacked on the south side and four courses on the north side to obtain a consistent height of 1.0 m. A well-defined hole is present in the center of the cairn and appears to have been part of the original structure. It is 0.25 m in diameter and 0.7 m deep, and it may be a posthole.

Feature M, a small cave shelter, is located along the west-facing slope of the ridge, 15.0 m south of Feature K. The entrance to the tube cave is oriented to the west and is 1.14 m above the cave floor; it is rather small (0.79 by 0.55 m). The main chamber of the shelter is 6.0 m long, 2.28 m wide, and has a ceiling height of 0.8 m. The tube continues as a crawlspace for a distance of 10.0 m northward from the main chamber. It is accessible, but only with difficulty. Minor modifications occur inside the cave and are confined to rockfall clearing and piling. A pile of rockfall near the entrance appears to have been formed into a circle for use as a hearth; however, there was no concentration of ash or midden within this formation.

Portable remains observed in the shelter include Conidae, Cypraeidae, Neritidae (common) and Thaididae shellfish families; waterworn pebbbles; a few Echinoidea spines; and a modern Pepsi can. This deposit of material represents the most concentrated occurrence on the site; however, it is quite sparse. One crevice directly beneath Feature K may have been artificially filled.

T-64 Complex

This extensive complex is located 10.0 to 20.0 m west of Sites T-20 and T-21. It covers a roughly circular area of 8,100 sq m; however, most of the features form a linear pattern 90.0 m east-west by 40.0 m north-south. Twenty-three features were located and plotted on a site plan map; these include six rubble piles, five cairns, two C-shaped shelters, two cleared blisters, a cave shelter, an overhang shelter, a modified outcrop, two enclosures, a paved area, a filled crevice, and surface midden.

Feature A, a C-shaped shelter, is situated on level, broken pahoehoe at the southern edge of the complex. It is constructed from pahoehoe slabs and medium to small pieces of rubble. The wall has a major east-west axis of 3.5 m, measured from the exterior sides, and a north-south axis of 3.0 m. Interior space is 3.7 sq m (2.0 by 1.85 m), with the opening oriented to the north. Wall height varies from 0.34 to 0.45 m, and width varies from 1.2 to 1.85 m. Shell fragments representing four shellfish families occur in low numbers within the shelter; these include Cypraeidae, Littorinidae, Neritidae and Thaididae. A single waterworn basalt boulder is also present.

Feature B consists of two stone-lined cupboards located 9.6 m northeast of Feature A. These cupboards are adjacent to one another in a low pahoehoe blister and were constructed by stacking pahoehoe slabs in an excavated area 3.6 by 1.5 m, so as to create two, vertical-walled pits. The holes have inside dimensions of 0.8 by 0.67 m and 0.6 by 0.7 m; depths are 0.5 and 0.48 m, respectively. No portable remains were observed in or near these two faced pits.

Feature C is a small overhang and crevice which has been cleared of rockfall to create a depression beneath the overhang. The modified area (1.2 by 0.6 m) is under a rock shelf, which has a ceiling height of 0.65 m. This small compartment may represent another storage feature; it is located c. 25.0 m north of Feature B.

Feature D consists of two adjoining rubble piles of varied sizes; they are located 13.0 m directly north of Feature C. The larger of the two piles is 1.75 by 1.9 m at its base and is 0.67 m high. The smaller pile is 1.0 by 1.1 m at its base and is 0.55 m high. Maximum length of the two piles, which are not distinctively separated, is 2.94 m. The smaller pile has a depressed center, and a portion of the larger pile is defined with an alignment of boulders around the base. These piles may represent shelter post supports. No portable remains were observed in the vicinity.

Feature E, a rubble pile, is located 9.0 m northwest of Feature D. It has a circular plan, with a basal diameter of 3.55 m, and the surface is rounded to a maximum central height of 0.35 m. There is no structure to this haphazard pile of small slabs, and no portable remains were observed in the vicinity.

Feature F, a walled shelter, is located 11.0 m northeast of Feature D. It is situated in a small blister and incorporates the natural blister wall into a low, roughly U-shaped wall. The structure is rectangular, with a major north/south axis of 4.5 m and a minor axis of 4.0 m (from the exterior sides). The walls enclose an interior space of 5.2 sq m (2.76 by 1.9 m). Maximum wall height is currently 0.41 m along the east wall, which is stacked three courses high. The northern wall consists primarily of bedrock, with a few stones stacked at the northwest corner. The south side is open, with the exception of a rubble pile at the southwest corner, which may represent a shelter post support. This pile is 1.82 by 1.9 m at its base and is 0.45 m high.

Portable remains located inside the shelter include sparse amounts of Conidae, Cypriaedae, Neritidae, and Thaididae shell fragments and a few pieces of waterworn coral.

Feature G is a rubble pile located 9.0 m northwest of Feature E. It is one of seven features (D-H, J, and K) which together form a distinct ring, 20.0 m in diameter. These features are relatively evenly spaced about the ring, with distances ranging from 8.0 to 15.0 m apart. Most, and possibly all, of the features represent small temporary shelters. Feature G is a circular pile of pahoehoe slabs with a depressed center. Basal diameter is 3.3 m, and maximum height is 0.5 m. A single piece of weathered coral was observed near this pile.

Feature H, a C-shaped rubble pile, is located 8.0 m northeast of Feature G. It is 2.5 m long and 2.0 m wide, with a maximum height of 0.4 m. The pile may represent a collapsed, walled structure. Conidae, Cypraeidae, Neritidae, and Thaididae shellfish fragments are sparsely scattered adjacent to the rubble pile, in addition to a single piece of weathered coral.

Feature I, an irregularly shaped rock pavement, is defined by aligned cobbles that are slightly larger than the paving stones. The paving has a maximum length of 2.4 m and a maximum width of 2.0 m. Two large boulders are located on the paved area near its center. These boulders are uniformly sized (0.42 by 0.23 m and 0.45 by 0.25 m). The pavement is a single layer of stone, and there is no indication that a crevice or low area was filled.

Feature J, a modified collapsed blister, is located 8.0 m northeast of Feature H. It consists of a cleared blister, walled along the northeastern perimeter, and an adjoining rubble pile. The collapsed blister opening is 4.6 by 1.0 m and is walled along the northeastern perimeter for a distance of 2.2 m. The wall continues westward for a distance of 3.4 m and forms a small rubble pile with a central depression that has axes of 0.7 by 0.45 m. Overall dimensions of the rubble pile are 3.2 by 1.6 m. The wall is of stacked pahoehoe slabs and has an average width of 0.45 m; height varies from 0.4 to 0.25 m. Adjacent to the rubble pile on the west is a long (18.0 m), narrow crevice that is partially filled with loose rubble. This crevice is oriented north-south and extends to within 2.4 m of Feature H.

Portable remains observed around the walled blister include Conidae, Cypraeidae, and Neritidae shell fragments, in addition to coral cobbles.

Feature K, a circular rubble pile, is located 8.0 m southeast of Feature J. The mound has a north-south axis of 4.8 m and an east-west axis of 4.3 m. Height varies from 0.53 m at the west side to 0.33 m at the east side. A semicircular alignment of large slabs is located in the west side of the mound, the ends of which are defined by large, waterworn boulders. Two slab-faced holes are present in the top of the mound; the largest is at the south end and is 0.53 m deep. A single, large Thaididae shell and a single piece of weathered coral were observed on the rubble mound.

Feature L consists of two cairns located 5.0 m apart on a slight rise 23.0 m east of Feature K. The easternmost cairn is a simple stack of three pahoehoe slabs with a piece of weathered coral on top. It is 0.47 by 0.53 m at its base and is 0.36 m high. The westernmost cairn is a simple stack of three slabs, 0.53 by 0.63 m at the base and 0.29 m high. These features are probably more recent than are most of the other features within the complex.

Feature M, a modified outcrop shelter, is located 10.0 m southeast of Feature L. It consists of a small collapsed tube wall from which loose rockfall has been cleared to form five, small, protected depressions beneath an overhang. The removed stones were piled in front of the depressions, forming what appear to be storage areas. The depressions are of relatively uniform size; the smallest is 0.5 wide, 1.5 m long, and 0.5 m deep, and the largest is 0.9 m square and 0.6 m deep. Three of the depressions have weathered coral inside, and one has weathered and unweathered coral. The fifth depression has no portable remains.

Feature N is a deposit of surface midden and jumbled cobbles that may represent a disturbed pavement. It is located 10.0 m northwest of Feature J. The scatter covers an area of 12.0 sq m (3.0 by 4.0 m) and includes a moderate amount of Cypraeidae, Neritidae, and Thaididae shells, in addition to coral pieces and small, waterworn basalt cobbles and pebbles. Stones occur as one to two layers, with no well-defined perimeters.

Feature O, a cave shelter, is located 25.0 m northeast of Feature M. The cave shows minimal modification, limited to a single loosely stacked wall along the south side of the entrance. The entrance is a sloping passageway, 1.6 m long and 0.58 m wide, and 0.72 m high at the dripline. The main chamber of the cave has an area of 10.5 sq m (3.0 by 3.5 m) and is generally devoid of portable material. A second entranceway connects the main cave chamber with a lava tube that extends c. 20.0 m to the east. This internal passage is only 0.4 m high, and it does not appear that the tube was utilized. All portable remains were located along the passageway into the cave and are limited to a single Conidae shell fragment and a single Cypraeidae shell fragment.

Feature P, a cairn, is located at the western edge of the site, 20.0 m northwest of Feature H. It is oval in plan, with basal axes of 2.1 and 1.45 m; current height is 0.45 m. It is constructed from stacked pahoehoe slabs, and a single piece of weathered coral is on the cairn.

Feature Q, a cleared pahoehoe blister, is located 11.5 m northeast of Feature P. The blister is 10.3 m long and 6.4 m wide. It has two sections of varied depth (1.0 to 0.5 m), including a low, cleared area at the west end and a raised section on collapsed stone to the east. Small pieces of rubble have been piled at the eastern end of the blister, and additional small stones mixed with shell midden are scattered on the rock shelf. Shellfish families represented are Cypraeidae, Neritidae, and Thaididae. Also present are small, waterworn pebbles and pieces of coral.

Feature R is located 6.0 m southwest of Feature P. It consists of an oval enclosure, a low rubble mound, and two small cairns. The enclosure wall is constructed from loose rubble piled 0.62 m high, with no vertical facing. The wall is 2.2 m wide and encloses an area 9.8 m east-west by 8.2 m north-south. An opening 1.4 m wide occurs at the southeast end of the enclosure. Two cairns within 1.0 m of one another are located in the center of the enclosure. The easternmost cairn is constructed of pahoehoe slabs stacked four courses high (0.39 m). It is oval in plan, with base axes of 0.66 by 0.54 m. The adjacent cairn is of similar construction, but is stacked only two courses high (0.34 m). It is also oval in plan, with basal axes of 0.61 by 0.83 m.

A linear rubble pile is located along the north side of the enclosure opening and extends eastward away from the enclosure. It is 4.0 m long, 1.5 m wide, and 0.32 m high. The west end of the mound adjoins the enclosure wall.

Shellfish remains observed within the enclosure include Chamidae, Conidae, Cypraeidae, Neritidae, and Thaididae. Weathered coral is also present in small amounts.

In summary, a minimum of seven temporary shelters was located at Site T-64. Nearly all of these shelters were constructed from loose pahoehoe slabs; only one is a cave shelter. All shelters have sparse surface scatters of shell midden and weathered coral. The coral pieces are consistently small and are of insufficient quantities to indicate that they were used for paving material. Likewise, their patterning does not suggest association with shrines or ceremonial features within the complex. It is possible that the coral was being transported to other locales (i.e., Sites T-20 and T-31) along a corridor that passed through this complex.

Site T-65 Wall Remnants

This site is located on a coral beach, adjacent to the coastal jeep road and in an area heavily modified by recreational vehicles. It consists of a partially buried alignment of large, waterworn boulders, a portion of which has been altered to form a C-shaped hearth area. The exposed alignment is c. 5.0 m long and appears to have a parallel alignment that would define a core-filled wall. It is unlikely that enough of this feature remains intact to determine its form and function. The area immediately surrounding the remnants has been used as a parking loop and is eroded to well below the basal depth of the alignment.

Site T-66 Complex

This site consists of five features which include three walled shelters, three cairns, and three rubble piles. It is located c. 45.0 m west of Site T-64, in an area of weathered and relatively level pahoehoe.

Feature A is a substantial C-shaped wall that opens to the southwest (250 degrees Az). The sides of the structure are 2.3 and 1.5 m wide, and the front wall (opposite the opening) is 1.9 m wide. Overall length measured from the exterior sides of the walls is 4.9 m; overall width is 3.0 to 3.5 m. Wall height varies from 0.32 to 0.43 m. The interior area of the wall is quite small in relation to the width of the walls, suggesting that the superstructure floor was positioned on top of the foundation, rather than inside. The wall covers an area of 15.7 sq m; however, the open area inside the C-shape is only 1.4 sq m (1.1 by 1.3 m).

No subsistence material was observed in or near the structure; however, seven pieces of branch coral, a large waterworn boulder, and pieces of weathered coral were observed inside. The structure is partially collapsed, and some stones are strewn about.

Feature B consists of three small, conical cairns located within a 4.0 sq m area. These cairns are very similar in construction and were

probably erected at the same time. Base dimensions vary from 0.52 by 0.42 m to 0.72 by 0.76 m; heights vary from 0.25 to 0.60 m. The cairns are constructed from pahoehoe slabs stacked four to seven courses high. Two pieces of coral are associated with them.

Feature C, a small, walled depression, is located 26.7 m south of Feature A and 5.0 m southwest of Feature B. It is constructed from thin pahoehoe slabs that outline a circular area 1.7 by 1.8 m (Figure 19). The slabs are loosely stacked, with the upper two courses vertically staggered so as to leave small gaps in the wall. The wall has a maximum height of 0.5 m above the interior floor, and it is 0.3 m wide. The interior surface of the depression is covered with stone, and it slopes gradually down from the base of the wall. The overall structure is quite fragile and is smaller than most habitation shelters. No portable remains were located in or around this feature.

Feature D, a U-shaped wall, is located 12.5 m southeast of Feature C. It is open to the north, and the exterior of the south wall is faced with slabs stacked to eight courses high. Maximum width of the wall is 2.6 m (to exterior sides of wall), and maximum length is 2.9 m. The interior area is 0.9 m wide and 1.46 m long. The base of the floor is indeterminate due to wall slumpage into the center; current wall height from the existing interior surface is 0.9 m. This structure appears to have been a substantial shelter at one time. No portable remains were observed in or around the structure.

Feature E is a cluster of three rubble piles located from 20.0 to 24.0 m southwest of Feature C. The piles are all of varied sizes, but are constructed from haphazardly deposited loose cobbles and boulders. They are immediately adjacent to a cleared, smooth pahoehoe surface, and they may represent clearing piles. The smallest pile is 1.0 by 1.3 m at the base and is 0.18 m high; the largest is 4.4 by 2.5 m at the base and is 0.5 m high. The third pile is 2.9 by 1.6 m at the base and is 0.33 m high.

Surface midden is scattered on the cleared bedrock in the immediate vicinity. Shellfish families represented include Cypraeidae, Neritidae, Conidae, Spondylidae, and Thaididae. Sparse weathered coral and a waterworn cobble are also present.

T-67 Complex

This extensive complex is located along the west face of a high lava flow ridge that consists of rough pahoehoe and patches of aa. Its southern edge is 61.0 m north of Site T-64, and it is within the coastal inland interface zone.

The complex consists of 17 features, including three caves, five cairns, a walled shelter, two modified overhangs, an alignment, and five pahoehoe excavations (Figure 20).

Figure 19. SITE T-66, FEATURE C. View to southwest.
(PHRI Neg.493-9)

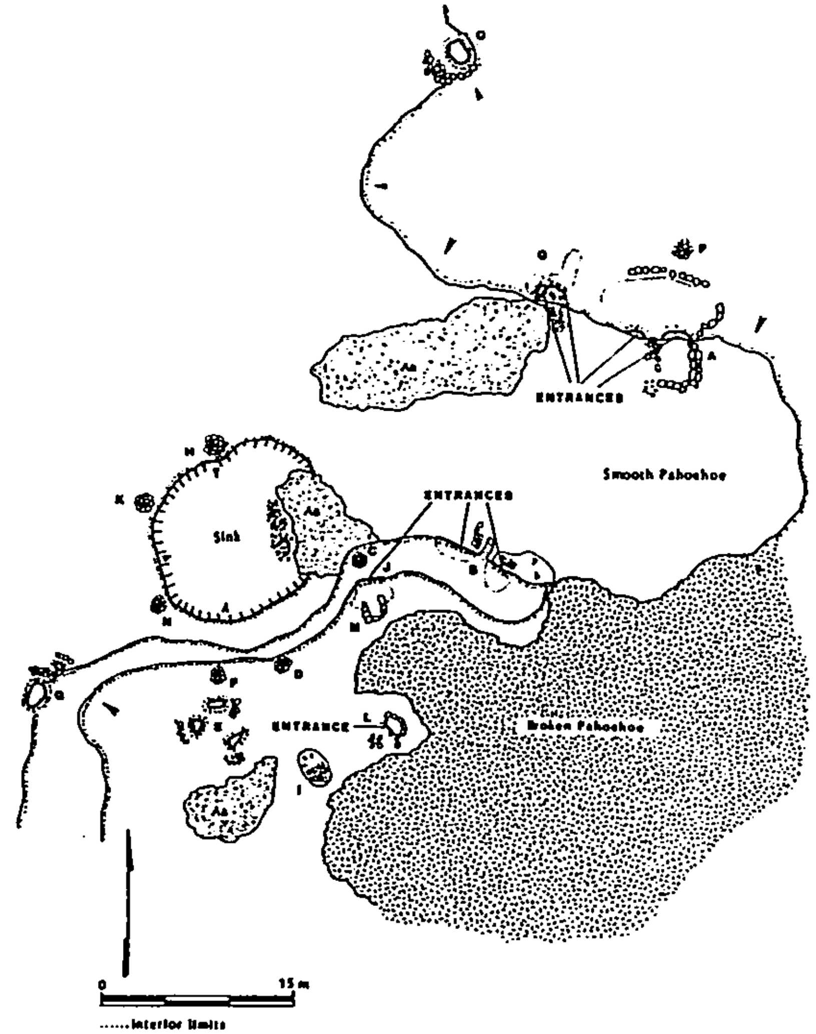

FIGURE 20. Site T-67, Features A-Q

Feature A, a modified cave shelter, is located in smooth pahoehoe at the head of a minor ravine at the northeastern edge of the site. The cave has two south-facing entrances that are separated by a 2.0-m-long rubble wall that has been stacked beneath the dripline. The cave has a maximum width of 6.10 m and is 3.5 m deep. Ceiling height averages 1.35 m. The cave floor is relatively level and is covered with a deposit of midden and organic soil to a depth of 5.0 cm.

The area immediately outside the eastern entrance is roughly enclosed by a slab wall. The wall abuts the dripline immediately east of the entrance and extends south for 3.3 m; it is 1.3 m wide and 0.95 m high. An east-west wall forms a corner at the south end and extends west for 1.75 m. This wall is 0.66 m wide and 0.40 m high. The western portion of this partial enclosure is 2.0 m long and does not continue to the dripline. It is in poor condition and is presently only 0.20 m high. The area inside the enclosure has been cleared of all surface rubble, and shell fragments are scattered about.

Two alignments of boulders are located on the cave roof, upslope from the entrances. The major alignment is 3.5 m from the dripline and is 7.0 m long; it is linear in shape. A second alignment curves to the west and is oriented north-south from the dripline at the eastern side of the entrance.

This cave, which is the most intensively occupied shelter within the complex, contains a wide variety of portable remains. Shellfish families represented include Chamidae, Cypraeidae, Isognomonidae, Neritidae, Patellidae, and Thaididae. Artifacts observed include Echinoidea spine abraders, a Patellidae scraper, coral abraders, and bamboo. Kukui nut shell, Echinoidea and coral fragments are also present. No materials were collected at the time of survey, since the deposit warrants a complete and systematic excavation.

Feature B, a small cave shelter, is located directly across the ravine from Feature A, 23.0 m to the south. The entrance faces north (20 degrees Az) and is 1.2 m wide and measures 0.75 m high at the dripline. The cave has a maximum depth of 2.1 m; however, habitable space averages 1.75 m deep. About half of the floor space in the cave has been cleared of rockfall, some of which was used to erect a 1.2 m-long-wall just outside the dripline. The wall is 0.40 to 0.60 m high on the interior side and is 0.2 m high on the exterior side. It is two to three stones wide and two to three courses high.

No portable remains are present inside the cave, and a single Patellidae shell was observed outside the entrance to the west.

Feature C, a large cairn, is situated on a prominent upthrust along the ridge slope, 11.6 m west of Feature B. It is constructed from large blocky boulders that are stacked in a conical form, incorporating portions of the naturally occurring bedrock. The cairn measures 1.1 by 1.1 m at the base and is 0.9 m high. It appears much higher from the north and west sides, due to its positioning, and it is not visible from the south. The lava escarpment drops 4.0 m vertically at this point along the ridge.

Feature D is a rubble pile that may actually be a dismantled cairn. It is located on a smooth pahoehoe flat, 9.0 m southwest and upslope of Feature C. It is presently a circular, jumbled pile of loose stones, 1.2 m in diameter at the base and 0.5 m high.

Feature E, an area of pahoehoe excavations, is located along a gradual north-facing slope of the ridge crest. Three excavations occur within an area of 9.0 sq m. The southernmost excavation has a maximum length of 1.55 m and a maximum width of 0.79 m. The pahoehoe is 0.31 m thick at this point, and the base of the excavation is flat, with a depth of 0.4 m. The eastern excavation is quite small (0.52 by 0.27 m by 0.5 m deep), and the pahoehoe is 0.34 m thick. The western excavation is 0.75 by 0.71 m and is 0.4 m deep. The interior is littered with small, broken pieces of pahoehoe, and larger chunks are scattered about the opening. The edges of this and the other excavations exhibit battered surfaces which apparently resulted from efforts to break off chunks of pahoehoe.

A large, basalt hammerstone (25.0 cm long, 17.0 cm wide) was observed immediately adjacent to the western excavation. This tool had been slightly modified in order to form a somewhat beveled striking surface (12.0 cm wide and 6.0 cm thick) that had been extensively battered. A smaller basalt hammerstone was located inside the excavation, 0.32 m from the larger artifact. This tool is 10.5 cm long, 8.0 cm wide and 3.3 cm thick. The margins are battered, but not to the extent exhibited on the larger stone. No other portable remains were located near these excavations.

Feature F, a cairn, is located adjacent to the northernmost excavation of Feature E. It is similar in form and materials to Feature D, which is 5.0 m to the east. This cairn is 1.2 by 1.3 m at the base and is 0.45 m high.

Feature G, a small, walled shelter, is located at the foot of a ridge slope, 13.4 m west of Feature F. It is in an area of broken pahoehoe blisters and is constructed in a crevice at the bottom of a collapsed blister. The modified portion of the crevice is 1.44 m long, 0.95 m wide, and 1.0 m deep. This area had been cleared of loose rockfall, which was stacked across the lowest (east) end of the area, separating it from the rest of the crevice. The stacked stones form a wall 2.2 m long, 0.5 m wide, and 0.3 m high (two to three courses). A very shallow overhang (0.6 m deep and 1.0 m wide) occurs along the west side of the shelter. No portable remains were observed within the modified area or within the larger collapsed blister.

Feature H, a cairn, is situated along the rim of a deep, collapsed blister at the foot of a steep lava ridge. It is located c. 5.0 to 6.0 m lower in elevation and 14.0 m northwest of Feature C (cairn). The cairn is constructed from chunky pahoehoe blocks stacked four to five courses high (0.7 m). It is roughly oval in plan, with base axes of 1.65 and 1.4 m. This feature is partially disturbed, but appears to be in generally fair preservation.

Feature I, a rubble-filled depression, is located near the upper crest of a ridge 8.5 m south of Feature D. It consists of a small depression that is defined by a low, stacked wall across a narrow ravine. The depression is partially filled with small pieces of pahoehoe and has a sloping surface. It is 1.5 by 1.73 m at its opening and is 0.8 m deep. The rubble fill is scattered with several pieces of branch coral, some of which is unweathered. No other portable remains are in the depression. This feature may represent a small shrine.

Feature J, a small cave shelter, is located along the slope of a lava ridge, 1.5 m south of Feature C (cairn). It is accessed through a small entrance that is 1.07 m wide, but only 0.36 m high. The 4.5 sq m chamber is all crawlspace, with a ceiling height of less than 0.4 m. The cave apparently functioned as a storage facility. Two pieces of modified wood and three bamboo pole sections were located inside. The wooden items appear to be broken sections of a circular post measuring 7.0 cm in diameter. Both pieces exhibit drilled holes, which did not appear to have been machine-drilled. These items were not collected at the time of survey.

Feature K, a small cairn, is located along the rim of a deep collapsed blister, 6.0 m west of Feature H. This cairn is collapsed and is scattered over an area 1.1 by 0.8 m; its present height is 0.3 m.

Feature L is a rockfall-filled overhang that has been modified to form a small cupboard. It is located in the same rock formation, 5.0 m east of Feature I, and is somewhat similar in construction. The overhang area is 2.55 m long and 0.5 m deep. A small, nearly square chamber was excavated into the loose rockfall under the overhang to create a vertical hole, 0.4 by 0.59 m at the opening and 0.6 m deep. Two large, flat slabs are adjacent to the opening and may have been utilized as a covering for the pit. One large piece of coral is located inside the overhang; no portable remains are inside the cupboard.

Feature M, a rectangular alignment of stones, is located 1.8 m south of Feature J. Flat pahoehoe slabs and blocky chunks have been used to form a 1.6 by 1.1 m alignment. A section of the western side is stacked with two courses; all other sides are a single course of stone. No portable remains are in the vicinity of this feature, which is directly over the back of the Feature J cave chamber.

Feature N, a pahoehoe clearing with an adjacent rubble pile, is located along the rim of a deep collapsed blister at the foot of a lava ridge. It is 7.5 m southwest of Feature K and is 11.0 m northwest of Feature D. The clearing is an area (1.0 by 0.6 m) from which loose rockfall was removed to a depth of 0.5 m and was stacked to form a cairn-like rubble pile. The pile of stones is 0.7 by 0.8 m at the base and is 0.3 m high (two courses of stone). The cleared area has no further modifications, and no portable remains are located in the immediate vicinity.

Feature O, a pahoehoe clearing, is located at the northernmost edge of the site, 38.0 m north of Feature C (cairn). It is situated in a disturbed area of pahoehoe at the foot of the lava ridge. The clearing was formed by removing loose rockfall slabs from an area 0.9 m long and 0.65 wide, to a maximum depth of 0.80 m. A small, natural overhang was exposed in the clearing, and removed stones were aligned along the south side of the opening. No portable remains were located in the feature, which possibly functioned for storage.

Feature P, a cairn, is located 6.5 m north of the eastern entrance to Feature A. It is situated on the lower slope of a smooth pahoehoe ridge. The cairn is constructed from upright slabs that were leaned against one another to form a 1.07 m high conical mound. The base of the cairn is 1.25 by 1.07 m.

Feature Q consists of two very small overhangs that have been cleared of rockfall. They are located in a pocket on the lower slope of a pahoehoe ridge, adjacent to a high as deposit. The removed rockfall has been stacked in front of the dripline of the overhangs, creating compartments that are partially sheltered by the overhangs. The overhang ceiling of the larger compartment is 0.7 m high; the chamber is 1.2 m deep and 0.75 m wide and has an inaccessible tube extension to the north.

The second compartment is 1.1 m west of the larger compartment and has been excavated down, as well as having been cleared. It is 0.58 m wide and 0.85 m deep and has a ceiling height of 0.4 m. The floor is 1.1 m below the surface at dripline. Removed stones are piled 0.3 m out from the dripline. No portable remains were observed in these compartments, which appear to be storage facilities.

In summary, this complex differs from the Site T-63 and T-64 complexes in that it consists of proportionately fewer habitation features. Only one feature (A) and possibly a second (G) are of sufficient size for human occupation. The majority of the features appear to represent storage facilities.

<u>T-68</u> <u>Modified Blister</u>

This site is located near the northern boundary of the project area, 24.0 m northwest of Site T-67. It is in the coastal zone, in an area of flat, weathered pahoehoe which has a collapsed blister. The modified blister is 5.0 m long and 0.95 m wide, with a partially collapsed roof and a variable depth floor. The northern, deepest half of the blister has been modified by stacking large slabs along the northern rim and by constructing a slab wall across the center to define a roughly circular chamber, 1.2 by 1.1 m and 1.2 m deep. The remainder of the blister floor is 0.4 to 0.8 m deep.

The constructed wall is relatively jumbled and is unfaced. It is currently three to four courses high. A low overhang occurs along the east wall of the circular chamber; it is 0.75 m deep and 0.75 m wide.

No portable remains were located in or around the feature, and a function could not be determined.

T-69 Complex

This site is located in the coastal zone, 30.5 m east of the coral storm beach and c. 12.0 m south of the northern project area boundary. It consists of two walled shelters, a cairn, and an alignment with associated surface rubble. It is situated in a very level, flat pahoehoe area which has few collapsed bubbles. The ground surface in this area is below the level of the coral beach berm.

Feature A, a walled shelter, is constructed in a naturally rectangular sinkhole with an opening that is 5.0 m long (east-west) and 4.2 m wide. Loose rockfall was removed from the sinkhole and was placed around the opening in a crude wall formation which averages 0.35 m high. A more substantial wall, constructed from large blocks, was placed along the southeast side of the sink, which has the lowest surface. Floor depth from the top of this faced wall is 0.75 m. The interior floor is partially covered with a layer of small rubble; the remaining area is covered with beach sand which is probably a natural deposit. No portable artifacts were observed in the area.

Feature B, a small sinkhole, is located 5.0 m southeast (120 degrees Az) of Feature A. This 3.4 m-long-hole is divided into two compartments by an alignment of large pahoehoe chunks. The alignment is 0.3 m high and 1.1 m long. The largest compartment is on the north side of the wall and has a major axis of 2.23 m; minor axis is 1.81 m. The smaller compartment is 1.57 by 1.31 m. Both sides are an average of 0.5 m deep. A second wall of stacked pahoehoe chunks (0.6 m high) has been constructed around the northern opening edge. This wall is 2.1 m long and appears to have been recently built, so that the northern compartment could be used as a lua. Modern tissue paper is scattered on the surface of the northern compartment, which also contains a sparse deposit of shell midden.

Shellfish families present in the northern compartment include Cypraeidae, Littorinidae, Neritidae, and Thaididae. Nerita picea shells are most common; less than 30 of these are present.

Feature C is a small beehive-shaped cairn located 7.1 m northeast of Feature A. It is oval in plan, with basal axes of 0.8 by 1.1 m, and is 0.7 m high.

Feature D is a formation of stone alignments and surface rubble paving located 13.4 m southeast of Feature A. The alignments consist of medium-sized pahoehoe chunks, and they outline a roughly rectangular area that is 26.4 m long and 6.4 m wide. Major axis is oriented 150 degrees Az. Within this area is a semicircular alignment outlining an oval area which has a major axis of 8.2 m. The pahoehoe bedrock within this formation is totally clear of rubble, and portions of the alignments follow shallow cracks in the bedrock surface.

Two areas of rubble paving occur outside and adjacent to the alignment formation. The largest of these is 7.5 m long and 3.0 m wide and is oriented 160 degrees Az. A smaller area of paving is located on the east

side of the alignments; these two deposits consist of fist-sized cobbles and may actually represent concentrations of surface stones that were pushed out of the alignment interior. No portable remains occur on the surface, within the alignment formation or on the rubble paving.

Feature E, a small cairn, is located 5.9 m east of Feature A. It is constructed from eight chunky pahoehoe stones stacked 0.43 m high. The cairn is 0.8 by 0.52 m at the base and it appears to be a recent construction.

Features F and G are rubble piles located 23.8 and 41.8 m east of Feature A. Feature F is 1.83 by 2.13 m at the base and is 0.7 m high. Feature G, 3.2 by 2.9 m at the base, is 0.24 m high. These piles appear to have had no former structure.

The location of this site correlates well with Reinecke's Site 74, which was described as a "Shelter about a shallow cave; remains of another shelter; an ahu" (1930:16). Reinecke's features appear to correspond with Features A, B, and C, described above.

T-70 Complex

This small shelter complex was located while searching for Site T-45. It is 25.0 m northeast of Site T-45 and consists of two C-shaped shelters and a cairn. Feature A is a C-shaped wall that opens to the west. Major axis is 3.5 m, and minor axis is 1.8 m. Wall thickness averages 0.5 m, and height ranges from 0.25 to 0.35 m. It is constructed from piled pahoehoe slabs that are relatively jumbled and unfaced.

Feature B, a similarly constructed C-shaped wall, is 2.8 m north-south by 2.0 m east-west. This shelter opens to the west and has a wall width of 0.5 m. Wall height ranges from 0.15 to 0.30 m. Both shelters are collapsed, and no portable remains were observed in the vicinity.

Feature C is a cairn located at the southwest corner of Feature B. It is constructed of piled pahoehoe slabs and is circular in plan, with a base diameter of 0.6 m. Height of the cairn is 0.3 m.

This site is interpreted as a temporary habitation locale and was tagged PHRI-4 during field work.

T-71 Footpath

This footpath section was located in the inland area during the search for Site T-6. It is 75.0 m southwest (245 degrees Az) of Site T-6 and consists of a 12.0-m-long alignment of pahoehoe slabs arranged as steppingstones. The path is oriented east-west (80 degrees Az) and crosses an area of rough, broken pahoehoe. The path could not be traced beyond the ends of the slab alignment. This site was tagged PHRI-5 during field work.

T-72 Rubble Pile

This newly located inland site is situated on a relatively level pahoehoe flat, south of a major aa flow. It is a linear pile of pahoehoe slabs, situated adjacent to a small sinkhole. The pile is 3.0 m long (east-west) and 1.0 m wide; it has a height of 0.3 m. The adjacent sinkhole is 3.5 m long and 2.0 m wide. It does not appear to have been cleared or modified. No portable remains were present in the sinkhole or near the rubble pile. This site was tagged PHRI-6 during field work.

T-73 Cairns

These two cairns were newly located in the inland area while searching for Site T-28. They are located 8.0 m apart on broken pahoehoe, 24.0 m northwest (210 degrees Az) of Site T-28. The easternmost cairn is oval in plan (1.9 by 1.1 m at the base) and is constructed from loose slabs piled three courses high (0.3 m).

Feature B is similarly constructed and is oval to linear in plan (2.8 by 1.2 at the base). It is four courses (0.45 m) high and is in relatively poor preservation. No portable remains or other associated features were observed in the vicinity of these cairns, which were tagged PHRI-7 during field work.

SITE DESCRIPTIONS—BISHOP MUSEUM SITES

50-Ha-D15-1 Complex

This site is part of a complex first recorded by Reinecke as Site 68 and later recorded by Martin in 1971 as Site 50-10-27-1910. Eight features were located by Martin, two of which were later differentiated as Site D15-2 by Cordy. The reason for breaking up this complex is unclear, since the distance between features at Sites D15-1 and D15-2 is no greater than the distance between the two features of Site D15-2. It is clear that an accurate plan map of the entire area must be completed before meaningful boundaries (if any) can be drawn between the two sites.

Site D15-1 is located at the west-central edge of a broad aa flow that extends to the coral beach. The features are situated along the west-facing slope of the flow and are 2.0 to 5.0 m above the coral beach. The entire site area has been exposed to storm wash.

Feature designations used here correspond with those assigned on the state inventory form. Features A through D correspond with Features 1 through 4, as shown on Cordy's plan map of the site (1986a:15).

Feature A is a large, nearly square (9.0 by 10.0 m) coral pavement that is subdivided into two levels. The upper level is at the southern end of the pavement and is 2.9 m wide; it is defined by an eroded retain-

ing wall and is a maximum of 0.2 m above the rest of the paving. The northeast corner of the pavement has been faced in order to maintain a leveled surface, and small patches of bedrock are exposed in areas. A small, raised platform is present in the southwest corner.

Two linear rubble mounds extend out from the northwestern corner of the pavement. These mounds are situated between the platform and a prominent rock outcrop; they are 2.5 m long, 1.0 m wide, and 0.04 to 0.5 m high. The western mound is constructed from small aa cobbles and has a relatively flat surface. The eastern mound is constructed from larger aa boulders, but is also platform-like in form. Both mounds have morphological characteristics of burials.

A rubble mound is also located at the southeast corner of the pavement; this feature is more amorphous than the two linear mounds and may represent a clearing pile. A disturbed waterworn boulder is located at the northeast corner; this stone was apparently upright at the time of Cordy's survey. A second waterworn boulder is located on one of the linear mounds.

A single, 1.0-m-sq test unit was excavated by Cordy in the northeast quarter of the pavement. No artifacts or volcanic glass specimens for dating were recovered from this unit (Cordy 1981:242, 248). Cordy interpreted the feature as a men's house, on the basis of size and on the presence of coral, which indicated to him a ceremonial function.

Feature B is a walled shelter that incorporates a 1.55-m-high upthrust of bedrock (Figure 21). Two nearly straight walls have been constructed on the north side of the bedrock to form a roughly U-shaped shelter. The west wall is 2.4 m long and 0.9 m wide. It is double-faced and is core-filled to a maximum height of 1.0 m. The east wall is 2.2 m long and 0.8 to 1.0 m wide. It is faced on the interior and exterior sides and is stacked three to five stones wide, rather than being core filled. This wall has a maximum height of 1.10 m (six courses of stone). The deposit inside this small shelter (c. 2.5 sq m) is extremely rich in subsistence remains, charcoal, and lithic debris, and the floor appears to have been paved with small beach pebbles (<u>'ili'ili</u>).

This feature was interpreted as a special-purpose house and was designated as Site D15-1-3 by Cordy. A 1.0-m-sq test unit was excavated along the inside of the west wall. Two volcanic glass specimens collected from this unit were dated, along with four additional specimens collected from the surface of the feature. Four of the dates cluster within a range of AD 1550 to 1721. Two surface specimens are comparatively early (AD 1485-1611) or late (AD 1708-1832). Cordy reports no artifacts collected from this feature; however, there is no question that a quantity of midden would have been collected from the excavation unit.

Feature C, a three-sided, C-shaped wall, is constructed from rough pahoehoe and aa slabs interspersed with waterworn basalt stones. Cordy designated this structure as Site D15-1-2. The wall opens to the west and is aligned with a steppingstone path that leads westward for a distance of

Figure 21. SITE 50-Ha-D15-1, FEATURE B. View to south.
(PHRI Neg.493-9)

c. 6.0 m. The interior sides of the walls are nicely faced and are stacked three to four courses high (0.7 m). The exterior sides slope outward from top to base; width at the top is 0.7 m and at the bottom is 0.9 m. A bedrock outcrop occurs at the southeast corner of the structure, behind which is a filled crevice and a small cupboard-like excavation.

The deposit inside this structure is similar in composition to that in Feature B; however, it is less dense and contains considerably less wood charcoal. A test unit was excavated by Cordy along the interior side of the north wall. Eight hydration rind dates were determined from material collected from the test unit. These dates range from AD 1485 to 1746 and are within the date range indicated for Feature B. A ninth date was determined from a surface-collected flake; this date is near the center of the range indicated above (Cordy 1981:248). No artifacts were recovered from this excavation; the feature was interpreted as a sleeping house by Cordy.

Feature D is a platform constructed on a narrow projection of lava. It is nearly level with ground surface on the south side and is 0.6 m high on the north side. The general shape is rectangular (5.0 by 4.0 m), and the surface consists of chunky pahoehoe boulders without smaller paving stones. A small depression occurs in the center of the platform, and a small, low-walled, C-shaped structure occurs immediately to the south. Cordy excavated a test unit at the southern edge of the platform where it was extremely shallow. No datable volcanic glass specimens or artifacts were recovered.

Feature E, a walled shelter, is located 11.0 m northeast of Feature C, and they are connected by a well-worn footpath (Feature E). It consists of two naturally uprighted lava slabs which form the roof for a sheltered area. The shelter measures 1.3 m wide and 0.8 m deep, with a ceiling height of 0.9 m. The area inside the overhang is cleared and leveled and is surrounded by a wall. The wall, which incorporates naturally occurring bedrock, encloses an area 2.89 m wide and 1.9 m deep, in front of the rock shelter. It is 0.9 m high and is roughly faced on the interior side. The exterior side slopes outward from top to bottom; there is a central opening in the wall. Shellfish remains are scattered inside the shelter.

Feature F is a walled shelter similar in form and construction to Feature E; however, it is somewhat smaller, and the surrounding wall has no entranceway. This feature is located along the path that connects Features C and E.

This site has been determined to be significant as a site type example (Cordy 1986a), and it may also be significant as a ceremonial/burial locale.

<u>50-Ha-D15-2 Complex</u>

As noted above, this site was designated by Reinecke and Martin as a component of a single complex which included Site D15-1. It consists of three major features and a steppingstone footpath that connects Features A and B. The site is located northeast of Site D15-1, on a west-facing slope of the rough pahoehoe and aa flow. A plan map of the site is given by Cordy (1986a:18).

Feature A, an enclosure, is situated along the lower slope, immediately east of an anchialine seep. It is 8.0 m long and 7.1 m wide, with the long axis oriented northwest-southeast. The walls are constructed from aa and rough pahoehoe slabs that are well stacked and faced on two sides. Wall height varies from 1.0 to 1.9 m, and thickness varies from 0.7 to 0.9 m.

Three small, low, pebble and weathered coral platforms are located inside the enclosure. The longest of these platforms is located in the northeast corner and extends along the west wall of the enclosure. It is 4.7 m long, 1.6 m wide and 0.2 m high. A second platform is located at the northwest corner; it is 3.0 m long, 2.1 m wide and 0.2 m high. The third platform is along the center of the south wall; it is 3.7 m long, 2.1 m wide and 0.2 m high. These platforms do not have faced sides.

A smaller, L-shaped wall section extends south from the southeast corner of the enclosure. This wall is 0.4 m thick and 0.5 m high. It is not as well constructed as the main enclosure wall and consists of piled aa boulders. The long axis is 3.2 m, and the shorter, east-west section is 2.3 m long. A small wall remnant is present, parallel to the long wall, suggesting that this feature may have been a small, adjoining enclosure. Adjacent to the east wall at the southeast corner of the main enclosure is a concentration of weathered coral and cobbles.

This feature was designated as Site D15-2-1 by Cordy and was interpreted as a special-purpose house. A test unit was excavated just off the long platform within the enclosure. A single volcanic glass specimen was dated from this feature, obtained from a surface provenience identified as Square 2. Only one square is shown on Cordy's map, and it is not labeled, so the location of the dated specimen is uncertain. The date obtained ranges from AD 1547 to 1661, with a mean of 1604. A number of shellfish varieties were observed within the enclosure, as well as Echinoidea fragments.

Feature B is located c. 35.0 m east and upslope from Feature A. It is a rectangular enclosure measuring 5.5 m long and 4.5 m wide, with a small opening at the northwest corner. The walls are well-faced on the interior and exterior sides and are constructed from aa and rough pahoehoe slabs. They are 0.7 m wide and range in height from 1.0 to 1.2 m. The interior and exterior areas immediately west of the wall are paved with weathered coral pebbles. The exterior pavement extends 4.0 m west from the wall and averages 4.7 m long. No artifacts were visible in the area; however, four shellfish families are represented in the surface scatter.

Feature B was interpreted by Cordy as a sleeping house and was designated D15-2-2. Two test units were excavated; one inside the structure at the southwest corner and another outside in the coral pavement. No

volcanic glass specimens were dated, so apparently none was recovered. Three artifacts were recovered from inside the enclosure: a piece of metal wire (near surface), a coral abrader, and a bone fishhook (Cordy 1981: 242).

Feature C is a steppingstone path that connects Features A and B. The path is best defined at the western end, where slabs and waterworn basalt boulders are in place for a distance of 10.0 m from Feature B. The remainder of its distance is defined primarily by coral cobbles. Its exact location in relation to Feature A is uncertain.

Feature D is a walled shelter located 20.3 m southeast (120 degrees Az) of Feature B. It consists of a shallow overhang (2.3 m wide and 1.2 m deep) that is partially enclosed by two short walls. The southern wall extends up to the dripline of the overhang, increasing the sheltered area to 3.3 by 2.5 m. This wall is 2.0 m long and 0.8 m high. The opposite wall is 1.2 m long; both walls are 0.3 to 0.5 m wide. A sparse scatter of shellfish remains was observed on the surface inside the shelter. Chamidae, Cypraeidae, Neritidae, and Thaididae families are present. No artifacts were observed.

50-Ha-D15-3 Complex

This site is part of a complex designated by Reinecke as Site 69; it included a large cattle pen (D14-16) and a platform to the north (D14-17), in addition to the "Remains of two old platforms and an ahu to the north" (1930:15). It was later designated as Site 50-10-27-1912, following Martin's 1971 DLNR survey. Martin identified four features at the site, including a faint platform on the seaward side of the jeep road. His map indicates that the jeep road was perhaps further east at the time of his survey than at the time of Cordy's survey in 1975. Cordy identified five features in addition to the cairn (ahu). This latter feature was designated Site T-33 by Barrera, who apparently did not see any of the adjacent structures at the time of his survey. Cordy's plan map of the site (1986a:21) conforms relatively well with features observed; however, feature edges are generally less distinct than is indicated on the map.

Feature designations A through C follow those originally assigned by Martin. The location of Martin's Feature D is uncertain, and it may have been destroyed, especially if the jeep road moved westward.

Feature A is a low enclosure with a west-facing entrance at the southwest corner. The enclosed area is rectangular (6.8 by 5.4 m), with the major axis oriented northwest-southeast. The walls are in very poor preservation and are collapsed at the northwest corner. Wall height varies from 0.2 to 0.3 m. Waterworn basalt boulders were used in construction of the wall, and the interior area is covered with coral pebbles and sand, which is probably a natural deposit. Beneath this layer is a very rocky deposit which may extend to a maximum depth of 0.2 m. A few scattered shellfish remains were observed among the fill stones.

Feature A was designated D15-3-1 by Cordy, who interpreted it as a sleeping house. He excavated a test unit immediately inside the west wall, near the entrance. Five volcanic glass specimens were dated from this unit, all of which were recovered from "surface fill" (Cordy 1981: 248). The date ranges are within a relatively tight cluster ranging from AD 1559 to 1729. Means range from AD 1606 to 1662.

Feature B, a large rock mound, is located 6.2 m southwest (240 degrees Az) of Feature A. It is roughly square in plan, with basal dimensions of 2.2 by 2.6 m. It is faced on all sides, with three to four courses (0.6 to 0.8 m) still intact. Jumbled stones are piled on top of the faced portion, to a maximum height of 1.10 m. The feature has a waterworn basalt boulder base, and a coral concretion boulder is incorporated into the structure. Barrera describes this feature (T-33) as a stone mound, "possibly a grave" (1985:38).

Feature C, a very low terrace (4.4 by 5.0 m), is located 11.4 m southeast (115 degrees Az) of Feature B. Two sides of the structure are along a sloping ground surface and are 0.5 to 0.4 m high. The western side is nearly even with the ground surface, with a maximum height of 0.15 m. The raised sides of the terrace are not faced, and stones are dispersed along the slopes on the north and east sides. The terrace surface is a rough fill of boulders and cobbles with coral pebbles (possibly natural deposit). A small area (0.8 by 0.6 m) in the center of the terrace is outlined with waterworn and rough boulders. This depression is interpreted by Cordy and Martin as a firepit or hearth.

Cordy excavated a test unit adjacent to the hearth, on the west side. No dates were determined for this feature. Cordy designated it Site D15-3-2 and interpreted the feature as a sleeping house.

Feature D is a very poorly preserved terrace or platform, located 3.3 m northwest (330 degrees Az) of Feature B. It consists of a somewhat amorphous and dispersed arrangement of basalt cobbles, with a major axis of 5.2 m and a minor axis of 3.7 m. The northwest and southwest sides are slightly raised; however, no side walls or facing are present. Surface concentrations of basalt boulders occur along three sides and probably represent collapsed sides.

This feature was designated as Site D15-3-4 by Cordy, who excavated a test unit along the southwest wall. A single, dated, volcanic glass specimen was reported by Cordy; it yielded a range of AD 1601 to 1705 (mean AD 1653).

Feature E is a filled and leveled crevice with a very poorly defined semicircular alignment adjoining to the west. The filled area is terraced, primarily by naturally occurring bedrock, to form two levels. The upper level is 2.8 m long and 2.6 m wide; the lower level is 2.8 m long and 2.0 m wide. The alignment adjoins the upper level at the north and southwestern corners. It is roughly D-shaped (3.0 by 2.0 m), and the south side is indistinct to nonexistent.

Feature E was subdivided into two distinct features (D15-3-3 and -5) by Cordy, who suggested they represent two special-purpose structures. A test unit was excavated inside the alignment, at the southeast corner. Two volcanic glass specimens were dated, and their determinations (AD 1703±61 and AD 1719±28) are later than the dates determined from Feature A; however, the ranges from both features overlap.

50-Ha-D15-4 Complex

This site is part of a complex originally defined by Reinecke as Site 71; it included Cordy's Site D15-8, as well as features located between the two sites that were not included in Site D15-4 or in Site D15-8. It is described as follows:

> A knob partly walled on its slopes, with a house site. Adjoining it on the south is a rough platform with three smooth boulders—heiau and kuula? (Site D15-4). Back of this is a house platform (D15-8) and a platform about a fine shelter cave (between D15-4 and 8). Another platform and wall are about a slight natural depression filled with bones, including those of a whale (D15-4) (Reinecke 1930:16).

Martin's 1971 DLNR survey included this site as only part of a larger complex (50-10-27-1914), which included all the cave shelters located to the east of Site D15-8. Martin identified three major cave shelters, "a large number of burials," and platforms. He indicates that the Site 1914 complex is mauka of Reinecke's Site 71, so it is uncertain whether he included the main platforms from Site D15-4 in this complex. Unfortunately, a sketch map was not compiled, so it is impossible to correlate features. Cordy's plan map of the site (1986a:22) shows only two features and does not indicate that other features are present.

Efforts were made to accurately plot the numerous features of this complex and to determine if site boundaries could be found. A somewhat arbitrary boundary between Sites D15-4 and D15-8 was established between a cave and a small burial platform spaced 25.2 m apart. Thirteen features are identified here as part of Site D15-4 (Figure 22).

Features A through E are shown on Cordy's plan map of the site. They include a rectangular platform (Feature A) adjacent to a walled depression that may represent a collapsed well (Feature D); a larger platform with four, upright waterworn boulders at its east end (Feature B); and a small, square platform (Feature C) adjacent to Feature B. These features are situated at the western edge of a prominent lava ridge that is comprised of aa and with very rough pahoehoe. A 2.0 to 4.0 m drop occurs immediately west of these features; the upper portions of this dropoff are faced, and crevices along the slope are filled with rubble. The area surrounding Features A and D is paved with small aa cobbles.

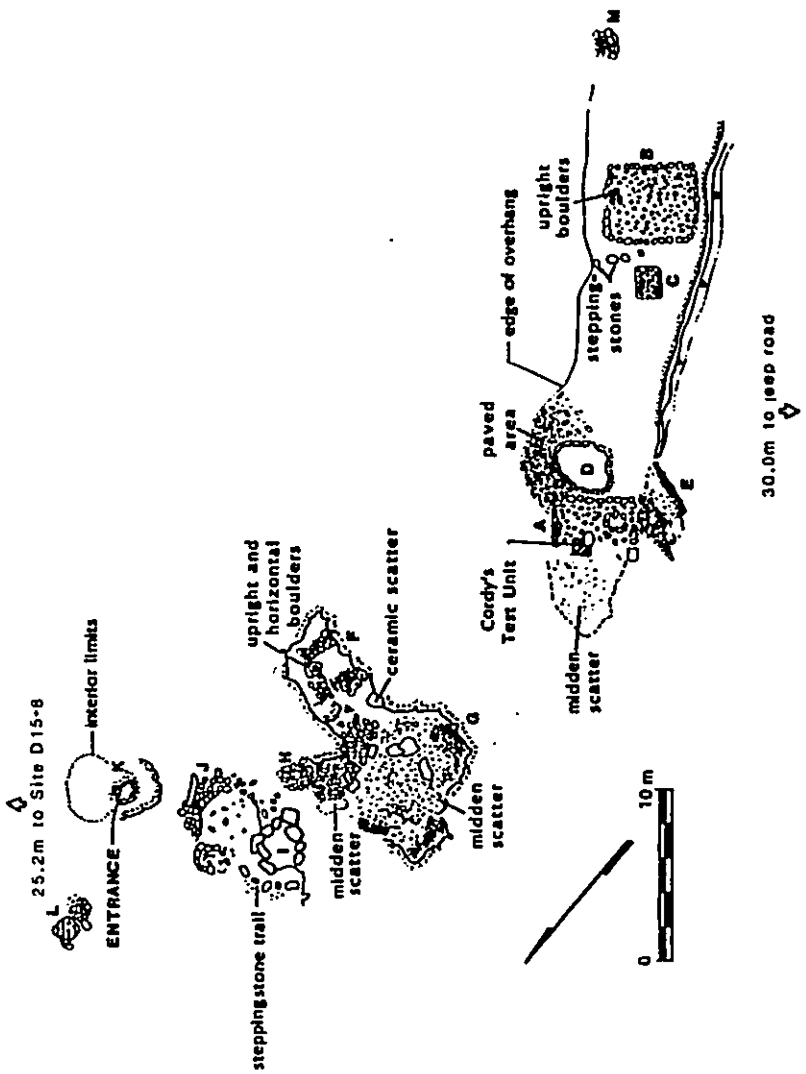

FIGURE 22. Site 50-Ha-D15-4, Features A-M

Feature F is located 14.0 m north of Feature A. It is a well-preserved shrine constructed within a small, protected section of a collapsed blister. Two faced walls enclose a rectangular area, 4.0 m long and 3.0 m wide, in which are located three waterworn boulders (upright, horizontal, and smaller rounded).

Adjacent to Feature F to the west is a large sinkhole surrounded by a rubble pavement. This sinkhole (Feature G) contains a large amount of midden and a more recent (?) deposit of Patellidae shells. Midden scatter continues northward from the sinkhole to a paved area (Feature H), 4.0 m long and 2.5 m wide. To the north of the paved area is a small enclosure (Feature I, 3.0 by 3.0 m). A steppingstone path adjacent to Feature I on the northwest side connects this enclosure with a larger enclosure (Feature J) that opens to the west. This structure is roughly circular (3.6 m in diameter) and has walls faced on the interior side.

Feature K is located 3.5 m northeast of Feature J. It is a cave shelter with a small, vertical entrance. A stacked wall is located just below the entrance, along the north side. The main chamber has an area of 18.8 sq m (3.3 by 5.7 m); ceiling height averages 1.06 m. Weathered coral, historic glass sherds, and Cypraeidae shell are present in the cave.

Feature L is 7.5 m northeast of the cave and consists of a nearly square excavation in loose rockfall, measuring 1.2 by 1.2 m at the opening and 0.8 m deep.

Feature M, a cairn, is located 7.0 m southwest of Feature B. This cairn is circular in plan, with a base diameter of 1.6 m and a maximum height of 1.0 m. It is situated on the top of a small overhang formation that is c. 1.5 m wide at the opening and has a ceiling height of 0.75 m.

Feature A was designated Site D15-4-1 by Cordy and was interpreted as a sleeping house. He excavated a test unit at the northern edge of the platform and apparently recovered no datable materials. A volcanic glass specimen was collected from surface midden 1.0 m northwest of the feature and was dated to AD 1783±38 (range of AD 1742-1821). No other test units were excavated in Feature B, which was interpreted as a men's house variant.

50-Ha-D15-5 Complex

This site was originally recorded by Reinecke as Site 72, "Ruins of a pen" (1930:16). It may have been identified by Martin as a feature of Site 1916, which was recorded as an extensive complex of over 25 features. Martin identified an enclosure makai of the jeep road in the vicinity of Site D15-7. Unfortunately, the complex identified as Site 1916 was not mapped, and no tie-in distances were recorded.

Cordy identified four enclosure segments within the overall enclosure, in addition to an earlier wall base and a possible platform. His plan map is given in the field check report (1986a:24). Two building phases are suggested by Cordy. Six hydration rind age determinations, from depths of 8.0 to 23.0 cm below surface and associated with the earlier building stage, range from AD 1430 to 1720. They were recovered by Cordy from a unit located along the interior east wall of Enclosure 1. The earliest date determined from the entire project area (AD 1523±96) was collected from the shallowest context (8-18 cm); three additional determinations from this provenience cluster within the same time span.

No additional work was conducted at the site during this recent study, since the structural remains observed correlated with the map compiled by Cordy in 1975. No additional features were located.

Site D15-5 is the only site west of the coastal jeep road that has been dated. It is perhaps significant that this site has produced more age determination means that predate AD 1550 than any other site in the project area. There were apparently a number of habitation sites close to the current shoreline, indicated now by badly eroded wall bases and mounds of remnants, some of which were described in 1930 by Reinecke as house platforms. It is therefore possible that the earlier habitation sites were generally located closer to the present shoreline than were the later prehistoric and historic house sites. The acquisition of dating materials from features at Sites T-48 and T-62 may help in determining if this hypothesis is feasible.

50-Ha-D15-6 Platform

This site was recorded by Cordy as a single feature. It is located 20.0 m northeast of Site D15-19, but it was not mentioned by Reinecke, who described D15-19 as Site 73. It may be included as one of several house platforms within the Site 1916 complex; however specific platform descriptions are not given by Martin on the inventory form.

The platform is constructed of leveled pahoehoe slabs that are roughly piled, with unfaced sides. It is rectangular in plan (6.0 by 3.0 m) and is raised 0.25 m above ground surface. An area of surface paving (Feature B) is located directly north of the platform, and a low rubble wall (Feature D) is located nearby. Surface midden is scattered continuously from this platform to Site D15-19.

Cordy excavated a single test unit at the eastern edge of the platform. Two volcanic glass specimens were recovered and dated; both dates are within a time span of AD 1542 to 1646, with means of AD 1581 and 1594 (Cordy 1981:248). The feature was interpreted as a sleeping house.

50-Ha-D15-7 Complex

Cordy suggests that this site was originally recorded by Reinecke as Site 75, which is described as follows:

> Trace of site; house platform; enclosure on shore. There are many faint traces of sites on this strip of coast. Toward the north is an unmistakable small site (Reinecke 1930:16).

Reinecke marks three locations on his site map for Site 75; the southernmost mark corresponds with the location of Site D15-7, which correlates with the "trace of site" description. The two other locations are on and north of the Ooma II boundary.

Martin apparently included this site as part of his Site 1916 complex. Barrera recorded the two major features of this site as two different sites, T-37 and T-38. His site identification flagging tape was located on these features, so there is no question that this correlation is accurate. Barrera's Site T-37 correlates with Cordy's Feature 1 (Feature A here); and Barrera's Site T-38 correlates with Cordy's Feature 2 (Feature B here). No additional features were identified by Barrera.

Cordy identified three features and two areas of surface scatter during his study of the site. These include two rectangular platforms and a small, square platform. Six additional features were identified and mapped during this study, and they are briefly described here (Figure 23).

Feature A is the largest platform on the site. It is shown by Cordy as a rectangular structure (designated D15-7-1); however, at the time of our study, the structure was more amorphous in shape. The exterior walls were somewhat scattered, and large perimeter boulders had been thrown into the center of the feature. It has a maximum length of 7.0 m (east-west) and a width of 4.5 m; average height is 0.3 to 0.35 m. A possible hearth area occurs near the center; it is a small, rectangular depression defined by partially buried upright slabs. The platform surface pavement appears to be intact at the southeast corner only; it consists of small, waterworn pebble and coral fill over larger pieces of pahoehoe. Shellfish remains are scattered between the stones of the platform fill, and an unusually dense shellfish, fish bone, and kukui nut shell deposit was observed in Cordy's excavation unit.

Cordy recovered several artifacts from his test unit, which was located at the south edge of the platform. These items include a polished basalt fragment, an unknown number of Echinoides spine abraders, an unknown number of square nails, and the point of a two-piece fishhook (Cordy 1981:242).

Three volcanic glass specimens recovered from Feature A fill were submitted by Cordy for age determination. The ranges of these dates span a broad period from AD 1489 to 1779. The standard deviation for the earliest date (AD 1575±86) does not overlap with the ranges for the two later dates, which have means of AD 1736 and 1740.

Two additional specimens for dating were collected from surface midden scatters near Feature A. The means of these dates are AD 1597 and 1705, which correlate well with the two clusters from platform fill.

Feature B is a smaller, better-preserved platform located 3.8 m northeast of Feature A. Its major axis (6.0 m) is oriented north-south; the minor axis is 3.8 m. It is constructed of coral and cobble paving over

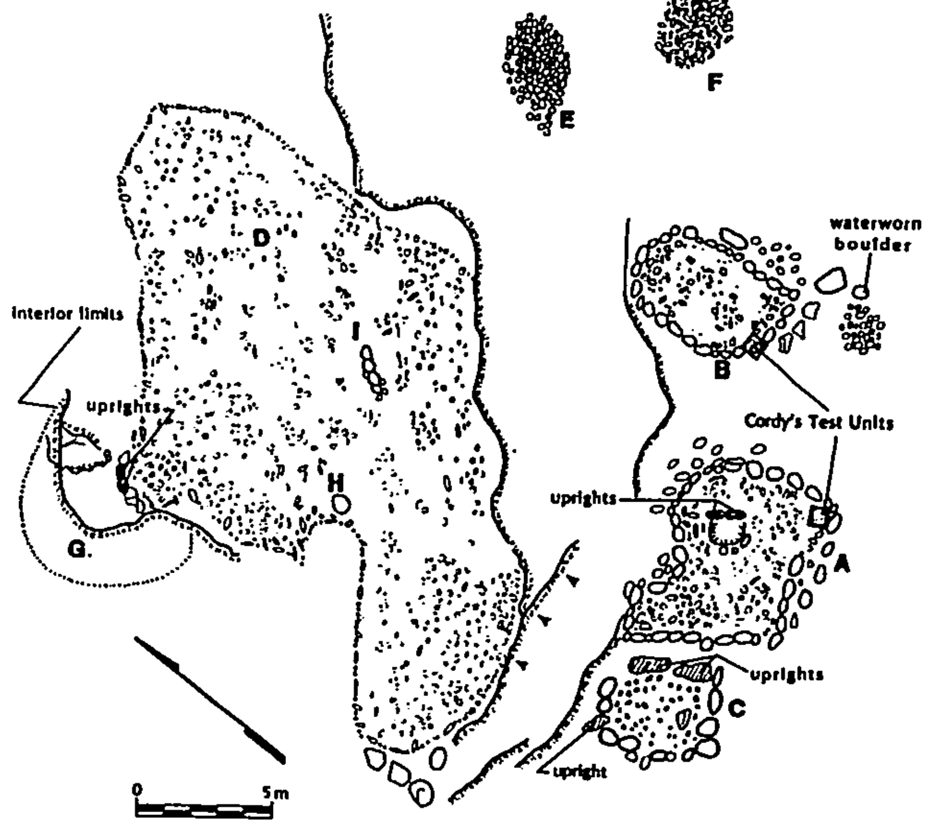

FIGURE 23. Site 50-Ha-D15-7, Features A-I

pahoehoe slabs and is outlined with larger boulders. A waterworn basalt boulder is near the southeast corner of the platform, and other large stones are scattered on the surface to the east.

Feature C, a small, round-to-square platform, is located 0.4 m west of Feature A. This platform is filled and paved in a manner similar to the larger platforms, except the perimeter stones include three uprights. It has an average height of 0.35 m (Figure 24).

Feature D, a large, amorphous area of surface rubble pavement, is located 3.6 m north of Feature A. It consists of what is generally a single layer of small, broken pieces of pahoehoe, with additional fill added in low areas. The pavement has an overall length of 25.4 m and a variable width of 5.0 to 14.0 m. Half of the eastern perimeter is defined by exposed bedrock, and the western perimeter is defined by the wall of Feature G (Figure 23). The northern perimeter is somewhat indistinct and appears to have been disturbed. Shellfish remains are scattered through the rubble of this feature.

A well-defined concentration of coral (Feature H) is located within the paved area, near the western edge. This concentration is circular, with a diameter of c. 0.6 m. Its depth was not determined; however, it appears to be more substantial than a shallow surface deposit.

A short, linear alignment (Feature I) is also present within the paved area. This alignment is oriented northeast-southwest and is 2.8 m long. It consists of a series of large boulders, with a few smaller stones located between.

Features E and F are deposits of rubble, located 6.0 m apart from center to center and 6.0 m east of Feature B. Feature E is a rubble mound, roughly oval in shape (4.0 by 2.4 m), with a maximum height of 0.4 m. Stones in the pile are very similar in size to those used in the paving. A basalt hammerstone fragment was located east of and adjacent to this pile.

Feature F is a shallow rubble deposit that may represent a pavement. It is 3.6 m long (east-west) and 2.8 m wide. The perimeter of this deposit extends to within 3.0 m of the Feature E rubble mound.

Feature G is a walled shelter constructed in a shallow, collapsed blister. It is located 20.0 m north of Feature A and includes a shallow overhang, a faced retaining wall, and a filled, leveled area. The overhang is located at the western end of the small blister and opens to the east. It is 4.8 m wide at dripline, 2.04 m deep, and has a ceiling height of 0.62 m at dripline. Ceiling height averages 0.26 m. The blister opening is elliptical, with a major axis of 4.8 m. The floor is irregular, and the eastern half has been filled to the east side of a 0.30 to 0.54 m high retaining wall. This wall is constructed with upright pahoehoe slabs. The filled area is level with the adjoining rubble pavement (Feature D).

Figure 24. SITE 50-Ha-D15-7, FEATURE C. View to northeast.
(PHRI Neg.493-11)

A midden and soil deposit at least 5.0 cm thick occurs in this shelter. A number of shellfish families were observed, including Chamidae, Conidae, Cypraeidae, Littorinidae, Neritidae, Patellidae, and Thaididae. Nerita picea predominates in the deposit, and the Patellidae shells observed were the large species, Cellana talcosa.

The available dating information indicates two relatively well-defined clusters of means. Two dates have means of AD 1575 and 1597; three dates have means of AD 1705, 1736, and 1740. There is very little overlap of standard deviations. On the basis of these two date clusters, Cordy indicates that Site D15-7 was continuously occupied from AD 1450 to 1780 (Cordy 1981:167). An alternative interpretation of the dates would suggest that two distinct occupation periods are indicated; these are separated by a period of site non-use between c. 1630 and 1680 (minimally).

50-Ha-D15-8 Complex

As discussed above, this complex was included as part of Reinecke's Site 71 and Martin's Site 50-10-27-1914. It was recorded by Cordy as two platforms with adjacent midden scatters and cave features. The site was subsequently identified by Barrera as Site T-18, which he describes as a complex of about 10 to 12 features.

As described here, Site D15-8 consists of 13 features (Figure 25). Feature A is a rectangular platform and correlates with Cordy's D15-8-1. This platform is raised 0.7 to 1.0 m above ground surface and is 5.8 by 4.0 m in plan. Cordy excavated a test unit at the northeast corner of the platform and recovered two volcanic glass specimens for dating. The dates range from AD 1480 to 1594, with means of AD 1525 and 1542. Additional dated specimens were recovered from midden scatter proveniences that are not specified, but that may have occurred just off the northeast corner of the platform. These dates diverge from the platform fill dates and range from AD 1534 to 1857, with means of AD 1614, 1627, and 1825 (Cordy 1981:249).

Feature B, a smaller, square platform with an adjacent enclosure, is located less than 1.0 m west of Feature A. It was designated D15-8-2 by Cordy, who collected dating specimens from an adjacent surface midden deposit. Two dates were determined; they have a broad range of AD 1585 to 1832. Means are 1640 and 1769, with no overlap of standard deviations (Cordy 1981:249).

Feature C, a modified and paved depression, is located 8.0 m south of Feature A. It is 7.4 m long and 4.8 m wide, and it covers the northern half of a shallow collapse in rough pahoehoe. Adjacent and to the west of this feature are two small cupboards, a walled depression, and surface midden (Figure 25). Immediately to the southwest is a second shallow collapse, with a cave at the southern end (Feature D). A cairn, which may actually be a collapsed rock mound, is located 3.0 m south of the cave entrance. This feature is circular in plan at the base (1.5 m in diameter) and is 0.3 to 0.4 m high. Stones have been displaced from the feature and are scattered about its base.

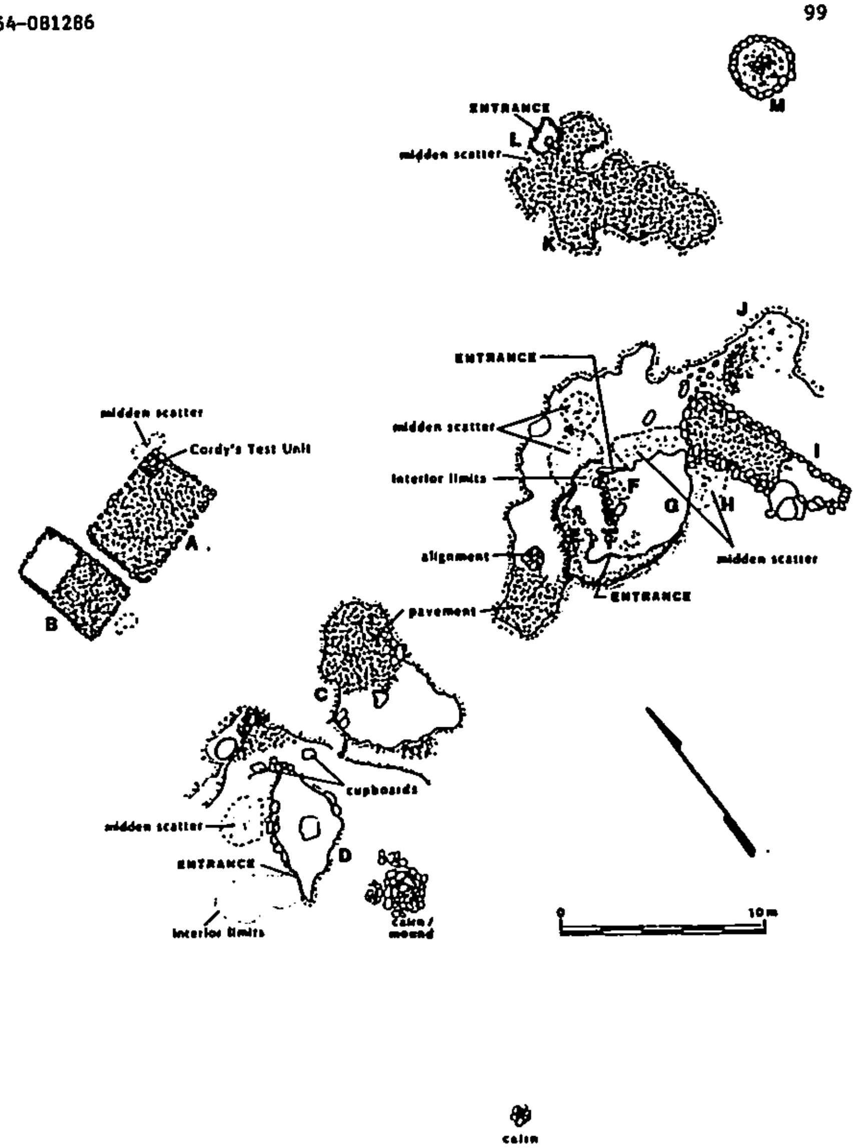

FIGURE 25. Site 50-He-D15-8, Features A-M

Features E through J all occur in a large depression along the base of a minor pahoehoe pressure ridge. The western edge of this depression is 5.0 m northeast of Feature C. Feature E is a terrace located along the western edge of the depression, just outside the entrance to a small, shallow cave. Immediately to the east is a 3.0 m long, stacked wall (Feature F) which spans a sinkhole and partially encloses the entrances to two caves. The southern rim of the sinkhole (Feature G) is defined with a low, stacked wall, and surface midden is scattered around the perimeter of the sink (Feature H). At least two caves are accessed around the edges of the sinkhole; these features were not extensively examined at the time of survey.

Feature I, a long, narrow platform (9.0 by 3.0 m), is situated at the eastern edge of the modified sinkhole. The northern portion of the platform has been filled with loose rubble in order to level the surface with a bedrock surface that is exposed at the southern end. It is defined with larger pahoehoe slabs and boulders. Surface midden and rubble paving occur adjacent to the platform to the east and west. A rubble-filled depression (Feature J) occurs immediately northeast of the platform's northeast corner.

Feature K, a large, paved depression, is located 5.0 m north of Feature J. It is amorphous in shape and has been filled to an indeterminate depth. Maximum length is 8.8 m, and maximum width is 6.0 m. At the northern end of the depression is a small cave (Feature L) with a vertical entrance.

Feature M is a small, circular platform with a slightly mounded surface. This feature is 6.0 m east of Feature K and is 25.2 m from a cave feature at Site D15-4. The platform is outlined with large slabs and boulders and is filled with smaller, rough lava rocks. It is 3.0 m in diameter and varies in height from 1.8 to 0.5 m. This feature has morphological characteristics of a burial.

Surface midden and cave deposits are extensive and rich on this site and represent a significant information source.

Hydration rind dates determined from Site D15-8 exhibit the greatest time span among the nine, dated sites for Ooma II (AD 1480-1857). Cordy infers a continuous occupation of this site for the entire period bracketed by hydration date ranges; however, at least two separate occupation periods are suggested by the dates, with a possible abandonment period around AD 1680-1720. Additional work at this site should focus on dating specific features and on identifying possible functional variations that may reflect temporal change in site use. As indicated in the discussion of Site D15-4, these features are not significantly separate from the Site D15-4 complex and were recorded by Reinecke and by Martin as part of the same complex.

50-Ha-D15-16 High-walled Enclosure

This feature was originally recorded as part of Reinecke's Site 69, and was later included as a component of Martin's Site 1911. It was recorded as a separate site by Cordy and later was given another number by Barrera (T-32). It consists of a rectangular wall that encloses an area 30.3 m long and 12.7 m wide. The wall is constructed from waterworn basalt and pahoehoe boulders, with inclusions of coral concretions and limestone boulders. It is double faced with boulder fill and currently stands eight to nine courses high (2.20 m maximum height). Average wall thickness is 1.20 m. Sections of the wall have collapsed, particularly along the west side. The interior surface of the enclosure is covered with storm wash, and no use-related deposit is observable. The enclosure was interpreted by Reinecke as a cattle pen and by Martin as "perhaps for goats." It exhibits no features of a habitation enclosure.

Cordy recorded this site, but did not conduct excavations, due to the nature of the site, which he defines as a historic animal pen (Cordy 1986b:29).

50-Ha-D15-17 Platform

This single feature was first recorded by Reinecke as part of Site 69, and it may have been included in Martin's later designation of Site 1911. It was recorded by Cordy, but was apparently not tested, since no site map or age determination results were included in his discussions of Ooma II sites (Cordy 1981, 1986a). Correlation of a specific platform with Site D15-17 in the field was entirely dependent upon Cordy's site distribution map, which indicates that D15-17 is immediately north of D15-16 (Cordy 1986a:10). The location shown by Cordy correlates with the location of Barrera's Site T-34.

This platform is 12.7 m northeast (29 degrees Az) of the west corner of the Site D15-16 enclosure. It is roughly rectangular in plan, with a length of 11.5 m and width of 7.0 m; major axis is oriented northeast-southwest. Height of the platform varies from 0.7 to 0.9 m. It is constructed from large, waterworn basalt boulders and pahoehoe slabs, with inclusions of weathered coral and limestone cobbles and boulders. Three of the sides are faced, with three to four courses of stone. The southwest side is extremely disturbed, and it is difficult to determine the exact location of the edge. This disturbance may account for differences in length between that reported here and that reported by Barrera, which was "about" 20.0 m (1985:39).

Platform fill consists of large boulders, cobbles, and weathered coral; the surface is roughly level. A sparse scatter of shellfish remains, kukui nut shell, branch coral, and recent glass and aluminum beverage containers occurs on the platform surface.

50-Ha-D15-18 Complex

This site was first designated as Site 70 by Reinecke, who described it as follows:

> Walled platform, S.E. corner terraced, badly broken down. Platform auka (mauka). The walls of this and of Site 73 are built of thin plates of surface lava, rather unusual in appearance (Reinecke 1930:15).

Reinecke's description of the building material refers to the fact that waterworn basalt boulders were not used in the construction of the main platform; rather, the building stones are flat-surfaced pieces of rather porous pahoehoe, similar in shape to sections removed from pahoehoe excavations at Sites T-55 and T-56.

Martin, who located the main platform and identified it as a heiau, recorded this site as 50-10-27-1913. He also located three, associated platforms to the east. Cordy recorded the heiau only and does not indicate additional platforms. This is surprising, since he was specifically looking for platforms of this type during his survey, and Martin described them as "house platforms." Barrera did not record the major feature, since it was located west of the coastal jeep road. He did record the largest platform to the west as Site T-35. This feature is described as containing a slab-lined central firepit, which Martin also identified in the largest associated platform.

Four features were identified as part of this complex during the PHRI investigation. These features are spatially patterned, as shown on Martin's site plan map, and include the main heiau (Feature A) in addition to three platforms of variable sizes. The platforms are currently located directly across the jeep road, 22.0 m west of the heiau. The largest platform (Feature B) is visible on the project area aerial photograph, as is the heiau. Features C and D are located south of Feature B.

Feature A, a large rectangular, walled platform, is situated on a pahoehoe bedrock finger which is elevated above the adjacent coral beach. This location has undoubtedly contributed to the preservation of the site, which is unusually good for a high, walled structure so close to the shoreline.

Overall length of the structure is 19.5 m, and overall width is 15.25 m. The walls are double-faced and core-filled along the west side. The platform has been filled up to within 0.5 to 0.7 m of the top of the wall. Fill material is pahoehoe and aa rubble, with weathered basalt and coral pebbles used as paving material. Larger coral cobbles also occur on the platform surface. Two smaller platforms occur along the north and eastern walls of the platform; these are raised 0.4 m above the surface.

Feature B is nearly square, with a length of 5.5 m and a width of 5.0 m. It is defined by a perimeter of large boulders and is filled with variable-sized rubble. The surface is leveled, waterworn pebbles and coral. The feature is storm-washed, and it is difficult to determine whether the coral deposit is totally natural. A rectangular, slab-lined depression occurs in the center of the plaform; it is 0.53 m long and 0.34 m wide. The depression has been partially filled with beach wash, and it is impossible to determine actual depth without excavation.

Features C and D are smaller in size, but are constructed with techniques and materials similar to those used for Feature A. Feature D is located 10.0 m southwest of Feature C. It is square in plan (2.6 by 2.6 m) and is outlined with large boulders and filled with small pieces of pahoehoe. This feature has morphological characteristics of a burial monument.

50-Ha-D15-19 Complex

This large, walled platform was originally recorded by Reinecke, who identified the feature as a "modern" house site (Figure 26). His description is as follows:

> Site 73. Apparently a modern dwelling site of unusual construction: two terraces of pebbles, the upper 29x25x2 in front and 4-5' high elsewhere; the lower 19+10x25x3, with a three-sided pen at N.E.; surrounded by a carefully laid wall (Reinecke 1930:16).

The site was later recorded by Martin as 50-10-27-1915; he also interpreted it as a historic habitation that had been "incorrectly identified on the U.S.G.S. Quad map as a heiau" (HRHP Archaeological form, Site 1915). Martin located ceramics, iron fragments, and bottle glass dating between AD 1850 and 1910, and a wide range of subsistence materials. Martin describes the structure as being "Very carefully built; unusual architecture." He also makes the following observation: "Probably represents fairly late and modified Hawaiian but with really very little European flavor" (HRHP Archaeological form Site 1915).

Cordy investigated the site in 1975 and excavated two test units into the platform; one unit was located at the southern end of the platform, in the area of the former house foundation. The second test unit was located at the northern end of the lower level of the platform (see Cordy's site map, 1986a:32). Four hydration rind dates with ranges of AD 1590-1720 are listed on Cordy's site map; however, no dates are reported in his published table of hydration dates from Ooma II (1981: 248-249). Two of the dates (AD 1640±48 and 1653±35), were attributed to surface midden scatters located west of the platform. The location of the remaining two dates (AD 1657±64 and 1658±55) is not given. Eleven surface artifacts were apparently collected by Cordy; again, these are listed on his site map, but are not in the published list of artifacts recovered (1981: 243). All material is historic and includes glass, metal, and ceramic sherds.

Figure 26. SITE 50-Ha-D15-19, PLATFORM SURFACE. View to southwest. (PHRI Neg.493-27)

Cordy interpreted the site as having two construction phases. Phase I represents the historic house, which was not specifically dated. Phase 2 represents a prehistoric period bracketed by the hydration rind dates. Cordy offered no interpretation of the prehistoric component in his site map notes, but he indicated that the lower, northern portion of the platform was probably a modified earlier structure. The prehistoric component was not included in any discussions of Ooma II sites in Cordy's settlement pattern study (1981), since a function had not been identifiable. In his 1985 Working Paper, Cordy identifies Site D15-19 as a heiau, but does not indicate which structural features are associated with this heiau. His brief discussion of the site implies that the platform (previously identified as a house platform) is the site of the heiau:

> Last, there are 2 very large solitary structures in the coastal zone in Ooma 1 [2] (sites D15-18, and -19) which have been interpreted as heiau. D15-18 is a large enclosure, 300 sq m, with 2 internal platforms and a paving. D15-19 is a smaller structure, a high platform (160 sq.m.). Midden scatters near D15-19 are 5-10 cm deep, and the platform has a 10 cm deposit on top of its fill (Cordy 1985:31).

Cordy includes Site D15-19 in two lists of significant sites—those which would provide good site type examples for exhibition, and those with cultural significance. In the latter discussion, D15-19 is described as a "Possible heiau or other type of religious structure" (1985:45).

As specified in the scope of work, no additional testing or mapping was conducted at Site D15-19 during the PHRI survey. The structure was examined briefly, and no indications of different building stages were apparent. The lower tier along the west wall of the platform and the northern extension seem to have been built at the same time as the main platform. The location of a former superstructure, where two partially buried stone alignments and aligned postholes occur, is easily discernable on the main platform. These alignments are oriented east-west and are spaced 2.5 m apart, 6.0 m long. Postholes vary in size, with the largest c. 0.45 m in diameter. The platform has been verbally described by Reinecke and by Martin and has been mapped by Cordy and by Martin. These studies do not mention additional features that are located in the immediate vicinity, including a pavement (Feature B), a walled shelter (Feature C), rubble piles (Feature D), a rock mound (Feature E), and a filled depression (Feature F).

The rock mound (Feature E) is located 30.0 m east (90 degrees Az) of the platform (Feature A) and is the most distant associated feature (if in fact associated). The mound is constructed from aa boulders and waterworn basalt interspersed with some coral. It has a maximum height of 0.8 m and a diameter of 2.7 m. The mound had been opened at the southern side, near the base, exposing a depression that extends below ground surface and a number of fragmented skeletal (skull) remains. The remains were not accessible without additional excavation; they appeared to be human and are interpreted as such until further examined.

A small surface concentration of coral paving (0.9 m in diameter) occurs 1.20 m east of Feature E. Rubble piles (Feature D) and filled depression (Feature F) occur to the north of the aa flow and are associated with surface midden scatters. These features also have associated coral and may be burials.

Data recovery is recommended at this site and is necessary in order to settle the confusion over site type definition. Morphologically, the main platform has characteristics of a relatively elaborate historic house site. Recovered artifacts support this interpretation; however, the hydration rind dates do not. The dates may be associated with a former structure which was either disassembled or was incorporated into the latter house platform.

DATA ANALYSIS

AGE DETERMINATIONS

A total of 69 volcanic glass hydration rind dates has been determined from 15 sites within the project area to date. Forty-nine of these dates were determined from volcanic glass specimens recovered by Cordy during his dissertation field work in 1975. All specimens submitted for dating by Cordy were recovered from sites interpreted as permanent habitations, with the exception of Site D15-19, which was interpreted as a prehistoric heiau with a historic habitation component. Specimens for dating were collected by Cordy from a number of proveniences, including platform fill, surface midden adjacent to the platforms, surface of the platform, and adjacent cave deposits (1981:102-106). Since no cave proveniences are indicated for the Ooma II dates listed by Cordy (1981: 248-249), it is assumed that specimens from this latter provenience were possibly collected, but not submitted for dating. Proveniences identified in the list of dated specimens include fill, platform fill, surface fill, midden scatter, and base of platform fill (1981:248-249). All of these proveniences are expected to provide reliable dates for the occupation of all house platforms located at each site. All house platforms within a site boundary are expected to be contemporaneous (Cordy 1981: 102-107).

Cordy's collected specimens were analyzed in 1976 by Hawaiian Marine Research. Dated specimens were described by Olson as being predominantly from PuuWaaWaa (Cordy 1981:190), and a hydration rate of 11.77 microns per 1,000 years is given as the general rate in use for Hawaii at the time the determinations were completed (Cordy 1981:99).

Twenty additional volcanic glass specimens collected from six temporary habitation/shelter sites were submitted to Mohlab in October 1986 for hydration rind age determination. Specimens collected from all sites, except Sites T-17 and T-39, were from surface proveniences; specimens from the latter two sites were recovered from test unit excavations less than 10.0 cm deep, as well as from surface proveniences (Table 6).

Source affinity tests were conducted for five specimens recovered from Sites T-4, T-5, T-17, T-27 and T-39. Source affinities were determined by petrographic comparison for all other specimens. Three source areas are reflected in the volcanic glass collection submitted for hydration rind dating: PuuWaaWaa, Puuanahulu, and Pusa 2. Determinations for seven specimens (35%) from only two sites (T-17, T-61) indicate their derivation from the PuuWaaWaa source area. The current hydration rate used for this material is 51.64 microns^2/1,000 years (Michels, pers. comm. 12/5/86).

Twelve specimens (including four tested for source affinity) are derived from the Pusa 2 source. This source was first identified in samples collected from south of Kailua-Kona. The samples were subsequently subjected to an induced hydration experiment by Mohlab (Michels 1986). This material occurs at five of the six sites from which volcanic

Table 6.

SUMMARY OF VOLCANIC GLASS HYDRATION RIND AGE DETERMINATIONS

PHRI Lab. No. VG-	MOHLAB Lab. No. (380-)	*Hawaii Source	Excav. Unit	Provenience	Hydration Rind (microns)	Calendric Date Yrs. AD	Calendric Range Yrs. AD (2 sigmas)
Site T-4							
517	26	59		Surface	1.58±0.06	1708±23	1662-1754
Site T-5							
518	43	59		Surface	1.51±0.03	1731±09	1713-1749
Site T-17							
519	49	59	TU-1	Level 1, 0-10 cmbs	1.57±0.06	1710±23	1664-1756
520	62	11		Feature A, Surface	3.74±0.10	1716±14	1688-1744
521	64	11		Feature A, Surface	3.66±0.04	1727±05	1717-1737
522	126a	59		Feature B, Surface	1.75±0.09	1643±36	1571-1715
523	126b	59		Feature B, Surface	1.61±0.04	1695±16	1663-1727
524	137a	59	TU-1	Feature A, Level 1, 0-10 cmbs	1.59±0.04	1702±15	1672-1732
525	138a	59	TU-1	Feature A, Level 1, 0-10 cmbs	1.65±0.10	1680±39	1602-1758
526	138b	11	TU-1	Feature A, Level 1, 0-10 cmbs	3.73±0.06	1717±09	1699-1735
527	138c	11	TU-1	Feature A, Level 1, 0-10 cmbs	4.04±0.10	1670±16	1638-1702

*Source numbers indicate the following locations: 11 = PuuWaawaa; 59 = Pusa 2; 62 = Puuanahulu

Table 6. (Cont.)

PHRI Lab. No. YG-	MOHLAB Lab. No. (380-)	Hawaii Source	Excav. Unit	Provenience	Hydration Rind (microns)	Calendric Date Yrs. AD	Calendric Range Yrs. AD (2 sigmas)
Site T-17 (Cont.)							
528	139a	62	TU-1	Feature A, Level 1, 0-10 cmbs	1.91±0.08	1592±33	1526-1658
529	139b	11	TU-1	Feature A, Level 1, 0-10 cmbs	3.77±0.11	1710±17	1676-1744
530	139c	59	TU-1	Feature A, Level 1 0-10 cmbs	2.87±0.03	1756±05	1746-1766
Site T-27							
531	4a	59		Surface	1.66±0.05	1678±19	1640-1716
532	4b	59		Surface	1.58±0.05	1708±19	1670-1746
Site T-39							
533	120a	59		BF-2, Surface	1.76±0.04	1641±17	1607-1675
534	120b	59		BF-2, Surface	1.82±0.05	1615±21	1573-1657
Site T-61							
535	70	11		Feature B, Surface	3.95±0.10	1683±15	1653-1713
536	71	11		Feature B, Surface	4.00±0.09	1676±14	1648-1704

glass was collected and is expected to be the most common lithic material within the project area. The geological source of this material has not yet been identified. The current hydration rate used for this material is 8.95 microns^2/1,000 years (Michels, pers. comm. 12/5/86).

A single specimen from Site T-17 was associated by source affinity test to the Puuanahulu material recently recovered at the Bobcat Trail Habitation Cave (Haun 1986); it was subjected to an induced hydration experiment by Mohlab (Michels 1986b). The current hydration rate for this material is 4.09 microns^2/1,000 years (Michels, pers. comm. 12-5-86). The Puuanahulu volcanic glass specimen has the earliest determined age among the twenty dated specimens (AD 1592±33). It was recovered from mixed midden, along with specimens dated primarily to the late 1600s and early 1700s.

The volcanic glass dates associated with the permanent habitation sites of Ooma II were used as the basis for Cordy's settlement and

population model for the ahupua'a. A principal assumption of this model is that all sites were continuously occupied between the earliest and latest ranges for all hydration rind age determinations from each site. The period of site occupation therefore correlates directly with the period bracketed by all hydration date ranges (Figure 27). Sites with one or few age determinations, such as D15-2, D15-4, and D15-6, are automatically given a very limited period of occupation in this scheme. Similarly, sites with a broad spread in date means, such as D15-7 and D15-8, are given an extensive period of continuous occupation, rather than distinct periods of occupation and abandonment. It is expected that the determination of additional dates from the permanent habitation sites will permit a refinement of the settlement chronology offered by Cordy.

Dates associated with temporary habitation and shelter sites fall within a relatively tight 240-year time span of AD 1526-1766. This time span is exhibited among the Site T-17 dates, which includes the earliest and latest means and ranges among the twenty determinations (Figure 27). The 240-year time span for Site T-17 cannot be inferred here to reflect a single period of continuous occupation. It is interpreted as the period during which the most intensive utilization of the site as a temporary habitation locale occurred. It is expected that the range of dates from this site will expand with the acquisition of additional specimens from other proveniences on the site. Age determinations completed to date indicate that the most intensive use of the cave occurred during the latter half of this 240-year time span (AD 1656-1776).

Dates associated with Sites T-4, T-5, T-27, and T-39 represent the entire range obtainable from those sites (all volcanic glass present was collected and submitted for age determination), and as such, they should be more reliable reflections of the probable date or period of shelter use, which was minimal. These dates indicate that Site T-39 was utilized one or more times between AD 1573 and 1675. The other three shelters reflect more recent usage, beginning after AD 1650 and ending before contact c. AD 1754.

Hydration rind age determinations from the temporary habitation site (T-17) and cave shelters (T-4, T-5, T-27 and T-39) provide data that do not conflict with the hypothesized period of earliest settlement at Ooma II, as offered by Cordy (1981). There is, however, a potential conflict in the patterning of dates, as reflected in permanent versus temporary sites. The majority of the date means (16 out of 20) and ranges (13 out of 20) for temporary sites postdate the period of clustered means and ranges for permanent sites, which is hypothesized by Cordy to be the period of greatest population density at Ooma II (AD 1550-1650). This variance may reflect one or more of the following factors: (a) differences in hydration rates used in determing age of volcanic glass (i.e., dates determined in 1976 are generally 50-100 years earlier than those determined in 1986); (b) insufficient sampling for permanent and for temporary sites, resulting in an incomplete pattern for both groups of sites; or, (c) a general increase in upland/coastal mobility after AD 1650 that is perhaps related to an expansion of permanent habitation into upland locales. The potential effect of the first two factors can be evaluated

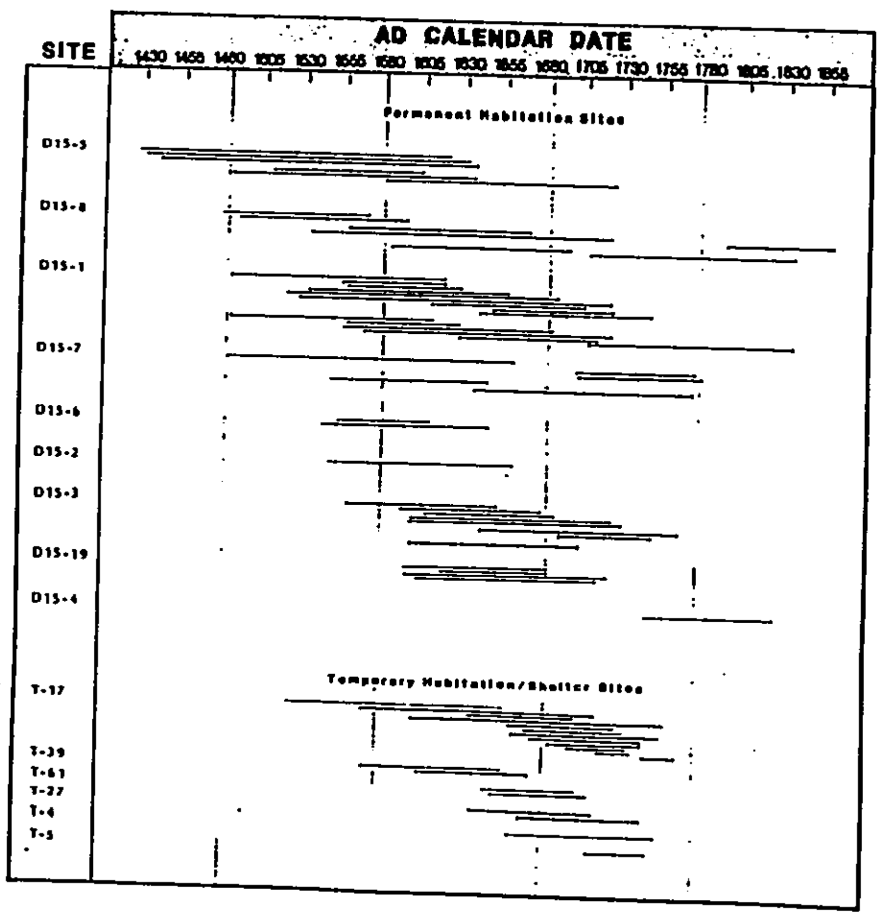

FIGURE 27. Hydration Rind Dates, Ooma II Sites

by determining additional dates from permanent habitation sites as well as from coastal shelters. The third factor is an interpretive issue that can be addressed only after the first two are resolved.

PORTABLE REMAINS

Midden

Midden samples were collected from eight sites within the project area, and lists of surface material were compiled for an additional 15 sites. All collections are from temporary habitation or shelter sites, such as caves or overhangs. With the exception of Site T-17, the midden collections represent all or nearly all of the material present at the sites. The lists of observed material likewise represent all material present, with the exception of Site T-61. This site and Site T-17 contain substantial midden deposits; the Site T-17 collection represents less than 5% of the actual deposit. No excavation has been conducted at Site T-61. Midden was not collected from the permanent habitation sites in the coastal zone, or from adjacent shelters, during this study (see Scope of Work). It is expected that the general patterns of resource exploitation inferred from these data will vary from patterns reflected in permanent site midden collections.

Categories of subsistence materials observed and/or collected include invertebrates (gastropods, bivalves, Echinoidea, Crustacea), vertebrates (fish, mammal, bird), and vegetal (kukui nut shell, seeds, gourd, coconut). Invertebrate remains constitute the bulk of subsistence material collected and observed in the project area and are the focus of the following discussion.

A total of 8,659.17 g of invertebrates (1/4-inch size grade) was collected and sorted, 4% of which represents Echinoidea and 0.3% of which (26.3 g) represents Crustacea (Table 7). Vertebrate remains recovered and observed are predominantly from fish; at this time these remains have not been identified to the species level. Most of the vertebrate remains collected (67%) are from Site T-17 and are primarily fish scales from small- to medium-sized fish. These remains should be analyzed at a future date as part of the data recovery program. The vegetal materials are not exclusively related to subsistence, and they may represent fuel, fragmented containers, or portions of various fibrous artifacts.

Twenty-one shellfish families are represented among the observed and collected remains; species identification was completed only for collected remains, in order to reduce interpretive error. The collected materials were also used for more detailed comparisons between sites.

In order to facilitate frequency comparisons, estimations of minimum number of individual shells were calculated for the six most frequently occurring shellfish species or families--Nerita picea, Thaididae, Cypraeidae, Conidae, Cellana sp., and Isognomonidae. The largest and most varied

Table 7.

QUANTITATIVE DISTRIBUTION OF MIDDEN REMAINS

Category	T-4 TU-1 I	T-12 TU-1 I	T-17 Feature A TU-1 Lev-1	T-17 Feature B HP-2 I	T-17 Feature B HP-3 S	Sub Total	T-22 Feature A S	T-24 TU-1 S	T-39 HP-1 S	T-39 HP-2 TU-1 I	T-39 HP-3 S	T-39 HP-5 Lev-1	Sub Total	T-41 TU-1 I	T-45 S	Grand Total
INVERTEBRATES																
Gastropods																
Cellana spp.	38.94	10.40	38.38	4.21	10.24	53.81	8.70	-	13.38	18.54	14.50	3.84	80.07	19.47	0.21	170.69
Trochus intextus	-	0.14	1.18	-	-	1.18	-	-	-	-	-	-	0.00	-	-	1.30
Nerita picea	140.70	89.12	722.80	38.70	23.31	784.81	0.81	27.83	261.08	478.38	38.44	78.01	883.92	312.74	12.54	2194.24
N. polita	0.88	1.08	57.42	24.30	23.03	104.78	-	-	-	3.18	-	4.48	7.84	2.31	-	118.48
Theodoxus spp.	-	-	4.83	-	0.91	5.84	-	0.43	4.10	-	2.06	-	6.16	0.27	-	12.27
Littorina pintado	0.93	1.40	14.07	2.24	1.44	17.78	0.81	-	9.19	18.40	0.74	4.85	31.18	3.92	0.15	55.99
Strombus maculatus	-	4.41	4.08	-	-	4.05	-	1.84	-	.32	-	-	0.32	0.15	-	8.93
Cypraeidae	236.10	97.84	1207.93	-	77.47	1285.40	49.70	66.74	217.22	318.93	184.80	58.10	788.84	128.39	68.85	2835.92
Hipponicidae	-	-	1.22	0.24	-	1.46	-	-	-	-	14.22	-	14.22	-	-	15.68
Cymatiidae	-	-	3.15	-	-	3.18	-	-	-	0.28	-	-	0.28	-	-	3.41
Thaididae	174.20	54.01	488.23	29.20	10.02	525.48	1.64	28.00	201.63	344.10	85.13	60.70	883.87	198.92	15.55	1883.84
Neothais harpa	-	0.46	1.58	-	-	1.58	-	-	-	-	-	-	0.00	-	-	2.05
Fasciolariidae	-	-	0.51	-	-	0.51	-	-	-	-	-	-	0.00	-	-	0.51
Nitridae	-	-	-	-	-	0.00	-	-	-	1.48	-	-	1.48	-	-	1.45
Melampus castaneus	-	-	0.08	-	-	0.08	-	-	-	-	-	-	0.00	0.12	-	0.20
Conidae	14.05	9.54	224.12	39.31	3.77	288.20	-	6.24	18.68	63.80	8.15	13.83	124.47	30.76	24.60	489.82
Opercula	-	-	-	-	0.07	0.07	-	-	-	.19	-	-	0.18	-	-	0.26
Unident. Gastropods	27.92	95.53	143.22	0.34	26.24	168.80	-	0.53	110.68	58.05	-	6.11	174.84	8.88	-	477.07
SUBTOTAL GASTROPODS	634.72	383.78	2911.64	138.54	178.80	3228.68	58.38	131.71	835.86	1234.47	357.84	230.73	2748.43	696.03	121.90	7848.88

Table 7. (Cont.)

Category	T-4 TU-1 I	T-12 TU-1 I	T-17 Feature A TU-1 Lev-1	T-17 Feature B HP-2 I	T-17 Feature B HP-3 S	Sub Total	T-22 Feature A S	T-24 TU-1 S	T-39 HP-1 S	T-39 HP-2 I	T-39 HP-3 S	T-39 HP-5 Lev-1	Sub Total	T-41 TU-1 I	T-45 S	Grand Total
Bivalvia																
Brachidontes crebristriatus	0.58	0.17	0.48	0.21	-	0.67	-	0.27	5.56	7.68	-	3.30	16.55	0.16	-	18.13
Isognomonidae	7.68	4.87	30.44	9.30	3.21	42.95	-	-	11.44	16.61	9.48	6.24	43.78	18.45	-	114.71
I. californicus	0.92	10.33	4.77	-	-	4.77	-	-	2.45	0.24	-	-	2.68	44.52	-	63.23
Spondylidae	-	-	-	-	-	-	-	-	-	-	-	-	-	0.86	-	0.86
Chamidae	-	-	4.19	-	-	4.19	-	-	-	5.04	-	-	5.04	0.28	-	9.51
Tellinidae	-	-	3.38	-	-	3.38	-	-	4.53	0.53	-	-	5.06	-	-	8.42
Tellina elizabethae	-	-	0.34	-	-	0.34	-	-	-	3.92	-	-	3.92	-	-	4.26
Veneridae	-	-	7.41	-	-	7.41	-	-	-	-	-	-	-	-	-	7.41
Periglypta reticulata	-	-	7.07	-	-	7.07	-	-	-	1.11	-	-	1.11	-	-	8.18
Unident. Bivalvia	-	-	5.43	-	4.18	9.61	-	-	-	5.54	-	1.32	6.86	0.83	-	17.40
SUBTOTAL BIVALVIA	9.18	15.37	83.47	9.51	7.39	80.37	-	0.27	23.98	40.68	9.48	10.86	85.01	62.20	-	282.11
Other Invertebrates																
Echinoidea	21.97	11.07	76.10	50.18	33.87	159.93	2.83	1.80	45.26	52.81	37.29	53.49	188.85	13.25	-	397.90
Crustacea	0.93	2.36	7.22	5.08	2.44	14.94	-	0.58	0.81	3.09	0.58	2.44	8.70	0.78	-	25.71
Non-marine gastropods	-	-	-	-	-	-	-	-	-	-	0.30	-	0.20	-	-	0.20
TOTAL INVERTEBRATES	666.79	382.98	3068.43	203.28	219.30	3480.92	61.18	134.36	905.83	1420.48	405.38	297.82	3029.18	772.28	121.90	8824.81
VERTEBRATES																
Bone	19.50	-	24.00	28.27	21.24	71.31	4.78	0.06	1.32	7.04	0.52	0.94	8.62	1.13	-	106.74
VEGETAL	23.11	6.94	243.96	45.88	35.34	325.18	-	1.04	4.88	8.83	0.73	7.55	21.88	7.06	-	388.25
REMAINDERS	794.50	1056.00	1037.50	248.01	138.83	1422.34	-	289.70	278.53	3693.14	843.30	708.70	5224.67	1149.80	-	9647.31
GRAND TOTAL	1505.88	1483.52	4363.89	521.23	414.81	5299.93	65.96	425.16	1181.56	5131.48	849.93	1012.71	8285.66	1930.25	121.90	18863.11

midden sample, collected from a backpile at Site T-17, Feature A, was selected as a control collection. This single collection represents 36% of the total gross weight of all invertebrates collected, and it has by far the largest amounts of all species represented within the project area. A mean weight per individual was calculated for each species or family group, using actual individual counts and total weights for the control collection. Other site collections were then compared with the control group to insure that no major size variations occurred; the mean individual weight was divided into the total group weight for an estimation of minimum number of individuals. The reliability of this process will be further tested when additional data are collected; it appears that reliability varies somewhat with the species or family being counted.

The most reliable estimates of minimum number counts are obtainable with Nerita picea, due to the predominance of complete shells in all collections. The Site T-17 N. picea collection contains 1,285 complete shells and 235 large fragments that were clearly distinct individuals. Only 90 pieces from the 1/4-inch collection represent redundant individuals. The estimated mean individual weight for N. picea (0.43 g) is probably slightly skewed by the fact that the shells were not soaked or individually washed prior to weighing. This factor is, however, constant for all collections compared here and should not significantly affect these results. The size range of N. picea shells is relatively small within the control collection, and no anomalies were observed from other sites. The shells range from 13.0 to 18.5 mm in length and from 9.6 to 12.4 mm in width.

The proportion of complete individuals among Thaididae shell remains is considerably smaller in the control collection. Only 13% of the total 272 items are complete shells. A total of 78 other individuals was identified from the collection, using the apertural denticles as the principal indicator. Within this collection, fragmented individuals are represented by four or five pieces (1/4-inch size grade). Complete individuals range in length from 11.0 to 23.0 mm; the majority are within a tighter range of 15.0 to 20.0 mm. Ten exceptionally large individuals (all fragmentary) that were probably over 30.0 mm long were observed in this collection and occur in other collections as well. Mean individual weight is 2.29 g.

Cypraeidae remains exhibit the lowest frequency of complete individuals; only one complete shell is present among 462 (1/4-inch) pieces in the control collection. A total of 98 additional individuals was identified by counting labial teeth sections and by dividing the total by two. A relatively uniform breakage pattern occurs within this collection, whereby the ventral portion of the shell is split, and the dorsal section is shattered into small pieces. Roughly 65% of the shell fragments are pieces of shattered dorsal portions, and each individual is represented by five to six pieces (1/4-inch). Much of the dorsal shatter appears to have passed through 1/4-inch screens and is in the 1/8-inch size grade collection. Individual shell length is indeterminate for most pieces; however, a range of 26 to 49 mm is indicated. Mean individual weight is 6.6 g.

Cellana sp. shells exhibit the greatest variation in size within the control collection, and they are predominantly incomplete (two of seven

individuals are complete). The small size of this collection mitigates against reliable size range measurements; however, most appear to be between 26.5 and 41.5 mm long. Mean individual weight calculated from this small collection (28.2 g) is 4.03 g.

Conidae and Isognomonidae collections are too small for reliable mean weight calculations, and all collections were simply examined for determination of minimum numbers of individuals (less than ten in all collections except that from Site T-17). Within the T-17 collection, three complete and seventeen partial individuals were identified. Each fragmented shell is represented by an average of five pieces in the 1/4-inch size grade, and mean individual weight is 8.29 g. Fourteen Isognomonidae individuals (one complete valve) were identified from the 30.44 g control collection. Only three 1/4-inch pieces were present per individual; these were identified from paired hinge sections. Mean individual weight calculated from this collection is 2.17 g. The single complete valve is 46.0 mm long and is an unusually large specimen, compared with the remainder of the collection.

Twelve shellfish families are represented among the 15 surface midden lists compiled at 15 sites (Table 8). Over half (59%) of the 68 observations are represented by three families--Neritidae, Cypraeidae and Thaididae. These three species also account for 77% of the gross weight of all invertebrates collected from eight sites (Table 8). This pattern of predominance by three shellfish families is consistent for all examined temporary habitation and shelter sites within the project area that have shellfish remains. A similar pattern is expected to occur among the shelters associated with permanent habitation sites in the immediate coastal area. The predominance of Neritidae, Cypraeidae and Thaididae among temporary site midden assemblages also occurs at Makalawena, a North Kona ahupua'a located 9.0 km to the north of Ooma II (Donham 1986b).

The observed Neritidae shells are predominantly Nerita picea, with small amounts of Nerita polita present at nearly all sites with collected samples. Small amounts of N. polita were observed in the uncollected shelters as well. These species are most abundant in the intertidal zones along wave-swept, rocky shorelines (Kay 1979:234). The predominant Thaididae observed were Drupa morum and Morula granulata, both of which are very common on hard substrata in the intertidal zone where, there is strong wave action (Kay 1979:241, 248). Nearly all Cypraeidae remains observed were from smaller species which tend to inhabit intertidal zones.

It appears that the bulk of the shellfish exploited was obtained from the littoral biotope and was collected by hand or with hand nets, probably during periods of low tide. There does not appear to be any clear relationship between nearness to the shoreline and numbers or variety of shellfish represented at the temporary sites. Three of the four collections with three or fewer shellfish families are located in the immediate coastal zone (Sites T-47, T-57, and T-59). There are four collections from shelters located in the inland area that contain four or more families. One of these collections, from Site T-4, contains eight different families and is located at the eastern edge of the project area.

Table 8.

SHELLFISH FAMILIES OBSERVED AT TEMPORARY HABITATION SITES

	Site T-															
	5	6	7	11	27	43	47	57	59	61	63	64	66	67	69	Total
Brachidontes crebristriatus	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	1
Chamidae	-	-	-	-	-	-	-	-	-	-	-	+	-	+	-	2
Conidae	-	+	+	+	-	-	-	-	-	+	+	+	+	-	-	7
Cypraeidae	+	+	+	+	+	+	+	+	-	+	+	+	+	+	+	14
Isognomidae	-	-	-	-	-	+	-	-	-	+	-	-	-	+	-	3
Littorinidae	-	-	-	-	+	-	-	-	-	+	-	+	-	-	+	4
Neritidae	+	+	-	+	+	+	+	+	+	+	+	+	+	+	+	14
Patellidae	-	+	+	+	+	+	+	-	-	+	-	-	-	+	-	8
Spondylidae	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	1
Strombidae	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	1
Tellinidae	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	1
Thaididae	-	+	+	+	+	+	-	+	-	+	+	+	+	+	+	12

Among the three major shellfish families represented, Nerita picea is clearly the predominant species. At least 5,185 N. picea are represented in the collected midden samples, as compared to 740 Thaididae and 410 Cypraeidae individuals (Table 9). In general, 12 to 13 N. picea were collected for each Cypraeidae individual, and 7 N. picea were collected for each Thaididae individual. This pattern may reflect the greater natural abundance of this species rather than a culinary preference. Among the collections with at least 100 individual shellfish represented, the proportion of N. picea to Thaididae varies from 9.7:1 (Site T-17B) to 4.3:1 (Site T-4). In this instance, relative distance from the site to the shoreline may be a factor affecting the relative abundance of the easily obtainable N. picea.

Other littoral shellfish, such as the generally abundant Littorina pintado and the less abundant Chama iostoma, are relatively rare among the observed and the collected midden samples. These two groups were, however, more frequently observed than deep-water families such as Strombidae (one occurrence) and Spondylidae (one occurrence).

Shellfish species which tolerate freshwater outflows along limestone shorelines and which occur in anchialine ponds or springs are conspicuously rare in Ooma II site collections. Brachidontes crebistriatus, not observed in any of the small site surface scatters, accounts for only 0.2% by gross weight of all invertebrates among collected midden samples. Quantities of this species in amounts greater than one gram occur only in the Site T-17 composite collection (Features A and B combined). Theodoxus sp. is likewise relatively sparse and accounts for only 0.5% by weight of all Neritids. This species was observed at three sites only. The very low frequency of B. crebristriatus and Theodoxus sp. shell indicates that

Table 9.

MINIMUM NUMBER ESTIMATIONS FOR MAJOR SHELLFISH COLLECTIONS

	Site T-									
	4	12	17A	17B	22	24	39	41	45	Total
Cellana sp.	10	3	10	3	1	-	15	5	1	48
Conidae	2	1	27	6	-	1	15	3	3	58
Cypraeidae	36	15	183	12	3	10	121	20	10	410
Isognomonidae	5	7	16	5	-	-	22	27	-	82
Nerita picea	327	207	1,680	165	3	65	1,985	727	29	5,188
Thaididae	76	24	212	17	1	12	304	87	7	740
Totals	456	257	2,128	208	8	88	2,462	869	50	6,526

shellfish were not consistently carried into the area from the adjacent anchialine pond area at Kohana-Iki. These species are reported to have been extensively exploited where obtainable (Kirch 1979:121-133), and they should have been easily obtainable from the numerous anchialine ponds or freshwater outflow areas immediately to the south.

B. crebristriatus was observed at five shelter sites in Kohana-Iki, and Theodoxus sp. was observed at three sites during a recent reconnaissance survey (Donham 1986a). The occurrence pattern for Theodoxus is surprisingly similar; however, the increased frequency of B. crebristriatus at Kohana-Iki suggests that some restrictions on use of the anchialine pond by nonresidents may have occurred, or that travelers within the Ooma II Ahupua'a simply did not venture into Kohana-Iki for shellfish gathering.

Artifacts

A total of 152 portable artifacts or artifact fragments was recovered from 13 sites during reconnaissance. Half of these items (80, 53%) were recovered from the Feature A area of Site T-17 (Table 10). All other site-specific artifact collections contain 20 or fewer specimens, with the second highest count obtained at Site T-4 (20, 13%).

Artifacts representing seven material classes were recovered. The most frequently occurring material is coral, which was utilized as an abrading medium. Forty-six of these items, in various stages of modification, were collected from seven sites (T-4, T-12, T-17, T-24, T-39, T-41 and D15-8). Echinoidea spines, also used for abrading, occur with the second highest frequency; 34 spines were recovered from six sites

Table 10.

SUMMARY OF PORTABLE ARTIFACTS

Category	T-4	T-5	T-6	T-12	T-15	T-17 Feature A	T-17 Feature A TU-1	T-17 Feature B	T-17 Sub Total	T-24	Sub Grand Total
	S	S	S	S	S	S	Lev-1	S		TU-1 I	
FISHING GEAR											
Hook (bone)											
One-piece fragment	-	-	-	-	-	-	-	-	0	-	0
Two-piece point	-	-	1	-	-	-	-	-	0	-	1
Octopus Lure											
Cowrie (Cypraeidae)	1	-	1	-	-	1	-	-	1	-	3
DOMESTIC IMPLEMENTS											
Pick (bird bone)	1	-	-	-	-	-	-	-	0	-	1
Awl (bone)	1	-	-	-	-	-	-	-	0	-	1
Scraper (Cellana sp.)	-	-	-	-	-	2	1	-	3	-	3
FLAKED STONE											
Basalt flake	-	-	-	-	-	-	1	-	1	-	1
Volcanic glass	2	1	-	-	-	3	18	2	23	-	26
TOOLS											
Abrader											
Coral	4	-	-	2	-	24	2	1	27	2	35
Echinoidea	4	-	-	3	-	14	2	-	16	-	23
Scoria	3	-	-	1	-	3	-	-	3	-	7
Adze	-	-	-	-	1	-	-	-	0	-	1
Flake (basalt)	1	-	-	-	-	-	-	-	0	-	1
Hammerstone (basalt)	1	-	-	1	-	-	-	-	0	-	2
Polished basalt	-	-	-	-	-	3	-	-	3	-	3
MISCELLANEOUS/OTHER											
Modified:											
Bone	-	-	-	1	-	-	-	-	0	-	1
Pandanus key	-	-	-	-	-	1	-	-	1	-	1
Pearlshell	-	-	-	-	-	1	1	-	2	-	2
Unident. shell	-	-	-	-	-	1	-	-	1	-	1
Wood	2	-	-	-	-	-	-	-	0	-	2
Perforated shell:											
Cellana sp.	-	-	-	-	-	-	-	-	0	-	0
Conus spire	-	-	-	-	-	-	2	-	2	-	2
GRAND TOTAL	20	1	2	8	1	53	27	3	83	2	117

Table 10. (Cont.)

Category	T-37	T-39	T-39 XT-2	T-39 XT-4	T-39 Sub Total	T-41 Feature A	T-41 Feature A TU-1	T-41 Feature B	T-41 Sub Total	T-43 Feature A	T-81 Feature B	D10-7 Feature E	D10-8	Sub Grand Total	Grand Total
	S	S	Lev-1	S		S	1	S		S	S	S	S		
FISHING GEAR															
Hook (bone)															
One-piece fragment	-	-	-	-	0	-	1	-	1	-	-	-	-	1	1
Two-piece point	-	-	-	-	0	-	-	-	0	-	-	-	-	0	1
Octopus Lure															
Cowrie (Cypraeidae)	-	-	-	-	0	-	-	-	0	-	-	-	-	0	3
DOMESTIC IMPLEMENTS															
Pick (bird bone)	-	-	-	-	0	-	-	-	0	-	-	-	-	0	1
Awl (bone)	-	-	-	-	0	-	-	-	0	-	-	-	-	0	1
Scraper (Cellana sp.)	-	-	-	1	1	-	-	-	0	-	-	-	-	1	4
FLAKED STONE															
Basalt flake	-	-	-	-	0	-	-	-	0	-	-	-	-	0	1
Volcanic glass	2	-	2	-	2	-	-	-	0	-	2	-	-	6	32
TOOLS															
Abrader															
Coral	-	-	2	-	2	6	1	1	8	-	-	-	1	11	46
Echinoidea	-	1	7	-	8	-	2	-	2	1	-	-	-	11	34
Scoria	-	-	-	-	0	-	-	-	0	-	-	-	-	0	7
Adze	-	-	-	-	0	-	-	-	0	-	-	-	-	0	1
Flake (basalt)	-	-	-	-	0	-	-	-	0	1	-	-	-	1	2
Hammerstone (basalt)	-	-	-	-	0	-	-	-	0	-	-	1	-	1	3
Polished basalt	-	-	-	-	0	-	-	-	0	-	-	-	-	0	3
MISCELLANEOUS/OTHER															
Modified:															
Bone	-	-	1	-	1	-	-	-	0	-	-	-	-	1	2
Pandanus key	-	-	-	-	0	-	-	-	0	-	-	-	-	0	1
Pearl shell	-	-	-	-	0	-	-	-	0	-	-	-	-	0	2
Cellana sp.	-	-	-	-	0	-	-	-	0	-	-	-	-	0	1
Wood	-	-	-	-	0	-	-	-	0	-	-	-	-	0	2
Perforated Shell:															
Cellana sp.	-	-	-	-	0	2	-	-	2	-	-	-	-	2	2
Conus spire	-	-	-	-	0	-	-	-	0	-	-	-	-	0	2
GRAND TOTAL	2	1	12	1	14	8	4	1	13	2	2	1	1	38	155

Table 10.

SUMMARY OF PORTABLE ARTIFACTS

Category	T-4 S	T-5 S	T-6 S	T-12 S	T-15 S	T-17 Feature A S	T-17 Feature A TU-1 Lev-1	T-17 Feature B S	T-17 Sub Total	T-24 TU-1 1	Sub Grand Total
FISHING GEAR											
Hook (bone)											
One-piece fragment	-	-	-	-	-	-	-	-	0	-	0
Two-piece point	-	-	1	-	-	-	-	-	0	-	1
Octopus Lure											
Cowrie (Cypraeidae)	1	-	1	-	-	1	-	-	1	-	3
DOMESTIC IMPLEMENTS											
Pick (bird bone)	1	-	-	-	-	-	-	-	0	-	1
Awl (bone)	1	-	-	-	-	-	-	-	0	-	1
Scraper (Cellana sp.)	-	-	-	-	-	2	1	-	3	-	3
FLAKED STONE											
Basalt flake	-	-	-	-	-	-	1	-	1	-	1
Volcanic glass	2	1	-	-	-	2	19	2	23	-	26
TOOLS											
Abrader											
Coral	4	-	-	2	-	24	2	1	27	2	35
Echinoidea	4	-	-	3	-	14	2	-	16	-	23
Scoria	3	-	-	1	-	3	-	-	3	-	7
Adze	-	-	-	-	1	-	-	-	0	-	1
Flake (basalt)	1	-	-	-	-	-	-	-	0	-	1
Hammerstone (basalt)	1	-	-	1	-	-	-	-	0	-	2
Polished basalt	-	-	-	-	-	3	-	-	3	-	3
MISCELLANEOUS/OTHER											
Modified:											
Bone	-	-	-	1	-	-	-	-	0	-	1
Pandanus key	-	-	-	-	-	1	-	-	1	-	1
Pearlshell	-	-	-	-	-	1	1	-	2	-	2
Unident. shell	-	-	-	-	-	1	-	-	1	-	1
Wood	2	-	-	-	-	-	-	-	0	-	2
Perforated shell:											
Cellana sp.	-	-	-	-	-	-	-	-	0	-	0
Conus spire	-	-	-	-	-	-	2	-	2	-	2
GRAND TOTAL	20	1	2	8	1	52	28	3	83	2	117

Table 10. (Cont.)

Category	T-27 S	T-39 S	T-39 HF-2 Lev-1	T-39 HF-4 S	T-39 Sub Total	T-41 Feature A S	T-41 Feature A TU-1 1	T-41 Feature B S	T-41 Sub Total	T-43 Feature A S	T-41 Feature B S	D19-7 Feature E S	D19-8 S	Sub Grand Total	Grand Total
FISHING GEAR															
Hook (bone)															
One-piece fragment	-	-	-	-	0	-	1	-	1	-	-	-	-	1	1
Two-piece point	-	-	-	-	0	-	-	-	0	-	-	-	-	0	1
Octopus Lure															
Cowrie (Cypraeidae)	-	-	-	-	0	-	-	-	0	-	-	-	-	0	3
DOMESTIC IMPLEMENTS															
Pick (bird bone)	-	-	-	-	0	-	-	-	0	-	-	-	-	0	1
Awl (bone)	-	-	-	-	0	-	-	-	0	-	-	-	-	0	1
Scraper (Cellana sp.)	-	-	-	1	1	-	-	-	0	-	-	-	-	1	4
FLAKED STONE															
Basalt flake	-	-	-	-	0	-	-	-	0	-	-	-	-	0	1
Volcanic glass	2	-	2	-	2	-	-	-	0	-	2	-	-	6	32
TOOLS															
Abrader															
Coral	-	-	2	-	2	6	1	1	8	-	-	-	1	11	46
Echinoidea	-	1	7	-	8	-	2	-	2	1	-	-	-	11	34
Scoria	-	-	-	-	0	-	-	-	0	-	-	-	-	0	7
Adze	-	-	-	-	0	-	-	-	0	-	-	-	-	0	1
Flake (basalt)	-	-	-	-	0	-	-	-	0	1	-	-	-	1	2
Hammerstone (basalt)	-	-	-	-	0	-	-	-	0	-	-	1	-	1	3
Polished basalt	-	-	-	-	0	-	-	-	0	-	-	-	-	0	3
MISCELLANEOUS/OTHER															
Modified:															
Bone	-	-	1	-	1	-	-	-	0	-	-	-	-	1	2
Pandanus key	-	-	-	-	0	-	-	-	0	-	-	-	-	0	1
Pearl shell	-	-	-	-	0	-	-	-	0	-	-	-	-	0	2
Cellana sp.	-	-	-	-	0	-	-	-	0	-	-	-	-	0	1
Wood	-	-	-	-	0	-	-	-	0	-	-	-	-	0	2
Perforated Shell:															
Cellana sp.	-	-	-	-	0	2	-	-	2	-	-	-	-	2	2
Conus spire	-	-	-	-	0	-	-	-	0	-	-	-	-	0	2
GRAND TOTAL	2	1	12	1	14	8	4	1	13	2	2	1	1	35	152

(T-4, T-12, T-17, T-39, T-41 and T-43). Volcanic glass is represented by twenty-seven flakes and five cores, recovered from six sites (T-4, T-5, T-17, T-27, T-39, and T-61). Seventeen basalt items were recovered; this category includes one debitage flake, seven scoria abraders, one adze, three hammerstones, two adze flakes, and three polished basalt flakes recovered from six sites (T-4, T-12, T-15, T-17, T-43 and D15-7). Fourteen shell items, representing three octopus lures, four scrapers, four perforated pieces and three modified pieces, were recovered from five sites (T-4, T-6, T-17, T-39, and T-41). Six artifacts of bone were recovered, including two fishhook fragments, one pick, one awl and two modified fragments; these items occurred at five sites (T-4, T-6, T-12, T-39, T-41). Finally, four modified wood items (including two pieces of milled lumber) and a pandanus key were recovered from three sites (T-4, T-12, and T-17).

The recovered artifacts are described below, according to general functional categories; they are subgrouped by material class within each category. General categories include fishing gear (five items), domestic implements (six items), flaked stone (33 items), tools (96 items), and miscellaneous (12 items).

Fishing Gear. Two bone fishhook fragments representing different hook types were recovered; a single one-piece hook was collected during the excavation of TU-1 at Site T-41, and a knobbed point of a two-piece hook was located on the surface of Site T-6 (Figure 28a). This latter specimen is of the slender hook type, as described by Sinoto (1975:5). Overall length is 5.42 cm, and average thickness is 0.32 cm. The item is manufactured from a medium- to large-sized mammal bone and is twisted considerably to the right, from the base end. The concave side of the bone is oriented along the outer, convex side of the twist. The bone is bleached white and is extremely fragile.

The one-piece hook has a shank length of 1.8 cm and an indeterminate hook length due to breakage. The entire specimen is rounded in cross section (average thickness of 0.22 cm) and appears to be worn either from use or from weathering (Figure 28b). Overall form indicates a jabbing hook; the shank is straight, and the hook angles away from the shank at c. 65 degrees (V-shaped bend). The hook head is pointed, with the top slanted upward from outer to inner edge. A shallow notch occurs on the outer edge, producing a very slightly protruding knob (Sinoto's Head Type 1d; 1975:8). The specimen has been subjected to fire, and color varies from black to dark brown; it is in generally good preservation.

Three Cypraea sp. shell octopus lures were recovered from Sites T-4, T-6, and T-17. The specimens from Sites T-4 and T-17 are complete, and both are weathered; however, coloration is still discernable. The Site T-4 specimen is a Cypraea mauritiana; it is 5.85 cm long and has two amorphous holes pierced in the dorsal side. The holes are positioned in the center, 3.55 cm apart. The Site T-17 specimen is a Cypraea leviathan; it is 5.7 cm long and has two amorphous holes pierced in the dorsal side. The holes are positioned in the center, 4.0 cm apart. The Site T-6 specimen is a half-complete Cypraea mauritiana. This item was c. 6.7 cm long, with holes spaced 4.15 cm apart. The octopus lure and fishhook point described above are the only two artifacts recovered from Site T-6.

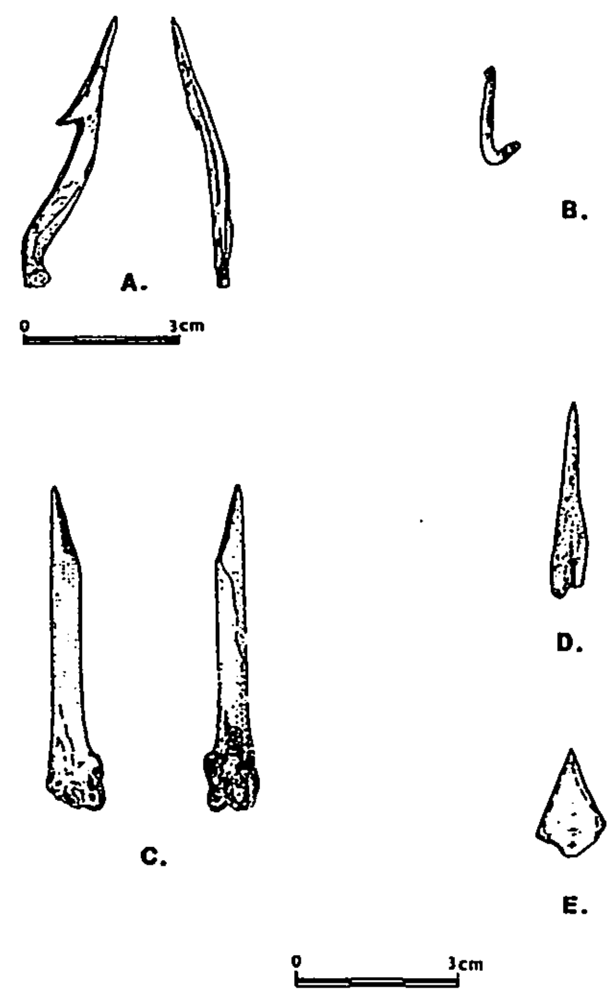

FIGURE 28. Bone and Shell Artifacts

Domestic Implements. Items categorized as domestic implements were recovered from Sites T-4, T-17 and T-39. Items recovered include a bird bone pick, a bone awl, and four *Cellana* sp. scrapers. Both bone tools were recovered from the surface of Site T-4. The pick is 5.9 cm long; it appears to be formed from an ulna of a medium-sized bird (Figure 28c). The awl is 3.55 cm long and has a sharp, rounded tip, 1.4 cm long (Figure 28d). The proximal end of this tool is worn smooth, apparently from handling.

Four *Cellana* sp. scrapers or scoop implements were recovered, three of which were located at Site T-17. All items exhibit extensive wear around the entire perimeter of the shell. One specimen from Site T-17 is an unusually large shell (8.3 cm major axis) that has been extensively worn, so that the current edges are 0.45 cm thick. This shell would have probably functioned better as a scoop than as a scraping tool. It was located on the surface at Feature A.

Flaked Stone. Twenty-seven lithic manufacturing debris flakes and five cores were recovered, nearly all of which are volcanic glass. A single basalt flake was collected from Site T-17, Feature A. It is an incomplete tertiary flake that exhibits an old platform surface at the bulb of percussion. The flake weighs 1.61 g and has not been utilized or otherwise modified.

The majority of the volcanic glass flakes (85%) were recovered from Site T-17. Eight of the twenty-three flakes collected from screened midden at this site are complete, and one exhibits use-related edge wear. Seven of the complete flakes and five incomplete flakes were submitted to Mohlab for hydration rind age determination. The source affinity of specific flakes and the associated induced hydration experiments conducted by Mohlab have been described above. The four additional volcanic glass flakes were recovered from Sites T-4, T-27, and T-39. Only one of these four flakes (Site T-4 specimen) is complete.

Five volcanic glass cores were collected from four sites; these include primary cores from Sites T-4 and T-39 and secondary cores from Sites T-5 (one specimen) and T-61 (two specimens). The two primary cores were collected along with a single volcanic glass flake; the secondary cores were associated with no additional debitage. Interestingly, no cores were recovered from the sampled midden at Site T-17, where volcanic glass flakes are numerous. It is expected that cores will be located during additional data recovery at the site.

Tools. Manufacturing and maintenance tools were recovered from ten sites within the project area. As a general category, these items outnumber all other artifacts and occur at more sites than do other categories. Tool forms recovered include abraders (87), hammerstones (2) and fragments (1), one adze, two adze flakes, and three polished basalt flakes. These latter items are probably also adze flakes.

Abrading tools of coral, Echinoidea spine, or scoria are the most frequently occurring items within all site collections, and they

constitute 57% of the total number of recovered artifacts (N=87). These tools outnumber volcanic glass flakes (2:1 ratio) within the collection from Site T-17, where most were collected from surface rather than excavation proveniences (42 out of 46 abraders are from surface collection). Abraders were located in discrete piles on the site surface and appeared to have been set aside, but not collected, by relic hunters. This post-abandonment disturbance has created a somewhat unrepresentative high proportion of abraders in the current assemblage from Site T-17, as well as in the collection as a whole.

Abraders are described here using general shape categories similar to those used by Hay et al. (1986) and by Barrera (1971). Each category consists of a general form identifier (cobble, pebble, linear, conical, or indeterminate fragment) and a cross-section identifier (round, rectangular, triangular, oval, irregular). Additional features noted for each specimen include the number of ground facets, degree of breakage, and extent of modification (i.e., formal vs. informal).

Among the 46 coral abraders recovered, 29 (63%) are linear in general form. All of the linear coral abraders are fragments, and most are midsections of relatively small tools with a size range very similar to Echinoidea spine abraders. These abraders occurred on all sites where two or more artifacts were collected. The activity indicated by this tool form is light abrading or fine finishing of small bone and shell artifacts, and it is very similar to the function indicated for Echinoidea spine abraders. Cross sections of the linear abraders show no predominance of any one shape; seven are round, seven are triangular, five are wedge-shaped and seven are rectangular. The smaller items tend to be rounded or oval in cross section, probably reflecting an advanced stage of use (Figure 29b). The larger linear abraders, such as the drilled item shown in Figure 29a, tend to exhibit straight sides with well-defined corners or lateral edges.

Seven informal (natural shape of stone still identifiable) cobble abraders were recovered from four sites (T-4, T-17, T-41, and D15-8). Each of these artifacts exhibits one or two flat abraded surfaces. Two pebbles with informal grinding on one surface only were also recovered, as well as one pebble with a wedge cross section. This item was very near to its original shape and appears to have been lightly used.

Two coral abraders have a conical shape and round cross section; these were recovered from Sites T-17 and T-41. Both items are awl-like, with pointed tips and broad proximal ends.

Thirty-four Echinoidea spine abraders were recovered from six sites within the project area. All abraders utilized spines of *Heterocentrotus mammillatus*; only two items are complete, and seven are nearly complete. Twelve distal ends are present, as well as ten midsections and one proximal tip. Due to the high proportion of incomplete artifacts, it is difficult to attempt a descriptive summary of the utilized facets on the spines. Only three spines (recovered from Sites T-39 and T-17) exhibit more than one utilized facet. All others have either flat or concave

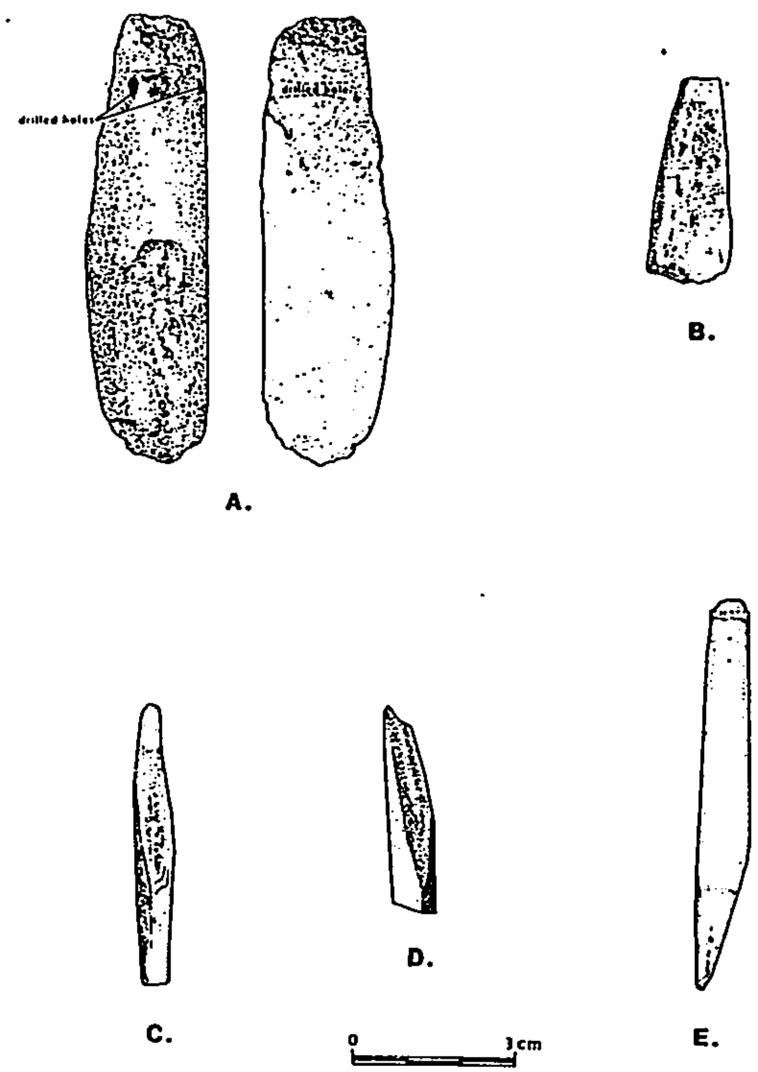

FIGURE 29. Coral and Echinoid Spine Abraders

ground surfaces on only one side of the spine. The end of the utilized spine is determinable for 24 items; proximal end use occurs on 10 spines, distal end use on 12 spines, and grinding along the entire length of the intact spine portion (nearly complete only) occurs on two items.

Nine Echinoidea spines exhibit concave ground surfaces that are curved in a broad, dish-like manner and have a narrow, trough-like indentation down the center, with the long axis of the spine (Figure 29c). This type of surface occurs more frequently on distal ends of spines than on proximal ends (seven of nine) and appears to represent a specialized finishing tool that would have a relatively limited use-life. These items were present at Sites T-4, T-17, T-39, and T-43.

The most common form of abraded surface on spines is a flat surface that is oriented at an angle (15-20 degrees) to the major axis of the spine (Figure 29e). Striations were observed on the abraded surface as well as on the dorsal side of the spine, behind the abraded surface, usually parallel to the long axis of the spine. No specimens were recovered with abraded surfaces located on opposite ends of the spine. Absence of this pattern may be a function of the high proportion of broken items rather than an actual use-pattern indication. Flat abraded surfaces on opposing sides of the same end of the spine occur on only one specimen from Site T-17 (Figure 29d). Adjacent abraded surfaces occur on two specimens, both of which are midsections of spines. These items were recovered from Site T-39.

Scoria abraders are much more limited in distribution and frequency than are the coral and Echinoidea spine abraders. Seven scoria abraders were recovered from three sites (T-4, T-12, and T-17) within the project area. Three of the abraders are formed artifacts; these small, well-ground items were recovered from Sites T-4 and T-17. The two, formed items from Site T-4 are conical abraders with round cross sections that are nearly identical in size and shape. The third item, from Site T-17, is linear, with an oval cross section and one blunt end; this specimen is partial. The remaining four abraders are flat, tabular pieces of scoria that exhibit light abrasion on one surface. The most extensively used of these items was recovered from Site T-4.

Two complete basalt hammerstones were recovered from Sites T-4 and T-12, and a large hammerstone flake was recovered from Site D15-7. All hammerstones are from surface proveniences, and the two complete items represent extremely varied sizes. The Site T-12 specimen weighs 484.6 g and exhibits light battering on two lateral edges (Figure 30b). The Site T-4 specimen is a massive waterworn boulder weighing over 12 kg. Extensive battering is exhibited on one edge only, at the narrow end of the 34.0-cm-long boulder. Similarly sized and battered boulders were located at Sites T-67 and T-65. These large hammerstones are apparently associated with lava quarrying activities.

The single adze recovered was collected at Site T-15, where it occurred on the ground surface above the entrance path to the sinkhole. This item is rectangular in cross section and exhibits polish on all sides

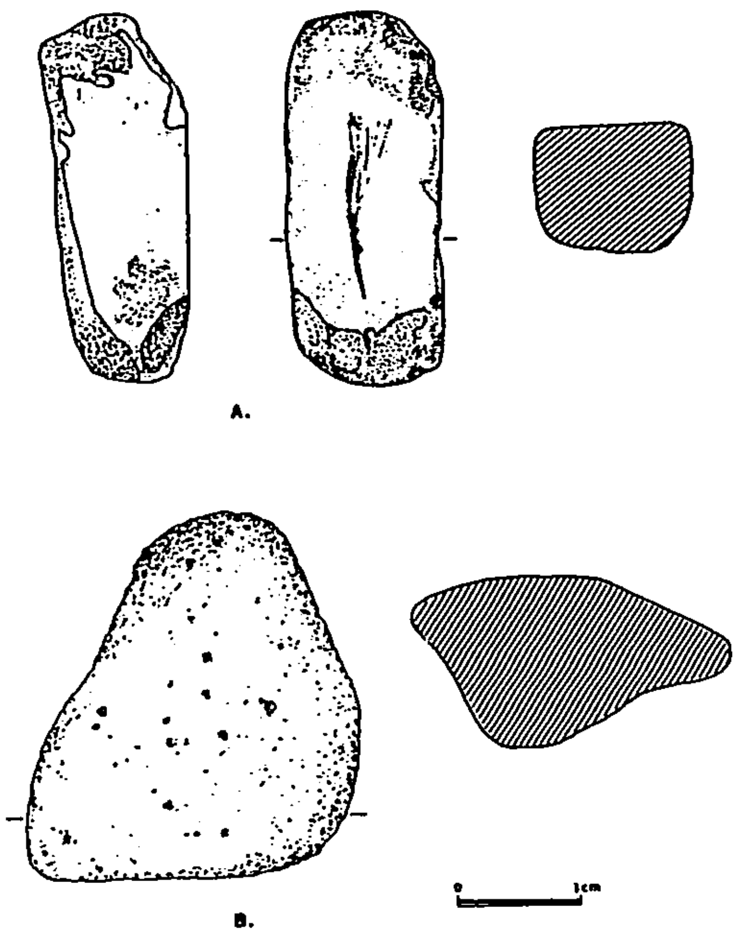

FIGURE 30. Basalt Adze and Hammerstone

(Figure 30a). It is slightly tanged and has been extensively battered on the bit and the butt end. The bit end appears to have been broken and roughly reworked to form a hammering, rather than a beveled, end. Overall length is 9.26 cm, maximum width is 3.95 cm, and maximum thickness is 3.4 cm at the center of the blade.

Adze flakes were recovered from Sites T-4 and T-43; both were from surface contexts. These items exhibit two polished surfaces and former use edges. Three flakes with single, polished surfaces were recovered from the surface of Site T-17; these items are probably adze flakes as well.

Miscellaneous/Other. Twelve miscellaneous items of bone, shell and wood were recovered from five sites within the project area. Bone items are two small, modified pieces of unidentifiable tools collected from the excavation of HF-2 at Site T-39 and from the surface of Site T-12. Shell items include two small, cut pieces of pearl shell, recovered from the surface and from TU-1 of Feature A, Site T-17, and a Cellana sp. shell modified to form a flat oval, recovered from the surface of Feature A, Site T-17. Both pieces of pearl shell are triangular; one is a thin fragment with a single cut edge, and one appears to be a complete awl point (Figure 28e). The lateral edges of this item have been cut by sawing through opposite sides, creating beveled edges on both sides of the cut. One lateral edge is slightly damaged, and the proximal end has been cut and snapped.

The modified Cellana sp. shell exhibits evidence of use for grinding and for cutting. The dorsal surface of this item has been extensively ground so as to nearly flatten the apex of the shell; numerous striations are visible on this surface. The ventral surface of the shell is water-worn and exhibits no grinding scars. The lateral edges have been cut and ground, and they are rounded along c. 70% of the perimeter. The remaining portion of the edge is straight.

Two perforated Cellana sp. shells were collected from the surface of Site T-41. Both items were perforated just above the apex of the shell, on or just off the center. The holes are relatively large (0.9 cm wide) and are somewhat triangular in shape. They appear to have been pecked rather than drilled, and the edges of the holes are relatively ragged. Other shell items include two naturally perforated conus shell spires, recovered from TU-1 at Site T-17.

Six pieces of wood were recovered from Sites T-4 and T-12. Four thin sapling sticks (2.5 cm thick) were collected from Site T-4. Modifications occur on two of the sticks, which have been crudely whittled to form blunt points. The bark has been removed from the sticks, and there is no evidence of burning. Maximum length of the longest stick is 94.0 cm. Other pieces are 45.0 to 54.0 cm long.

Modified wood collected from the surface at Site T-12 consists of two pieces of extremely weathered, milled lumber (not included on the artifact table, as they appear to be historic). These items are both 0.8 cm thick and are amorphous; they appear to be pieces of driftwood. One piece has two modified edges; one edge is straight and one is slightly curved inward. The third side exhibits rodent gnaw marks (weathered). Two adjacent (nail?) holes occur near the point formed by the two modified edges of this piece. The second piece has one straight edge; other edges are breaks.

Finally, a cut pandanus key was recovered from the surface of Site T-17. This item is well-preserved and is completely intact. It is 3.28 cm long and 1.5 cm wide. The ends of the fibrous strands of the key have been cut to form a straight distal end.

CONCLUSION

DISCUSSION

Survey findings are summarized here, and interpretive hypotheses are offered where appropriate. Conclusions are limited at this time by the level of work conducted at the large coastal complexes. Intensive survey was not conducted at these sites, since they had previously been tested (Cordy 1981) and determined to warrant comprehensive data recovery (Cordy 1986b; see Scope of Work). Interpretive analysis is therefore based on reconnaissance-level data collection in the coastal zone, supplemented with information previously collected by Cordy, and on intensive-level survey and testing in the inland zone (300 m to 870-1,477 m from shoreline). Interpretations are considered inconclusive until additional work is conducted at the coastal complexes. Comparative observations are offered, with particular attention to the recently examined cultural resources of Kohana-Iki, located adjacent to and south of Ooma II.

Twenty-five formal/functional types were identified among the 279 features located within the project area (Table 11). The majority of the type descriptions used are formal; however, a few features, such as the stationary hearth, salt pan stone and cupboards, have been assigned functional labels.

Formal Feature Types

Pavements, platforms, and terraces comprise 16.5% of all features located. These formal types are differentiated on the basis of height above ground surface.

Pavements. These types (N=16) consist of fill material a single course above the ground surface. Several courses may occur, in crevices or depressions beneath the pavement that have been filled in order to create a level surface, but these are not visible. Surfacing material used at the 16 pavement features at Ooma II includes coral transported from the storm beach, cobble- to pebble-sized pahoehoe pieces (some of which may have been purposely broken), and small chunks of aa lava. Waterworn basalt pebbles do not occur as a surface for pavements within the project area; however, they do occur as surfaces for platforms.

Coral pavement is generally considered to be more elaborate than lava rubble, and it is often associated with features of a ceremonial (sociopolitical and/or religious) nature. For example, Cordy interprets the large coral pavement at Site D15-1 as a men's house; such features had religious as well as economic functions (1981:161). The pavement at this site covers 90.0 sq m and is bi-leveled, with an upper level separated by a low (0.20 m) retaining alignment. The upper level covers 27.0 sq m and may represent the location of a narrow structure (9.0 m long by 3.0 m wide) which opened to the paved plaza area. Waterworn basalt boulders

Table 11.

FEATURE FREQUENCIES BY FORMAL/FUNCTION TYPE

Type	BPBH* Sites	Sites T-1 thru T-46	Sites T-47# thru T-73	Total
Platform	20	1	4	25
Terrace	3	2	-	5
Pavement	9	5	2	16
Enclosure	8	-	2	10
Single wall	2	3	3	8
C-shaped wall	2	2	11	15
Walled shelter	4	4	7	15
Cave shelter	5	12	8	25
Overhang shelter	-	5	8	13
Rock mound	2	2	-	4
Rubble pile	3	1	16	20
Filled depression	5	2	2	9
Cairn	2	24	26	52
Modified outcrop	-	-	9	9
Bedrock excavation	1	1	19	21
Pahoehoe clearing	-	4	3	7
Rock alignment	1	-	4	5
Petroglyph	-	1	-	1
Footpath	2	2	2	6
Well	-	1	-	1
Shrine	1	-	1	2
Cupboard	2	1	-	3
Surface midden	3	1	1	5
Stationary hearth	-	-	1	1
Salt pan stone	-	-	1	1
Total	75	74	130	279

*Count includes previously and newly identified features at these sites.

#Sites identified during PHRI (1986) survey. All features newly identified.

(disturbed) occur in association with this pavement, in addition to rock mounds, a platform, and C-shaped walls.

Coral pavements also occur at Sites T-14 and T-31, which are smaller coastal complexes with possible ceremonial functions. Two paved areas occur at Site T-14; one is quite small (1.8 sq m), and the other covers an area 19.25 sq m. These pavements are associated with filled crevices, a filled sinkhole, and rubble mounds; indicators of possible burials. The coral pavement at Site T-31 covers 40.0 sq m. This pavement follows natural contours and is irregularly shaped. If a structure were present on the feature, it would probably have been c. 20.0-25.0 sq m. Two upright waterworn boulders and a horizontal boulder are present on this pavement.

Pahoehoe rubble pavements at Sites D15-7 and D15-8 are amorphous and follow natural surface configurations, as does the Site T-31 coral pavement. The Site D15-7 pavement covers a 203.0-sq-m area and has space for a regularly shaped structure with a maximum area of 120.0 sq m. It is possible that no superstructure was present on this paved area. Three amorphous pavements occur at Site D15-8; all are in shallow, collapsed lava blisters. Surface area of these features measures 7.0, 16.0, and 33.5 sq m; they are associated with caves and walled shelters occurring along the perimeters of the blisters. Four platforms and additional stone features also occur on this site.

It appears that pavement features at Ooma II can be divided into categories of formal and informal. Formal pavements exhibit regularity in shape, such as straight to slightly curved sides and identifiable corners; informal pavements follow natural ground configurations and do not have corners or straight sides. Informal pavements are more likely to reflect landscaping, rather than architectural, modifications; however, some informal pavements are of sufficient size to include a regularly shaped superstructure within the total area. If such structures were present, additional alignments, rubble piles or walls should occur within this area. For example, the large pavement at Site D15-7 includes a centrally located alignment. No indications exist of superstructural supports at the Site T-31 coral pavement; however, this feature has been badly disturbed by looters. Informal pavements at Sites T-63 and T-64 are similar to those present at Site T-8 and are associated with small, natural shelter features.

The proportion of pavements among all features at Ooma II (5%) is only slightly higher than the proportion exhibited at Kohana-Iki, immediately to the south, where 10 of 262 (3.8%) features are pavements (Donham 1986a: 17). Formal and informal pavements also occur at Kohana-Iki.

<u>Platforms</u>. Twenty-five platforms have been located at Ooma II; most occur at the large complexes located in the coastal zone (N=20). These features, which are raised above the ground on all sides, exhibit a wide range of variability in size and construction. Seven of the 23 platforms measured have less than 10 sq m of surface area. Five of the seven have a surface area of 6.5 to 9.0 sq m, and two are less than 4.0 sq m. All are

square to nearly square in shape, with the exception of one round platform at Site D15-8. These small platforms occur at Sites T-17 and T-48 and at D15-4, D15-8, and D15-18. The four latter occurrences are thought to be burial platforms; they are associated with larger platforms and wall segments. These small platforms are characteristically constructed from large perimeter boulders and are filled with smaller cobbles and pebbles. Scattered coral is intermixed on the surface. The small platform at Site T-17 probably represents a temporary habitation structure; it is associated with surface midden and an adjacent cave shelter that has been intensively used. This platform does not have a differentiated perimeter or smaller fill material; it is constructed from uniformly sized pahoehoe cobbles.

Five platforms exhibit a surface area of 10.0 to 20.0 sq m. Area values are not clustered within this range; in fact, each of the five features is within its own 2.0 m interval. These five include Site D15-8B (10.24 sq m), Site D15-4A (12.32 sq m), Site D15-8I (14.31 sq m), Site D15-7C (16.2 sq m), and Site D15-6 (18.0 sq m). All but the last of these platforms are smaller than the 17.0 sq m cutoff used by Cordy in identifying permanent sleeping houses. They would, however, fit his special-purpose structure category. It should be noted that surface areas obtained during these investigations are at variance with some of the measurements reported by Cordy (1981:161). These discrepancies are probably related to how the edges of the features were identified.

The only cluster of platform area values occurs within the 20.0 to 23.0 sq m range, where five platforms from five different sites are clustered (Sites T-20 and T-62, and D15-1, D15-7, and D15-8). Features at the three latter sites were tested by Cordy and were assigned to the permanent sleeping house category. The Site T-20 platform is distinct from the other platforms in that it has a significantly greater height (1.5 m as compared with 0.3 to 0.5 m) and an unleveled surface. This feature probably represents a burial, and it was interpreted as such by Barrera (1985). The Site T-62 platform is problematic in that it fits Cordy's permanent sleeping structure characteristics; however, it is in spatial association with the Site D15-8 heiau platform. A specialized function may therefore be indicated.

Seven platforms within the project area have surface areas greater than 26.0 sq m; four of these are within the upper limits for sleeping houses (66.0 sq m), as determined by Cordy (1981:82). These four platforms occur at Sites T-49, D15-4, D15-7, and D15-18. Platforms at Sites D15-4 and D15-7 are very similar in surface area (30.0 and 31.5 sq m, respectively). These features co-occur with smaller platforms and with other features, such as informal paving, utilized caves and overhangs, and rubble piles or mounds. Interestingly, an unspecified number of square nails was recovered from the platform fill at Site D15-7 during Cordy's test excavations (Cordy 1981:243).

The platforms at Sites T-49 and D15-18 were not examined by Cordy; the former platform should probably be included in the permanent habitation category, whereas the latter may have a special purpose relative to the associated heiau and burial platforms.

Three unusually large platforms occur at Sites D15-17, D15-18 and D15-19. The first of these covers an area 80.5 sq m and was probably larger prior to disturbance from the jeep road; undisturbed portions are 1.0 m high. It is adjacent to the high-walled enclosure, Site T-16, and it was not tested by Cordy. The enclosure is a historic feature, and it is suggested here that the Site T-17 platform is also historic. The Site D15-19 platform has a surface area of 202.0 sq m and an average height of 1.2 m. It was tested by Cordy, but was not included in his settlement pattern analysis, due either to the fact that a specific prehistoric structure could not be identified for measuring, or that the prehistoric component was thought to be a heiau (see site description). Present evidence suggests that the platform is a historic habitation structure. Finally, the Site D15-18 platform has a surface area of 297.0 sq m. This platform is interpreted by prior investigators as a heiau. New information conflicting with this interpretation has not been collected to date.

Terraces. Terraces are relatively uncommon at Ooma II (N=5), and they appear to be pavement variants, raised above the ground on one to three sides in order to level a surface on irregular ground. These features occur at Sites T-15, T-31, D15-3 and D15-8. The two terraces at Site D15-3 have been interpreted as sleeping houses by Cordy; they have surface areas of 19.3 and 22.0 sq m. The Site T-15 terrace is part of a sinkhole that has been modified for habitation, and the Site T-31 terrace is a component of the coral pavement discussed above. The terrace at Site D15-8 is of informal design and is quite small; it is directly associated with a cave shelter and a rubble wall within the larger complex of platforms and pavements.

Terrace features are less common at Ooma II (1.7% of all features) than at Kohana-Iki, where 4.2% of all features are terraces (N=11). The higher incidence of terraces in Kohana-Iki is related to the presence of anchialine ponds, a number of which have terraces constructed along their shorelines.

Enclosures. Two enclosure variants were observed within the project area. A single example of a high-walled animal enclosure (D15-16) occurs along the coast. The remaining nine enclosures occur at Sites T-63, T-64, D15-2, D15-3, D15-4, and D15-5. The largest of these encloses an area of 80.3 sq m and is located at Site T-64. Numerous other features (N=17) occur on this site, most of which are temporary shelters. The walls of this feature are 2.2 m wide and 0.6 m high. It appears to have been a habitation feature with low walls that probably supported wood-and-thatch superstructures. The size of this enclosure falls within the range for men's houses, as defined by Cordy; however, its associated features do not conform to predicted intrasite associations.

The enclosures at Site D15-2 have interior areas of 12.7 sq m (Feature A) and 35.20 sq m (Feature B). These features are interpreted by Cordy as a special-purpose structure and a sleeping house, respectively (1981:161). The enclosures at Site D15-4 are smaller, with interior areas of 9.0 and 11.0 sq m. These two features were not identified by Cordy as part of the habitation site. They are within the size range for special-purpose structures and within that for temporary habitations.

C-shaped walls. A total of 15 C-shapes was recorded, 11 of which occur within 300 m from the shoreline. Two C-shapes of relatively substantial construction occur at Site D15-1. One is adjacent to the large coral pavement and was interpreted as a special-purpose structure by Cordy; it has considerable interior midden accumulation. The second C-shape is just south of the platform feature at Site D15-1; it was apparently also a special-purpose structure.

The remaining 13 C-shapes occur at sites interpreted as temporary habitations or specialized activity areas. Most of these (N=9) occur in the coastal zone and are scattered in a relatively regular pattern from north to south (Sites T-51, T-55, T-57, T-64, and T-66). Surface midden is present at the latter three sites. Inland sites with C-shapes are clustered in the northern corner of the project area (Sites T-25, T-44, and T-70). This clustering probably reflects more intense survey coverage here, rather than actual distribution patterns. Two of these three sites were located subsequent to Barrera's inland survey. No surface midden was observed at these sites.

The proportion and absolute number of C-shapes at Ooma II (N=15, 5.3%) is considerably higher than that exhibited at Kohana-Iki (N=4, 1.5%). This difference may reflect a higher incidence of coastal area visitation by non-residents, because most of the shelters are within close proximity to the permanent habitation sites and as such would not have been necessary for local residents. Such a pattern would be expected if the major portion of the Kohana-Iki shoreline was restricted, as indicated by the alignment of boundary cairns around the anchialine ponds at Kohana-Iki.

Shelters that utilize natural bedrock constitute 22% of all the features within the project area; these include caves (N=25), overhang shelters (N=13), walled shelters (N=15), modified outcrops (N=9), and a collapsed lava blister. These features occur at 37 sites, over half of which (N=21) are in the coastal zone. It is likely that the number of temporary shelters is higher than that indicated for the inland zone, given the degree of survey coverage conducted in this zone. A sample re-survey of the inland zone (c. 30% of the inland area) by Cordy resulted in an 80% increase in identified shelters (Cordy 1985). On the basis of this sample, it is likely that there are at least 25 temporary shelter sites in the inland zone.

Caves. Seven of the 25 caves in the project area appear as single, isolated features. All of these are in the inland zone and are widely dispersed within the project area. Surface shell midden was observed at all of these isolated caves (Sites T-6, T-7, T-11, T-12, T-24 and T-27); midden accumulation sufficient for collection occurred at two caves (T-4 and T-24). Artifacts were present at four of these features and include a fishhook (Site T-6), small abraders (Sites T-12 and T-24), and volcanic glass flakes (T-27).

Two or more caves together, or single caves in association with other temporary shelter features, occur at nine sites. Only three of these complexes occur in the inland zone (Sites T-4, T-41, and T-43). Sites T-4

and T-41 had sufficient midden accumulation for collection, and Site T-43 had a sparse surface scatter of shellfish remains. Artifacts were collected from all three sites and include fishing gear (Sites T-4 and T-41), domestic implements (Site T-4), flaked stone (T-4), abraders (all three sites), wood (T-4), and perforated shell (T-41).

Utilized cave shelters occur at three coastal habitation complexes; Sites D15-4, D15-7, and D15-8. In all cases, considerable midden accumulation was observed within the caves, but these features were not tested and midden was not collected during this study. Other coastal cave shelters that are components of complexes occur at Sites T-22, T-47, T-61, T-63, and T-67. Shell midden occurs at all of these features, with accumulations at Sites T-22, T-61, and T-67. No artifacts were located at Sites T-22, T-47 and T-63. Artifacts are expected to occur at Sites T-61 and T-67.

Overhang shelters. Two of the project area's 13 recorded overhang shelters occur as isolated features; both are located in the inland zone (Sites T-5 and T-45). All other overhangs are components of complexes and occur in the coastal zone. The two inland overhangs contain relatively low amounts of shell midden and no formal artifacts. These two overhangs exhibit less intensive use than do the isolated inland cave shelters. Coastal overhang shelters at Sites T-15, T-61 and T-67 exhibit more intense usage; shell midden from these features has not been collected to date.

Modified outcrops/Walled shelters. All of the modified outcrops, and all except two of the walled shelters, occur in the coastal zone. The modified outcrops do not exhibit surface midden, and no associated artifacts were found at these features. Four of the walled shelters occur at habitation complexes D15-1(2), D15-2, and D15-19 and generally are located at the inland edges of the sites; each contains light surface midden.

Rock mounds, rubble piles, cairns, and filled depressions comprise 30% (N=85) of the recorded features. These features are differentiated by structural aspects, rather than by building materials.

Rock mounds. Mounds (N=4) within the project area are well-defined features constructed from chunks or slabs of pahoehoe. The bases of these features generally are 2.0 m or greater, and the heights are at least 0.8 m; sides are either vertical or slightly in-sloping. Some rock mounds, such as Feature E at Site D15-19, have an interior chamber for interment purposes. All four of the rock mounds located within the project area have been interpreted as burial features.

Rubble piles. These features (N=20) consist of haphazard, poorly defined concentrations of stones. The bases of these features generally are scattered over areas ranging from 1.0 to 2.0 m in diameter; heights rarely exceed 0.4 m. Some of these features may represent dismantled cairns or loose stones that were cleared from a selected area and thrown into a pile. Others may have supported structural posts, racks, or small constructions. Most of the rubble piles (74% of 19) occur at four temporary shelter complexes in the coastal zone (Sites T-63, T-64, T-66, and T-69). One occurs at a coastal habitation site (D15-7), and two occur at Site D15-19. A single, isolated rubble pile occurs at one site only (T-72).

Cairns. A total of 52 cairns was located; 26 are newly identified features. Cairns are differentiated from rubble piles on the basis of overall base-to-height proportions. Cairns also exhibit purposive construction, which is not the case with rubble piles. Generally, cairns are markers of paths, boundaries, locales, or specific events at given locales. Definitive functional interpretation of cairns can only be offered when they are in direct association with another identifiable feature, such as a path or cave. Six sites were recorded which consist exclusively of cairns (Sites T-3, T-8, T-9, T-10, T-28, and T-73). One of these sites is a single cairn, and all others consist of two or three cairns in association. These sites all occur in the inland zone.

Pahoehoe clearings. These clearings (N=7) are depressions or horizontal holes cleared in areas where naturally loose stones occur, such as in collapsed blisters or tubes. Some pahoehoe clearings are large enough to have functioned as shelters; others are the size of cupboards. These features are associated with adjacent piles or with scatterings of removed stones; no portable remains were located at these features, and it is difficult to assign a specific function to them. A few clearings may represent removal of rockfall from blisters or crevices by relic hunters looking for burials or artifacts.

Bedrock excavations. These features (N=21) are vertical holes created by the removal of once-intact bedrock. Excavations exhibit battering around the openings where force was used to break away sections of pahoehoe. Bedrock excavations may have associated piles of stone, reflecting the removal of quarried stone to another locale. Several bedrock excavations were located at Site T-67, in addition to two basalt hammerstone tools that had apparently been used at these features. One of the hammerstones is of sufficient size to easily break away sections of the 0.3-m-thick layer of pahoehoe. These excavations are assumed to have a different function than do the pahoehoe clearings, and they appear to represent quarry sites for either the search or the acquisition of specific types of lava. The densest concentrations of pahoehoe excavations are at Sites T-55 and T-56; they are continuous portions of a large quarry area.

Shrines. Two small shrines were newly identified; one at Site D15-4 and another at Site T-63. Both shrines are in very good preservation; the latter has been recently attended, as evidenced by a glass vase with dried flowers. The shrine at Site D15-4 consists of constructed walls and a low terrace on which is positioned three waterworn stones. An upright horizontal and a small rounded stone are present.

With the exception of the stationary hearth (Site T-60), all other features listed in Table 11 occur at complexes with additional component features. The petroglyphs were newly located at Site T-22, a temporary

habitation cave shelter and walled shelter site. The salt pan stone occurs at a newly identified beach complex that includes a small platform (burial?) and two larger platforms (Site T-48).

Functional Interpretation

Tentative functional interpretations are inferred for 61 of the 74 recorded archaeological sites. The functional interpretation and an inventory of component features identified for each site are listed in Tables 3, 4, and 5 (at end).

Permanent habitation. Permanent habitations are defined by the criteria used by Cordy (1981:66). The category includes platforms, pavings and low enclosures with surface areas of 16.0 sq m or more that are of substantial construction and that are associated with small, special-purpose structures. Permanent habitation features are expected to show little to no internal lensing or superpositioning of hearths. Artifact assemblages were not used by Cordy to distinguish between permanent and temporary habitations, due primarily to a lack of systematic investigation of tool variability and occurrence patterning (1981:61). In addition, ecofact depositional patterns were not used in Cordy's definition.

Subsistence data may provide a clearer basis than do artifacts for delineating between permanent and temporary sites, because many tool forms cannot be assigned to specific tasks, and because activities categorically defined as "domestic" also occur at temporary sites. Permanent residential sites are expected to exhibit a greater proportion of domestic faunal remains, whereas temporary sites should exhibit a greater proportion of fish and/or wild bird remains. This difference is potentially indicated in Kirch's (1980) comparison of three ecofactual assemblages, where the permanent site assemblage differs significantly from two temporary sites in the proportion of dog and pig remains. In this comparison, however, the higher proportion of domesticated animal remains is attributed to variation in site settings, rather than to the permanency of the site (Kirch 1980:472).

Ecofactual remains should also be expected to exhibit different distribution patterns within permanent habitation sites that have multiple structures. Kirch suggests that a differentiation between sleeping and cooking houses was probably common at most habitation sites (1985:252). It should also be expected that a good deal of food preparation and consumption occurred out of doors at single-structure sites. This pattern implies that examination of a single feature, particularly a sleeping house, will not provide an accurate reflection of resident subsistence patterns.

Fifteen permanent habitation complexes have been identified at Ooma II (Figure 31a). Ten of these sites were previously recorded by Cordy, and nine were identified as permanent habitations (D15-1 thru D15-8, D15-17, and D15-19). Five additional permanent habitation sites were located in the coastal zone during this study (Sites T-48, T-49, T-60, T-62 and

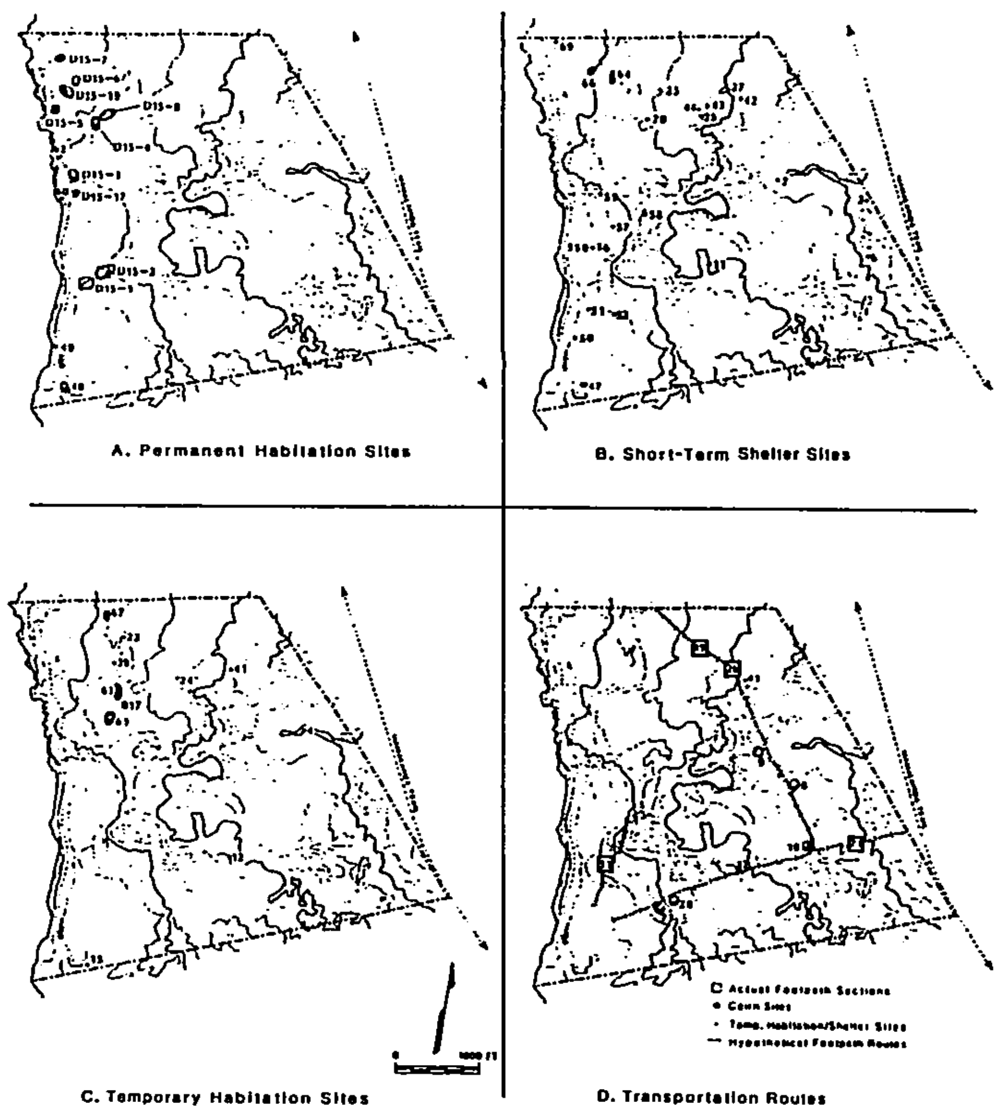

FIGURE 31. Site Patterns by Selected Functional Categories

T-63). Seven of these 15 sites appear to have component features suggestive of ceremonial and/or burial activities (Sites T-48, T-62, D15-1, D15-2, D15-3, D15-4 and D15-19), in addition to the indicated function of residency. Small burial platforms appear to be present at Sites T-48, D15-1, D15-3, and D15-19. A shrine is present at Site D15-4, and a large coral pavement with possible ceremonial significance is present at Site D15-1.

All of the permanent habitations at Ooma II are interpreted by Cordy to be commoner households, following the criteria that three or fewer associated structures occur and that no significant difference in labor was expended during construction (1981:84, 164). If the first criterion is applied to new data collected at the permanent habitation sites during reconnaissance-level mapping, not all sites can be placed in the "commoner" category. For example, at least three additional features fitting the "special-purpose" structure definition occur at Site D15-1 within a very small area of coral paving. The total number of structures within this complex could have been as high as seven or eight. This intrasite pattern is considerably different from that exhibited for Sites T-49, T-62, D15-6, and D15-17. These sites consist of single platforms, with no associated special-purpose structures identified to date.

A comparison of energy expended in the construction of various structures should account for the size differential within given functional parameters. For example, thirteen men's houses were identified within eight North Kona ahupua'a during Cordy's field work (1981:162-164). The mean area of these 13 structures is 84.2 sq m; only three structures are larger than 100 sq m, two of which are within the Ooma II Ahupua'a. The largest men's house at Kohana-Iki, which exhibits a similar to greater population density (1981:170), is 76.0 sq m. In the case of Ooma II, population density alone cannot account for the presence of two extremely large men's houses (or similar communal structure), or what Cordy has hypothesized to be two, large prehistoric-period heiau. If the functional interpretation of these features is correct, some degree of sociopolitical differentiation within the ahupua'a is indicated. Site D15-1 was perhaps a chiefly residence. Alternatively, the men's house at Site D15-1 was perhaps smaller than the size of the pavement, as indirectly suggested by the formal characteristics of the pavement. The men's house (actually a low enclosure) at Site D15-5 may in fact be a historical structure that has been erected over a prehistoric habitation site.

Temporary habitation. Temporary occupation is indicated at 34 sites within the project area. Two subgroups can be identified within this category—shelters with minimal, short-term use and temporary habitation sites with indications of numerous episodes of use. The short-term use shelters exhibit light to very sparse surface shell midden and very few to no portable artifacts. Temporary habitation sites exhibit medium to heavy midden accumulation and a number of portable artifacts representing a variety of activities.

The majority of the temporary sites are subgrouped as short-term shelters (N=24, 70%). They have no portable artifacts and contain very limited evidence of occupation (generally a few shellfish fragments). These sites occur primarily in the coastal zone and probably reflect fishing shelters, shelters associated with lava quarries or other unidentified local resources, or shelters used during visits to a possible ceremonial center or burial area (Figure 31b).

Temporary habitation is indicated at eleven sites (T-4, T-12, T-15, T-17, T-22, T-24, T-39, and T-41, T-61, T-63 and T-67). These sites tend to be clustered in the coastal/inland interface zone in the northern portion of the project area (Figure 31c). Six of the eleven temporary habitations occur between 220 and 320 m from the shoreline and within 410 m from the northern boundary of Ooma II. Two additional shelters, exhibiting repeated use, occur just inland from this cluster. Only one temporary habitation site occurs in the southern half of the project area (Site T-15). It is located on the southern boundary of the project area and is actually in Kohana-Iki. This patterning, which cannot be attributed solely to survey technique, clearly reflects more intense use of the northern portion of the project area by nonresidents or by persons who presumably did not reside in the coastal zone. Artifacts at these sites are predominantly small abraders and volcanic glass debitage; fishing gear and domestic implements occur at a few sites. Age determinations based on volcanic glass hydration rinds indicate that these shelters were in use principally between AD 1600 and 1750; a similar period of use is indicated for the few short-term shelters that contained volcanic glass.

Transportation. Transportation is directly indicated at four sites, where segments of footpaths (N=9) were identified (Sites T-19, T-26, T-53, and T-71). Two of these sites are located in the inland zone, and two are in the coastal zone (Figure 31d). All footpath segments were identified in areas where they crossed aa or rough, broken pahoehoe; they became indistinguishable over the smooth pahoehoe that covers most of the project area. Trail segments at Sites T-19 and T-26 are oriented northwest-southeast and are probably sections of the same footpath. A southward continuation of this path is strongly suggested by an alignment of three cairn sites (T-8, T-9, and T-10; Figure 31d). A temporary habitation cave (Site T-41) is located along this corridor, just south of the identified path segment at Site T-26.

The trail segment at Site T-71 is oriented east-west and may have continued to the coast, as indicated by aligned cairns at Sites T-28 and T-73. The only temporary habitation site in the southern half of the project area (Site T-12) is located along the projected corridor of this footpath. The probable intersection of these two footpaths is at or near Site T-10, where three cairns are located.

Unfortunately, datable remains that may have aided in determining the likely period of use for these footpaths were not recovered from Sites T-12 or T-41. Indirect evidence from other shelter sites suggests that use was probably more intense after c. AD 1600. The footpath corridor indicated at Site T-71 may have been in use while the Mamalahoa Trail was operational. This historic-period, government-built horse trail is immediately beyond the southeastern corner of the project area.

The final footpath segment (Site T-53) is located in aa lava within the coastal zone and is oriented north-south, parallel with the coast line. This footpath apparently connected Sites D15-1 and D15-2 with other locales to the south.

Burials. Burial activities are indicated at Sites T-13, T-20 and T-21. These sites consist of isolated rock mounds (T-13, T-21) and a high platform. Human skeletal remains were observed during testing at Site T-13.

Ceremonial. Sites T-14 and T-31 suggest ceremonial functions, based primarily on the presence of coral paving, waterworn basalt boulders in upright positions, and the relatively unique structural attributes of the sites. Such an interpretation is tenuous, and additional investigations at the sites are needed in order to better determine site function.

Other. Finally, two sites have been determined to have had specialized functions; these are the high-walled animal enclosure at Site D15-16 and a small, faced excavation in aa which appears to have functioned as a storage facility (Site T-54). Similar features occur as components of larger complexes.

Chronology

A general chronology for the West Hawaii region has recently been offered by Kirch (1985), who synthesized data collected by Cordy (1981), Hommon (1976), and Kirch (1980). According to currently available data, initial occupation along the North Kona coast began c. AD 900 in the area of Anaehoomalu (Barrera 1971). Settlement at this time in areas of marginal suitability for agriculture is hypothesized to be related to population expansion in the more favorable windward coast areas (Kirch 1985:288). The population of West Hawaii appears to have remained relatively low until c. AD 1200, when a noticeable rate of increase is indicated. Cordy's investigations suggest that substantial buffer zones occurred between pockets of human occupation, as the population began to increase. The Ooma II Ahupua'a was within this buffer zone, which is believed to have extended from the Kaloko fishpond to Kukio Bay (Cordy 1981:173).

Beginning c. AD 1400, settlements began to be established within the North Kona buffer zone, with pioneer households locating at Kohana-Iki and at Ooma II (Cordy 1981:168). According to Kirch, the overall population of the region nearly doubled each century between AD 1200 and 1600, followed by a leveling off and period of decline (1985:288). It was during this expansion period that the ahupua'a territorial system and land overlordship by nonresidents is thought to have combined with a pre-existing social stratification system to form the uniquely Hawaiian socio-political structure. Evidence of social stratification within the North Kona region has been suggested by Cordy et al. (1975), who identified three levels of social rank (as correlated with energy expenditure) among the residential sites of Kaloko. Cordy suggests that no social stratification was overt within the Ooma II Ahupua'a during this expansion period. Population estimates offered by Cordy indicate a general pattern of expansion which conforms with the overall West Hawaii pattern described by Kirch.

Permanent habitation sites occupied at Ooma II between AD 1400 and 1650 have been dated by Cordy on the basis of hydration-rind age determinations of volcanic glass recovered from the various sites. The earliest occupation appears to have occurred at Site D15-5, which is located closer to the shoreline than any of the remaining eight habitation sites identified by Cordy. This site is in very poor preservation, and it is likely that if additional early sites were present along the shoreline, they may have been washed away. It is obvious that archaeological remains along the shoreline have suffered considerable loss since 1930, when a number of now nonexistent platforms were observed by Reinecke. The temporal period(s) most likely to be underrepresented in the existing archaeological record is impossible to predict at this time. Site destruction by storm wash has, however, affected the existing population estimates and quite possibly the inital settlement dates for Ooma II. This impact has not been sufficiently examined or controlled for interpretive studies.

Additional permanent habitation sites occupied between AD 1400 and 1500 include D15-1, D15-7, and D15-8. Between AD 1500 and 1600, the four sites continued to be occupied, with additional settlements at Sites D15-2, D15-3, and D15-6. Within the next fifty years, Site D15-6 was abandoned, and by AD 1700, Site D15-2 was abandoned. New settlement after AD 1550 occurred at only one site, D15-4.

Available age determinations from temporary habitation and short-term shelter sites at Ooma II indicate that use of these sites did not begin at the same time that coastal habitation sites were established. The earliest volcanic glass date from a temporary habitation site (T-17) is AD 1592±33. This range, as well as all other ranges from temporary sites, indicates a post-AD 1600 use period. In fact, use of temporary shelters appears to be most intense at Ooma II after AD 1650, when the local population as well as the population of the region appears to have begun a significant decline (Kirch 1985:288; Hommon 1976:278). The increase in inland shelters and temporary habitations in the coastal zone during this period suggests population movement into upland areas. The apparent pattern of decrease for this period may be a factor of sampling techniques. The data for the North Kona regional patterns are derived primarily from coastal areas.

Hommon recognized the beginnings of general upland settlements between AD 1400 and 1550 on the Islands of Hawaii, Oahu and Molokai (1976:249). A similar pattern is suggested for the North Kohala ahupua'a of Lapakahi (Rosendahl 1972:495). Volcanic glass and radiocarbon dates from seven upland agricultural sites at Lapakahi indicate a cluster of calendric ranges between AD 1450 and 1750 (Rosendahl 1972:428-434). Rosendahl suggests a gradual shift in residential patterns began c. AD 1500, when development in agricultural technology and accompanying agricultural expansion permitted establishment of permanent residencies in upland areas formerly occupied on a seasonal basis (1972:499). A similar pattern is hypothesized by Hommon, who notes that this expansion did not result in

abandonment of coastal habitations; rather, it fostered specialized production of subsistence commodities for trade between the two environmental zones (1976:258).

The establishment of permanent upland residential sites may have occurred by AD 1450 in North Kona; however, given the apparently late dates for initial coastal settlement, it is reasonable to assume that upland settlement was uncommon before AD 1600.

The development of interacting residential groups in coastal and upland areas can be expected to cause increased coastal-upland mobility, because travel would not be restricted to seasonal tasks of field maintenance, planting, or harvesting of upland resources only; upland residents would now require movement of subsistence materials in a new direction. Social ties between upland and coastal residents would also tend to increase the rate of movement, thereby affecting increased use of inland shelters and temporary habitations.

Cordy has suggested a shift to upland habitation in the North Kona area during the nineteenth century (1985:35), when cartographic evidence of upland houses was first collected. Kuleana awards during the mahele were significantly more concentrated in the upland areas of North Kona than along the coast (Cordy 1986b:36). This pattern of land claims in upland zones certainly reflects a pre-existing pattern of land use for the region, because claims were honored only if claimants could demonstrate a prior attachment to the parcels. It is suggested here that upland expansion at Ooma II began c. AD 1650-1700.

The continuance of coastal habitation at Ooma II during the seventeenth and eighteenth centuries is indicated at four coastal sites (D15-1, D15-4, D15-7, and D15-8), all of which were apparently occupied at contact. The local coastal population at this time is estimated at 48 persons by Cordy (1981:170). This number is four times greater than the population estimated for Kohana-Iki (Cordy 1981:170). The rate of population decrease for Ooma II between AD 1700 and 1780 (11%) is significantly less than that indicated for Kohana-Iki (82%; from 66 to 12). The reason for this marked disparity in neighboring ahupua'a populations remains unclear.

Nineteenth-century habitation sites are indicated primarily on the basis of artifacts reported by Cordy and observed during this study. During his test excavations at Ooma II, Cordy recovered nineteenth to twentieth century artifacts at Sites D15-2, D15-3, D15-5, D15-7, and D15-19 (1981:242-243; 1986a:32). Cordy gave Sites D15-2 and D15-5 abandonment dates of AD 1660 and 1720, respectively (1981:166). In these cases, evidence for historic occupation is not used to infer a continuous occupation of the site through the contact period. Historic artifacts are not given equal weight with hydration-rind date ranges, which are used specifically to infer continuous periods of site occupation, despite the sometimes considerable differences between date means. If the assumption of continuous occupation were applied at sites which have evidence of nineteenth-century occupation, no population decrease would be indicated between AD 1700 and contact. The consideration of historic materials and of historic modifications to what have been assumed to be prehistoric structures should result in a significantly clearer picture of the cultural resources at Ooma II.

EVALUATIONS AND RECOMMENDATIONS

Evaluations

Tentative significance evaluations are summarized on a site-specific basis in Tables 3, 4, and 5 (at end). Prior evaluations have been briefly outlined by Cordy for the major coastal complexes (1986b), and four of these sites have been discussed in terms of their preservation potential (Cordy 1986a). These prior evaluations are included below, where relevant.

The significance of cultural remains can be defined in terms of potential scientific research, interpretive, and/or cultural values. The research potential of a given archaeological site is best determined when research problems are explicated and when the site is shown to contain information that may aid in solving these problems. Previous work by Cordy at Ooma II and other North Kona study areas has provided a base from which to direct further research. Cordy's hypotheses (outlined above) concerning the dates of earliest settlement, the social structure of the local population, and the functional uses of coastal sites have not been tested by other researchers. As is evident at Ooma II, new data are certainly present, both at the previously recorded sites and at newly recorded coastal sites. Specific problems that can be addressed at Ooma II include refining the means by which platforms, pavements, and terraces are functionally categorized. Until this problem is solved, higher levels of interpretation are possibly subject to major error. Sites with potentially significant information content for developing more accurate functional models include D15-1 through -8, T-31, T-39, and T-48.

In addition to defining the function of individual features, further work is badly needed to define and interpret the range of features present at the various coastal complexes. The categorization as commoner households of such markedly varied sites as D15-1 through -8 may be sufficient for generalization purposes, but it is not sufficient for understanding local or regional socio-economic patterns. In addition, Cordy's designation of these sites as commoner households is an untested hypothesis.

The problem of better understanding land use and resource exploitation requires intensive investigation at temporary habitation and extractive sites located in various environmental zones. Site patterning, chronological data, ecofactual remains and inferred site functions are the principal data sets used in developing land use models. Significant data are still uncollected at two newly recorded coastal area sites, T-61 and T-67, and at previously recorded Site T-17. Intensive survey at these sites has indicated that they warrant additional data recovery in a

mitigation program. Their value lies primarily in the extremely rich deposits of subsistence remains and in the presence of various feature forms. Additional work is also warranted at Sites T-14 and T-15, which also contain important information relevant to this research problem. These sites have been previously assessed for the adjacent Kohana-Iki Resort project area (Donham 1986a); their inclusion in this mitigation program is contingent upon accurate location of the project area boundary in the field.

In summary, future research at Ooma II should find significant new data for further examination of the following research topics:

Culture history— Examine and possibly revise the existing settlement chronology through dating of inland sites and features at coastal complexes; expand the local chronology to include the early historic period, late nineteenth/early twentieth centuries, and the modern period.

Settlement patterns——— Refine the functional model used to define households, document the range of variation reflected at habitation sites, determine archaeological correlates for ceremonial features.

Human ecology—— Identify key food resources exploited within the project area and those transported from upland or adjacent areas; investigate potential environmental change which may have been caused by population expansion during the late fourteenth/early fifteenth centuries and subsequent effects of this change on the structure of the local population.

Culture process— Identify variables which indicate synchronic variation possibly reflective of socio-political or socio-economic stratification within the project area; discuss temporal, functional, and organizational implications on the areal and regional level; explore the role of marine, upland, and barren inland resource exploitation through time, as indicated from portable remains, site locations and other functional inferences.

A number of sites within the project area have information of importance in addressing the above issues. This information has been collected at most of the inland sites, but additional information is present at 16 sites—(D15-1 thru -8, D15-19, T-14, T-15, T-17, T-31, T-48, T-61, and T-67).

Archaeological sites with potentially high interpretive value are those that provide well-preserved and integral examples of specific types of sites. A major condition in determining significance is the uniqueness of feature(s) and the immediate site setting. The interpretive value of specific sites is identified at this stage of analysis by considering the following criteria:

1. Site integrity--Are the structural remains of the site sufficiently well-preserved, or can original structural features be accurately reconstructed?

2. Site function—Can site function be accurately determined and sufficiently described so as to be informative to the general public? Can the temporal, social, and ethnic background of site builders/occupants be ascertained or reasonably indicated?

3. Site information--Does the site, together with interpretive data, create a non-redundant, informative, and generally interesting locale? Is the site representative of a structural or functional type, or is it a unique feature which has not been previously identified for the area?

Three coastal sites have been previously identified by Cordy as having high interpretive potential; these include Sites D15-1, D15-4, and D15-19 (Cordy 1985:45). A fourth coastal site with high interpretive potential is T-15, an extensively modified sinkhole with a faced well, pavement, walls, and modified overhangs. This site also contains important research information, all of which can be gathered without damage to the various structures within the site. Further work at Sites T-15, D15-1, and D15-4 is needed if the sites are to be properly interpreted.

A few additional inland sites have some potential for use as interpretive displays, due to the well-preserved or unique nature of the sites. Site T-51 is a well-preserved example of a C-shaped shelter constructed in aa lava. Site T-22 has the only petroglyphs located to date within the project area; these petroglyphs are five anthropomorphic figures carved within a 2.0 m area. They are very close to Site T-21, a rock mound that is probably a burial. This adjacent feature could be easily preserved in conjunction with the petroglyphs. Additional sites with interpretive value also have cultural value and are recommended for preservation; these are listed below.

Sites with potentially high cultural value are locations with traditional uses and those that have significant meaning in the context of a traditional way of life. Three sites within the project area have been previously identified by Cordy as having high cultural value as religious structures; these are D15-18, D15-19, and D15-4 (1986a:45). Other sites with high cultural value are burial mounds or platforms, a number of which appear to be present within the project area. Mounds at Sites T-13 and D15-19 are confirmed burial features, and it is likely that burials occur in similar mounds at Sites T-21 and T-33 (D15-3). At least one burial

platform is indicated at Sites T-48, T-62, T-20, D15-1, D15-3, D15-8, D15-18, and D15-19. The shrine at Site T-63 may be associated with a crevice burial. Preservation or a suitable reinterment program is warranted for burial features.

Recommendations

Additional data recovery is recommended at this time for 24 sites that have archaeological information of research value. These sites include major coastal complexes D15-1 through D15-8 and D15-17 through D15-19; two newly identified coastal platform complexes, Sites T-48 and T-62; a modified sinkhole and well, Site T-15; and two coastal sites that were possibly ceremonial in nature, T-14 and T-31. Data recovery is also recommended at three cave shelter sites with midden deposits (Sites T-17, T-61, and T-67) and at an inland trail section (Site T-71). Further investigations are also recommended at potential burial sites T-13, T-20, T-21 and T-63, if they are not to be preserved and protected.

Preservation is recommended for nine sites; five of these have high interpretive value (Sites T-15, D15-1, D15-4, D15-18, and D15-19). With the exception of Site T-15, these sites also have cultural value. Sites D15-1, D15-4, and D15-19 have been previously selected as sites with high interpretive value (Cordy 1986a). These sites are all relatively well preserved, and they are good examples of specific site types. Additional data recovery is recommended at Sites D15-1, D15-4, and T-15; such recovery is considered imperative if these sites are to be properly interpreted. Data recovery at Sites D15-1 and D15-4 should permit a clear definition of specific features that are of preservation quality. Both sites are quite large in area, and it may not be necessary to preserve the complexes in their entirety.

Preservation is also recommended for four sites, due to their cultural significance as burials or shrines; these include Sites T-13, T-20, T-21 and T-31. Preservation for cultural significance is provisionally recommended for six sites that may contain burial features (Sites D15-3, D15-8, T-14, T-48, T-62, and T-63). Burials were confirmed to be present in rock mounds at Sites T-13 and D15-19, and it is expected that they are present in mounds of very similar construction at Sites T-21 and D15-3 (Barrera's Site T-33). Burial platforms have been tentatively identified at Sites D15-1, D15-8, D15-18, D15-19, and T-48. Sites D15-1, D15-3, and D15-8 have been recommended for further work, and it is assumed that the potential burial features at these sites would be tested at that time. Sites D15-18 and D15-19 have been recommended for preservation; the associated platforms could therefore be preserved along with the major features. It might be added that the burial mound associated with Site D15-19 is c. 30.0 m from the main feature and that additional platform burials(?) occur between these features. In this case, preservation of the entire complex would require that a relatively large area be set aside.

Isolated burial mounds at Sites T-21 and T-13 should either be preserved or disassembled during the mitigation phase, with reinterment of the skeletal remains in a proper location, preferably within Ooma II. Finally, a recent small shrine at Site T-63 may indicate the presence of a crevice burial at the site (directly below the shrine). This feature should be examined.

Five additional sites have potential for interpretive development; however, their significance as site types is relatively lower than the significance of those sites listed above. These sites include coastal complexes D15-2 and D15-8, the petroglyphs at Site T-22, well-preserved C-shaped shelters at Site T-51, and the high-walled enclosure at Site D15-16.

In summary, sufficient research information was collected during the intensive survey and testing program to permit a recommendation of no further work at the majority (N=50) of the 74 archaeological sites within the Ooma II project area. A few sites merit preservation for their interpretive and/or cultural values, and additional research information is present at 20 sites. All 24 sites for which further work and/or preservation is recommended are listed below, with a brief description and a summary of recommended further action.

<u>Site D15-1</u> Major coastal complex with six previously identified features, and at least five additional features, including a large coral pavement, two burial platforms, four shelters, and other minor features.

Recommendations: <u>Additional data recovery</u>--map all component features, test burial platforms and rubble-filled depressions, collect midden in shelters, excavate additional units in coral platform to obtain construction and subsistence data.

<u>Preservation</u>--indicated for major features only, including coral paving, burial platforms, larger shelters (data recovery required for accurate interpretation of site).

<u>Site D15-2</u> Major coastal complex with four component features, including two habitation enclosures, a walled shelter, and a steppingstone path.

Recommendations: <u>Additional data recovery</u>--map all component features, collect midden from all features.

<u>Preservation</u>--the enclosure features are not particularly unique, but they are well preserved and have preservation potential; one or both could be incorporated into a landscape plan if desired.

<u>Site D15-3</u> Major coastal complex with five previously identified component features, including three terraces, an enclosure, and a burial mound (Site T-33); and possibly a sixth feature.

Recommendations: <u>Additional data recovery</u>--map all component features, excavate all platforms to extent necessary in order to determine function.

<u>Preservation</u>--the burial mound should be preserved, or reinterment of any preserved skeletal material will be necessary.

<u>Site D15-4</u> Major coastal complex with 13 component features, including three platforms, three pavements, a shrine, cave shelter, two enclosures, and other minor features.

Recommendations: <u>Data recovery</u>--map all component features, test platforms, excavate midden deposit in cave, and collect surface midden, test pavements and filled depressions.

<u>Preservation</u>--minimally, the major platforms and shrine should be preserved; peripheral features may not require preservation. This site was identified by the Historic Sites Section as having high interpretive and cultural values, and it also has high research value.

<u>Site D15-5</u> Coastal complex with three component features within a large enclosed area.

Recommendations: <u>Data recovery</u>--excavate to the extent necessary in order to determine more precisely the nature and function of the site; it is badly eroded and may not require extensive excavation.

<u>Preservation</u>--not indicated at this time.

<u>Site D15-6</u> Coastal complex with four component features, including a platform, pavement, cupboard and wall.

Recommendations: <u>Data recovery</u>--map component features, excavate additional units in platform and pavement in order to collect subsistence information, examine possible relationship between this site and D15-19, which is nearby.

<u>Preservation</u>--not indicated at this time.

Site D15-7 Major coastal complex with nine features, including three platforms, pavements, rubble piles, a cave shelter, and other minor features.

Recommendations: Data recovery--excavate units in platforms in order to collect subsistence data; collect deposit in cave, including dating materials.

Preservation--not indicated at this time; the site has been affected by recent recreational activities.

Site D15-8 Major coastal complex with 13 component features, including platforms, terraces, cave shelters, pavements, walls, and rubble-filled depressions.

Recommendations: Data recovery--map all component features, excavate deposits in caves, collect surface midden, conduct excavation of platforms and terraces in order to better determine feature function and to collect subsistence material.

Preservation--not imperative at this time, but data recovery findings may indicate features with high cultural value; this site is located very close to D15-4 and may be functionally related.

Site D15-17 Single large platform adjacent to high-walled enclosure; not tested by Cordy.

Recommendations: Data recovery--complete detailed plans and profiles of platform, excavate a sufficient area of the platform in order to determine period of use and general function.

Preservation--not indicated at this time.

Site D15-18 Coastal heiau site with four associated platforms; one was recorded at Site T-35 by Barrera.

Recommendations: Data recovery--map component features and complete detailed plans and profiles of heiau, test platforms in order to determine if they are burials or structural features, obtain dating and subsistence data if the latter function is indicated (these platforms have not been previously tested by Cordy).

Preservation--the heiau has been recommended for preservation by the Historic Sites Section; recommendation of preservation for associated platforms is contingent upon data recovery findings.

Site D15-19 Coastal historic habitation with possible prehistoric heiau component; five associated features, including pavements, rubble mounds, and one confirmed burial mound.

Recommendations: Data recovery--map component features and complete detailed plans and profiles of the platform, test platform in order to determine building stages, if present: test associated features in order to determine if they are burials.

Preservation--the site has been recommended for preservation by the Historic Sites Section; preservation of the associated burial mound and other features (if burials), or reinterment of any remaining skeletal material will be necessary if these are not to be preserved.

Site T-13 Isolated burial mound in inland zone, burial confirmed.

Recommendations: Disassemble mound and reinter skeletal remains, or preserve the feature intact.

Site T-14 Small coastal complex with five component features, including two small coral pavements, a rubble-filled blister, and other minor features. This site has been recorded for the Kohana-Iki project area as well.

Recommendations: Data recovery--determine project area boundary in relation to this site prior to any further work; map component features, test filled blister, and collect subsistence and dating data.

Preservation--not indicated at this time.

Site T-15 Extensively modified sinkhole in coastal zone, with seven component features, including a faced well, terrace, overhang shelters, paving, wall, and cairn. This site was previously recorded within the Kohana-Iki project area.

Recommendations: Data recovery--determine location of project area boundary prior to data recovery; collect midden deposits in overhangs, clear all vegetation, and complete detailed plan and profile maps.

Preservation--recommended by virtue of the unique nature of the site and well-preserved features, all of which are contained within a relatively small space; value is interpretive rather than cultural.

Site T-17 Inland/coastal transition zone complex with four component features, including cave shelters and a platform.

Recommendations: Data recovery--excavate all midden deposits in caves, test platform or excavate to extent possible in order to determine function; collect surface materials.

Preservation--not indicated at this time.

Site T-20 Rock platform, interpreted as probable burial.

Recommendations: Disassemble, and reinter any skeletal remains, or preserve the feature intact.

Site T-21 Rock mound interpreted as probable burial.

Recommendations: Disassemble, and reinter any skeletal remains, or preserve intact.

Site T-31 Coral-paved terrace with associated cairns and filled crevices; in coastal zone.

Recommendations: Data recovery--map associated features, excavate filled crevices to determine if burials are present, conduct limited subsurface testing of terrace, if the feature is to be preserved.

Preservation--Recommended for site due to cultural significance as a shrine; this may also include significance as a burial site, pending examination of filled crevices. Reconstruction of terrace, where affected by vandals, also recommended as part of preservation.

Site T-48 Coastal complex with three platforms and a stationary salt pan stone; not previously tested or mapped.

Recommendations: Data recovery--map all component features, excavate features in order to obtain dating and subsistence data.

Preservation--not indicated at this time; however, the large grinding stone has interpretive value as a display item; it should be curated or displayed in an appropriate place within the project area.

Site T-61 Complex in coastal/inland interface zone with seven component features, including five cave or overhang shelters, a cairn and rubble piles.

Recommendations: Data recovery--map all component features, excavate midden deposits in caves, collect surface material.

Preservation--not indicated at this time.

Site T-62 Single platform probably associated with the Site D15-18 complex; badly eroded by wave action.

Recommendations: Data recovery--excavate a few units in order to obtain dating and subsistence material.

Preservation--not indicated at this time.

Site T-63 Complex with 13 component features, including recent shrine over what may be crevice burial. Other features are rubble piles, pavements, walled shelters.

Recommendations: Data recovery--examine filled crevices and one large cairn in order to determine if burials are present; collect surface materials.

Preservation--not indicated at this time; however, additional findings may alter this recommendation.

Site T-67 Complex with 17 component features in coastal/inland interface zone; two caves, several cairns, walled shelters, other minor features and bedrock excavations present.

Recommendations: Data recovery--map all component features, excavate cave deposit, collect surface midden.

Preservation--not indicated at this time.

Site T-71 Inland steppingstone footpath segment that may be a portion of an upland/coastal transportation route.

Recommendations: Data recovery--conduct a thorough examination of areas east and west of trail segment, in order to determine if additional portions of the trail exist. Insure accurate locational plotting of the preserved section.

Preservation--not indicated at this time.

As an important initial step of further work in the project area, it is recommended that the project area boundaries be accurately marked in the field by professional surveyors and that all sites be accurately plotted on an appropriately scaled map by professional surveyors, with the help of a qualified archaeologist. This work would greatly aid development planning and would help in management decisions regarding sites with preservation value.

SUMMARY OF GENERAL SIGNIFICANCE ASSESSMENTS AND RECOMMENDED GENERAL TREATMENTS

To facilitate state and county review of the evaluations and recommendations discussed above, general significance assessments and recommended general treatments for all archaeological sites identified within the Ooma II project area are summarized in Table 12. Fifty-nine of the 74 identified archaeological sites have been determined to be significant solely for their information content. All data with potential for use with present or future reseach were collected from 50 of these 59 sites during the intensive survey and testing program. These 50 sites therefore no longer contain endangered uncollected information (Significance Category X), and no further data collection or other mitigative measures can be justifiably recommended at this time (Recommended Treatment NFW). The 50 sites included in this category are the following:

T-1 thru T-12, T-16, T-19, T-22 thru T-28, T-39, T-41 thru T-47, T-49 thru T-60, T-64 thru T-66, T-68 thru T-70, T-72, T-73, and D15-16.

The remaining nine sites determined to be significant solely for their information content still contain significant information (Significance Category A), and additional data collection has been recommended for these

sites (Recommended Treatment FDC). The following sites are within this category:

D15-2, D15-5 thru D15-7, D15-17, T-17, T-61, T-67, and T-71

Six sites have been determined to be significant for their information content, and they may also have cultural significance as burial sites (provisionally, Significance Category C), pending the findings of further investigation. Data collection is recommended at this time; if burials are found at any site, recommended treatment of these burials will be to preserve and protect the specific burial features (provisionally, Recommended Treatment PAI). If this treatment is not feasible, excavation for the disinterment of skeletal remains will have to be conducted, with additional studies focused on the skeletal remains. Reinterment of skeletal remains according to appropriate State Health Department regulations and procedures is recommended, after completion of proper scientific study. The following sites are within this category:

D15-3 and D15-8, T-14, T-48, T-62, and T-63

One site (T-15) has significant information content and is an excellent example of a site type. Further data collection is recommended at this site, with preservation and some level of interpretive development (Recommended Treatments FDC and PID). This recommendation is pending proper location of the project area boundary.

Four sites have been determined to be significant for information content, as excellent site type examples, and for their cultural value as religious/burial sites (Significance Categories A, B, and C). Recommended treatment for these sites is to conduct data collection and then to develop the principal features of the complexes as interpretive locales, or at least to preserve the principal features "as is" and to protect them from adverse effects of development. Sites in this category are:

D15-1, D15-4, D15-18, and D15-19

The remaining four sites have been determined to be significant for their information content and for their cultural value--three are burial sites (T-13, T-20 and T-21), and one is a shrine (T-31). Recommended treatment for all four of these sites is to preserve and protect the sites. If this treatment is not possible, data collection would have to be conducted. For the three burial sites, disinterment of skeletal remains would have to be conducted, with additional studies focused on the skeletal remains. Reinterment of skeletal remains according to appropriate State Health Department regulations and procedures is recommended, after completion of proper scientific study.

Table 12.

SUMMARY OF GENERAL SIGNIFICANCE ASSESSMENTS AND RECOMMENDED GENERAL TREATMENTS OOMA II RESORT DEVELOPMENT PROJECT AREA

Site or Feature No.	Significance Category A	X	B	C	Recommended Treatment FDC	NFW	PID	PAI
D15-2	+	-	-	-	+	-	-	-
D15-5	+	-	-	-	+	-	-	-
D15-6	+	-	-	-	+	-	-	-
D15-7	+	-	-	-	+	-	-	-
D15-17	+	-	-	-	+	-	-	-
T-17	+	-	-	-	+	-	-	-
T-61	+	-	-	-	+	-	-	-
T-67	+	-	-	-	+	-	-	-
T-71	+	-	-	-	+	-	-	-
Subtotal: 9	9	0	0	0	9	0	0	0

General Significance Categories:

A=Important for information content, further data collection necessary (PHRI=research value);
X=Important for information content, no further data collection necessary (PHRI=research value, SHPO=not significant);
B=Excellent example of site type at local, region, island, state, or national level (PHRI=interpretive value);
C=Culturally significant (PHRI=cultural value).

Recommended General Treatments:

FDC=Further data collection necessary (intensive survey and testing, and possibly subsequent data recovery/mitigation excavations);
NFW=No further work of any kind necessary, sufficient data collected, archaeological clearance recommended, 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);
PAI=Preservation "as is," with no further work (and possible inclusion into landscaping), or minimal further data collection necessary.

Table 12. (Cont.)

Site or Feature No.	Significance Category A	X	B	C	Recommended Treatment FDC	NFW	PID	PAI
T-48	+	-	-	*	+	-	-	*
D15-3	+	-	-	*	+	-	-	*
D15-8	+	-	-	*	+	-	-	*
T-14	+	-	-	*	+	-	-	*
T-62	+	-	-	*	+	-	-	*
T-63	+	-	-	*	+	-	-	*
Subtotal: 6	6	0	0	6	6	0	0	6
T-15	+	-	+	-	+	-	+	-
Subtotal: 1	1	0	1	0	1	0	1	0
D15-1	+	-	+	+	+	-	+	-
D15-4	+	-	+	+	+	-	+	-
D15-18	+	-	+	+	+	-	+	-
D15-19	+	-	+	+	+	-	+	-
Subtotal: 4	4	0	4	4	4	0	4	0
T-13	+	-	-	+	*	-	-	+
T-20	+	-	-	+	*	-	-	+
T-21	+	-	-	+	*	-	-	+
T-31	+	-	-	+	*	-	-	+
Subtotal: 4	4	0	0	4	4	0	0	4
All others	-	+	-	-	-	+	-	-
Subtotal: 50	0	50	0	0	0	50	0	0
Total: 74	24	50	5	14	24	50	5	10

*Provisional assessment, definite assessment pending further data collection (i.e., testing features for presence/absence of skeletal remains).

REFERENCES CITED

Armstrong, R. Warwick (ed.)

1973 Atlas of Hawaii. Honolulu: University of Hawaii Press.

Barrera, William J., Jr.

1971 Anaehoomalu: A Hawaiian Oasis. Pacific Anthropological Records No. 15. Dept. Anthro., B.P. Bishop Museum.

1985 Ooma II, Hawaii: Archaeological Reconnaissance. Chiniago, Inc. Prepared for Helber, Hastert, Van Horn & Kimura.

Cordy, Ross H.

1981 A Study of Prehistoric Social Change: The Development of Complex Societies in the Hawaiian Islands. New York: Academic Press. (Virtually identical to author's 1978 Ph.D. dissertation [Anthropology, University of Hawaii], with addition of an epilogue.)

1985 Hawaiian Island Archaeology: Ooma & Kalaoa Ahupua'a, Kekaha, North Kona. Working Paper I, Historic Sites Section, Division of State Parks, Dept. of Land and Natural Resources, State of Hawaii.

1986a Fieldcheck, Ooma II, North Kona, Hawaii. Manuscript on file, Historic Sites Section, Division of State Parks, Dept. of Land and Natural Resources, State of Hawaii.

1986b Ooma II Resort Historic Preservation Assessment Scope of Work. Historic Sites Section, Division of State Parks, Dept. of Land and Natural Resources, State of Hawaii. Prepared for Helber, Hastert, Van Horn & Kimura.

Cordy, Ross H., Robert C. Renger, Robert Hitchcock, and Joseph Tainter

1975 Archaeology of Kaloko; A Generalized Model of a Hawaiian Community's Social Organization and Adaptation. Manuscript on file, Dept. of Anthro., University of Hawaii.

Donham, Theresa K.

1986a Full Archaeological Reconnaissance Survey, Kohana-Iki Development Project Area, Land of Kohana-Iki, North Kona, Island of Hawaii. PHRI Report 216-040286. Prepared for Helber, Hastert, Van Horn & Kimura.

1986b Archaeological Reconnaissance Survey, Makalawena Coastal Development Area, Land of Makalawena, North Kona, Island of Hawaii. PHRI Report 245-091886. Prepared for The Kamehameha Schools/Bernice P. Bishop Estate.

Haun, Alan E.

1986 Archaeological Survey and Testing at the Bobcat Trail Habitation Cave Site (50-10-30-5004), Pohakuloa Training Area, Island of Hawaii, Hawaii. PHRI Report 184-041686. Prepared for U.S. Army Engineer District, Honolulu.

Hawaii Department of Land and Natural Resources [DLNR]

1970 An Inventory of Basic Water Resources Data: Island of Hawaii. Division of Water and Land Development. Hawaii Department of Land and Natural Resources Report R34. Honolulu.

Hay, Deborah, Alan E. Haun, and Paul H. Rosendahl

1986 Kahaluu Data Recovery Project: Excavations at Site 50-10-37-7702, Kahaluu Habitation Cave, Land of Kahaluu, North Kona, Island of Hawaii. PHRI Report 61-022084. Prepared for the Hawaii County Office of Housing and Community Development.

Hommon, Robert J.

1976 The Formation of Primitive States in Pre-Contact Hawaii. Ph.D. diss. University of Arizona.

Kay, E. Alison

1979 Hawaiian Marine Shells, Reef and Shore Fauna of Hawaii. Section 4: Mollusca. B.P. Bishop Museum Special Publication 64(4). Honolulu: Bishop Museum Press.

Kirch, Patrick V.

1979 Marine Exploitation in Prehistoric Hawaii: Archaeological Investigations at Kalahuipa'a, Hawaii Island. Pacific Anthropological Records 28. Dept. Anthro., B.P. Bishop Museum.

1980 Polynesian Prehistory: Cultural Adaptation in Island Ecosystems. American Scientist 68:39-48.

1982 The Ecology of Marine Exploitation in Prehistoric Hawaii. Human Ecology 10:455-476.

1985 Feathered Gods and Fishhooks: an Introduction to Hawaiian Archaeology and Prehistory. Honolulu: University of Hawaii Press.

Macdonald, Gordon A., Agatin T. Abbott, and Frank L. Peterson

1983 Volcanoes in the Sea. Honolulu: University of Hawaii Press. (Second edition.)

Michels, Joseph W.

1986a Hydration Rate Constants for Pua'a 2 (Kona) Volcanic Glass, Hawaii Island, Hawaii. Mohlab Technical Report No.59. State College, Pa.

1986b Hydration Rate Constants for Puuanahulu (North Kona) Volcanic Glass, Island of Hawaii. Mohlab Technical Report No.62. State College, Pa.

Reinecke, James E.

1930 Survey of Hawaiian Sites: From Kailua, Kona to Kalahuipuaa, Kohala. Dept. Anthro., B.P. Bishop Museum.

Rosendahl, Paul H.

1972 Aboriginal Agriculture and Residence Patterns in Upland Lapakahi, Island of Hawaii. Ph.D. diss. University of Hawaii-Manoa.

Sato, Harry H., Warren Ikeda, Robert Paeth, Richard Smythe, and Minoru Takehiro, Jr.

1973 Soil Survey of the Island of Hawaii, State of Hawaii. U.S. Dept. Agriculture-Soil Conservation Service and Univ. of Hawaii Agri. Experiment Station. Washington, D.C.: Government Printing Office.

Sinoto, Yosihiko H.

1975 Hawaiian Fishhook Classification and Coding System. Ms.082175. Dept. Anthro., B.P. Bishop Museum.

Springer, Hannah Kihalani

1985 Appendix B: Regional Notes from Kekaha: Kuki'o. IN Alan T. Walker and Paul H. Rosendahl, Full Archaeological Reconnaissance Survey, Kukio Resort Development Project Area, Land of Kukio 1st, North Kona, Island of Hawaii. PHRI Report 167-090385. Prepared for Phillips, Brandt, Reddick & Associates and Huehue Ranch.

Table 3.

SUMMARY OF SITES AND FEATURES PREVIOUSLY IDENTIFIED BY BARRERA (1985) AND CORDY (1986)

Site & Feature Number	Formal Site/Feature Type	Tentative Functional Interpretation	*Significance Evaluation R	I	C	#Field Work Tasks DR SC EX	Comments
T-1	Complex (4)+	Indeterminate	L	L	L	None	Cairn near Mamalahoa Trail
A	Cairn						
B-D	Pahoehoe clearings						
T-2	Pahoehoe clearing	Indeterminate	L	L	L	None	Loose rockfall pulled away from ledge, no structure to pile
T-3	Cairns (2)	Indeterminate	L	L	L	None	Very crude, haphazard piles, pahoehoe boulders
T-4	Complex (4)	Temporary habitation	H	H	H	None	Data collection completed; midden and artifacts concentrated in Fea. A.
A	Cave shelter						
B	Walled shelter						
C-D	Cairns						
T-5	Modified overhang shelter	Temporary habitation	H	L	L	None	Sparse midden deposit, some filling and leveling at entrance
T-6	Cave shelter	Temporary habitation	H	H	H	None	Thin ash deposits on floor with sparse midden scatter
T-7	Cave shelter	Temporary habitation	L	L	L	None	Sparse surface scatter, no modifications

*Significance Evaluation--Nature: R = scientific research, I = interpretive, C = cultural;
Degree: H = high, M = moderate, L = low.

#Field Work Tasks: DR = detailed recording (scaled drawings, photographs, and written descriptions), SC = surface collections, EX = test excavations.

+Number of component features within complex.

NOTE: Barrera (1985) sites = T-1 thru 40, Cordy (1986) sites = T-41 thru 46.

Table 3. (Cont.)

Site & Feature Number	Formal Site/Feature Type	Tentative Functional Interpretation	Significance Evaluation R	I	C	Field Work Tasks DR SC EX	Comments
T-8 A-C D	Complex (4) Cairns Rubble pile	Indeterminate	L	L	L	None	-
T-9	Cairns (2)	Indeterminate	L	L	L	None	-
T-10	Cairns (3)	Indeterminate	L	L	L	None	-
T-11	Cave shelter	Temporary habitation	L/M	L	L	None	Very sparse surface midden, no soil
T-12	Cave shelter	Temporary habitation	M	M	M	None	Moderate midden deposit; data recovery completed
T-13	Mound	Burial	M	M	H	- - +	Tested; skeletal material located
T-14 A B C D E	Complex (5) Filled blister Coral pavement Coral pavement Filled depression Cairn	Habitation/ ceremonial	M/H	M	M/H	+ + +	Recorded as T-175 in Kohana-Iki; recommended for further work
T-15 A B C D E F G	Complex (7) Faced well Pavement Overhang shelter Overhang shelter Wall Large cairn Faced terrace	Habitation	H	H	H	+ + +	Recorded as T-176 in Kohana-Iki; recommended for further work; dense midden in Feas. C and D; numerous historic artifacts
T-16	Wall	Indeterminate	L/M	L	L	None	Extremely eroded, only basal wall remains in sections
T-17 A B C D	Complex (4) Walled sinkhole Cave shelter Low platform Surface midden	Habitation	H	M	M	+ + +	Very dense deposit in Fea. A; additional excavation indicated

Table 3. (Cont.)

Site & Feature Number	Formal Site/Feature Type	Tentative Functional Interpretation	Significance Evaluation R	I	C	Field Work Tasks DR SC EX	Comments
T-19 A B-D	Complex (3) Trail Cairns	Transportation	L	L	M	None	Trail discernable for 24.0 m over aa, no associated deposit
T-20	Platform	Burial or shrine	H	M/H	H	None	Interpreted as possible grave by Barrera (1985)
T-21	Rock mound	Burial?	L/M	M	M/H	+ - +	Burial possible, given results of Site T-13 testing
T-22 A B C	Complex (3) Cave shelter Petroglyphs L-shaped wall	Temporary habitation	L	L/M	L	- + -	All surface material in cave (Fea. A)
T-23	Walled shelter	Temporary habitation	L/M	L	L	None	No portable remains; data recovery completed
T-24	Cave shelter	Temporary habitation	M	L	L	None	One hearth area present; data recovery completed
T-25	C-shaped wall	Temporary habitation	L	L	L	None	Very little surface material; data recovery completed
T-26	Footpath	Transportation	L/M	L	M/H	None	Short (10.0 m) section of path over aa
T-27	Cave shelter	Temporary habitation	M	L/M	L/M	None	No modifications, very sparse surface midden in cracks only
T-28	Cairn	Indeterminate	L	L	L	None	Poorly preserved, two additional cairns (T-73) to southwest

Table 3. (Cont.)

Site & Feature Number	Formal Site/Feature Type	Tentative Functional Interpretation	Significance Evaluation R	I	C	Field Work Tasks DR	SC	EX	Comments
T-31 A B-C	Complex (3) Coral pavement/ terrace Cairns	Ceremonial	M/H	M	M/H	+	-	+	Has been vandalized, but has preservation potential, no subsistence material observed, two uprights and horizontal waterworn boulders on pavement
T-39	Collapsed lava tube	Temporary habitation	M/H	L	L	None			Four horizontal features, moderate midden deposit; data collection completed
T-41 A B C D	Complex (4) Cave shelter Cleared/ leveled area Cupboard Faced excavation	Temporary habitation	M	M	M	None			All surface material in Fea. A cave; data recovery completed
T-42	Walled blister	Indeterminate	L	L	L	None			Wall associated with natural cave; no surface deposit
T-43 A B C	Complex (3) Cave shelter Cave shelter Cairn	Temporary habitation	L	L	L	None			Very light shell scatter in Fea. A only, species list obtained
T-44	C-shape	Temporary habitation	L	L	L	None			No portable remains; poor condition
T-45	Overhang shelter	Temporary habitation	L/M	L	L	None			Very sparse surface scatter, species list completed, no internal features or modifications
T-46	Cairns (2)	Indeterminate	L	L	L	None			Poor condition

Table 4.

SUMMARY OF SITES AND FEATURES NEWLY IDENTIFIED BY PHRI (1986)

Site & Feature Number	Formal Site/Feature Type	Tentative Functional Interpretation	*Significance Evaluation R	I	C	#Field Work Tasks DR	SC	EX	Comments
T-47 A B	Complex (2)+ Overhang shelter Cave shelter	Temporary habitation	L/M	L	L	None			Thin deposit, disturbed by recent activities
T-48 A B C D	Complex (4) Platform Salt pan stone Platform Wall	Habitation/ burial	M/H	M/H	H	+	+	+	Site affected by storm wash; Feas. A and C prob. burials; Fea. B has high interp. value (for display)
T-49	Platform	Habitation	M	L	L	None			Severely eroded and affected by recent campers
T-50	Pahoehoe clearing	Temporary habitation	M	L	L	None			Cleared depression, a portion walled; no portable remains
T-51 A B	Complex (2) C-shaped wall U-shaped wall	Temporary habitation	M	M	L	None			Well-preserved walled shelters; no portable remains
T-52	Modified outcrop	Temporary habitation	M	L	L	None			Natural shelter leveled and portion excavated; no portable remains
T-53 A B-D	Complex (4) Path Cairns	Transportation	M	L	M/L	None			Poorly defined segment with associated small cairn

*Significance Evaluation--Nature: R = scientific research, I = interpretive, C = cultural;
Degree: H = high, M = moderate, L = low.

#Field Work Tasks: DR = detailed recording (scaled drawings, photographs, and written descriptions), SC = surface collections, EX = test excavations.

+Number of component features within complex.

Table 4. (Cont.)

Site & Feature Number	Formal Site/Feature Type	Tentative Functional Interpretation	Significance Evaluation R	I	C	Field Work Tasks DR	SC	EX	Comments
T-54	Faced excavation	Storage	L/H	L	L	None			An area cleared and opening faced with stacked slabs, too small for shelter
T-55	Complex (3)*	Temporary habitation/ quarry	M	L	L	None			No portable remains except modern rubbish; Feature B currently a lua
A	C-shaped wall								
B	Modified outcrop								
C	Modified outcrop								
T-56	Complex (3)*	Quarry	M	L	L	None			No portable remains; continuous with Site T-55
A	Cairn								
B	Pahoehoe excavations (6)								
C	Pahoehoe excavations (6)								
T-57	Complex (3)	Temporary habitation	M	L	L	None			A few pieces of shell present and recorded; walls are poorly preserved
A	C-shaped wall								
B	C-shaped wall								
C	Cairn								
T-58	Complex (3)	Temporary habitation	M	L	L	None			Minimal modification to create a small shelter with associated storage (?) excavation; large basalt wedge on site
A	Modified outcrop								
B	Cairn								
C	Wall								
T-59	Walled shelter	Temporary habitation	M	L	L	None			Crude wall across a portion of collapsed blister; small amount of shellfish remains
T-60	Complex (2)	Habitation	M	L	L	None			On beach, probably historic; no recent refuse associated
A	Hearth								
B	Stone alignment								

*Twelve bedrock excavations occur within the area of Sites T-55 and T-56.

Table 4. (Cont.)

Site & Feature Number	Formal Site/Feature Type	Tentative Functional Interpretation	Significance Evaluation R	I	C	Field Work Tasks DR	SC	EX	Comments
T-61	Complex (7)	Temporary habitation	M/H	L	L	+	+	+	A and B have midden deposits and artifacts; volcanic glass collected
A	Cave shelter								
B	Cave shelter								
C	Overhang shelter								
D	Overhang shelter								
E	Cairn								
F	Rubble pile								
G	Rubble pile								
H	Overhang shelters (2)								
T-62	Platform	Possible burial	M/H	L/H	L/H	-	-	+	Feature is severely eroded; probably associated with Site D15-18, 26.0 m north
T-63	Complex (13)	Habitation	M	M/L	M/L	None			Little to no portable remains; Feature K shrine is recent-glass vase with flowers present; Feature M has sparse shell midden; Feature F is well-preserved enclosure wall
A	Cairn/mound								
B	Cairn								
C	Rubble pile								
D	Rubble pile								
E	Pavement								
F	Enclosure								
G	Rubble pile								
H	Rubble pile								
I	Alignment								
J	Modified outcrop								
K	Cairn/shrine								
L	Large cairn								
M	Cave shelter								
T-64	Complex (18)	Habitation	L	L	L	None			Area of continous small features and modifications with no substantial features and sparse midden scatters; Features F and H may have been semi-permanent habitation structures; recording and mapping completed
A	C-shaped wall								
B	Excavations (2)								
C	Overhang shelters								
D	Rubble piles (2)								
E	Rubble pile								
F	Walled shelter								
G	Rubble pile								
H	C-shaped wall								
I	Pavement								
J	Walled, filled crevice								

Table 4. (Cont.)

Site & Feature Number	Formal Site/Feature Type	Tentative Functional Interpretation	Significance Evaluation R	I	C	Field Work Tasks DR	SC	EX	Comments
T-64 (cont.)									
K	Rubble pile								
L	Cairns (2)								
M	Modified outcrop								
N	Surface midden/ rubble								
O	Cave shelter								
P	Cairn								
Q	Cleared blister shelter								
R	Enclosure								
T-65	Walls (partial)	Indeterminate	L	L	L	None			Severely eroded section on beach; intact portions not indicated
T-66	Complex (9)	Habitation	M	M	L	None			Very sparse surface midden; some branch coral and waterworn basalt associated with Feature A; most features partially dismantled except Feature C which is well-preserved
A	C-shaped wall								
B	Cairns (3)								
C	Walled depression								
D	U-shaped wall								
E	Rubble piles (3)								
T-67	Complex (17)	Habitation/ miscellaneous activities	M/H	M	L	+	+	+	Further work limited to Feature A cave, which has midden/soil deposit c. 5 cm thick; wide range of shellfish, artifacts and other subsistence materials; large and small basalt hammerstones associated directly with Feature E pahoehoe excavations
A	Cave shelter								
B	Cave shelter								
C	Large cairn								
D	Cairn								
E	Pahoehoe excavations (3)								
F	Cairn								
G	Walled shelter								
H	Cairn								
I	Rubble-filled depression								
J	Cave shelter								
K	Small cairn								
L	Modified overhang								
M	Alignment								
N	Pahoehoe clearing								

Table 4. (Cont.)

Site & Feature Number	Formal Site/Feature Type	Tentative Functional Interpretation	Significance Evaluation R	I	C	Field Work Tasks DR	SC	EX	Comments
T-67 (cont.)									
O	Pahoehoe clearing								
P	Cairn								
Q	Modified overhangs (2)								
T-68	Modified blister	Indeterminate	L	L	L	None			Natural opening in collapsed blister, partially walled and excavated; no portable remains
T-69	Complex (7)	Temporary habitation	M	L	L	None			Features partially dismantled and recently utilized, sparse shell in Feature B, heavy recent rubbish
A	Walled shelter								
B	Walled shelter								
C	Cairn								
D	Alignment and surface rubble								
E	Cairn								
F	Rubble pile								
G	Rubble pile								
T-70	Complex (2)	Temporary habitation	L	L	L	None			No surface deposit; walls in poor condition, collapsed
A	C-shape								
B	C-shape								
C	Cairn								
T-71	Steppingstone path	Transportation	M	M	M/H	+	-	-	12.0 m section of steppingstone path
T-72	Rubble pile	Indeterminate	L	L	L	None			Haphazard pile does not appear to be burial; adjacent to small sinkhole
T-73	Cairns (2)	Indeterminate	L	L	L	None			Two poorly preserved cairns 8.0 m apart

Table 5.

SUMMARY OF SITES AND FEATURES PREVIOUSLY IDENTIFIED BY CORDY (1975,1981) AND BY STATE INVENTORY (1971-72), AND COMPONENT FEATURES NEWLY IDENTIFIED BY PHRI (1986)

BPBM Site No. 50-Ha-	Formal Site/Fea. Type	Tentative Functional Interpretation	*Significance Evaluation R	I	C	#Field Work Tasks DR	SC	EX	Comments
D15-1	Complex (6)+	Habitation/ ceremonial	H	H	H	+	+	+	Interpreted by Cordy as commoner household with men's house (Fea. A), sleeping houses (Feas. C, D) and special-purpose house (Fea. B); Feas. 1-4 tested, dates range AD 1490-1832; midden deposit thickest in Feas. B, C and E
A	Coral pavement								
B	Walled shelter								
C	C-shape								
D	Platform								
E	Walled shelter								
F	Walled shelter								
D15-2	Complex (4)	Habitation/ ceremonial	H	H	H	+	+	+	Interpreted by Cordy as commoner household with special-purpose (Fea. 1) and sleeping house (Fea. 2); both features tested, dates range AD 1550-1660
A	Enclosure								
B	Enclosure								
C	Steppingstone path								
D**	Walled shelter								
D15-3	Complex (5)	Habitation/ poss. burial	M	M	M	+	+	+	Interpreted by Cordy as commoner household with three sleeping houses (A, B and D); date range AD 1560-1760; Feas. A, C, D and E tested; Fea. B interpreted by Barrera as possible grave
A	Low enclosure								
B	Rock mound (also T-33)								
C	Terrace								
D	Terrace								
E	Terraced, filled depression								
D15-4	Complex (13)	Habitation/ ceremonial	H	H	H	+	+	+	Interpreted by Cordy as a sleeping house (Fea. A) and a men's house variant (Fea. B);
A	Platform								
B	Platform								
C	Small platform								

*Significance Evaluation--Nature: R = scientific research, I = interpretive, C = cultural;
Degree: H = high, M = moderate, L = low.

#Field Work Tasks: DR = detailed recording (scaled drawings, photographs, and written descriptions), SC = surface collections, EX = test excavations.

+Number of component features within complex.

**Component feature newly identified by PHRI (1986).

Table 5. (Cont.)

BPBM Site No. 50-Ha-	Formal Site/Fea. Type	Tentative Functional Interpretation	Significance Evaluation R	I	C	Field Work Tasks DR	SC	EX	Comments
D15-4 (cont.)									
D	Faced depression								dates range AD 1742-1821, Fea. A tested
E	Pavement								
F**	Shrine								
G**	Pavement/midden								
H**	Pavement								
I**	Enclosure								
J**	Enclosure								
K**	Cave shelter								
L**	Excavation (cupboard)								
M**	Cairn								
D15-5	Complex (3)	Habitation/ indeterminate	H	L	L	+	+	+	Site is badly eroded and possibly partially buried; interpreted by Cordy as men's house with historic modifications; dates from Fea. I range AD 1430-1720
A	Platform								
B	Enclosure/ platform								
C	Enclosure								
D15-6	Complex (4)	Habitation	H	M	M	+	+	+	This site is 20.0 m NE from D15-19 and is probably associated; interpreted by Cordy as sleeping house; one test unit excavated, dates range AD 1540-1650; surface midden to side of platform
A	Platform								
B**	Paving								
C**	Cupboard								
D**	Wall								
D15-7	Complex (9)	Habitation	H	M	M	+	+	+	Interpreted by Cordy as sleeping house (Fea. A) and special-purpose structure (Fea. B); dates from Fea. A range AD 1490-contact; area between platform and cave is paved; dense midden observed in excavation unit of Fea. A
A	Platform								
B	Platform								
C	Platform								
D**	Large paved area								
E**	Rubble pile								
F**	Pavement								
G**	Walled cave shelter								
H	Coral concentration								
I	Alignment								
D15-8	Complex (13)	Habitation/ ceremonial	H	H	H	+	+	+	One feature (A) tested by Cordy, who collected additional glass from
A	Platform								
B	Platform								

Table 5. (Cont.)

BPBH Site No. 50-Ha-	Formal Site/Fea. Type	Tentative Functional Interp.	Significance Evaluation R	I	C	Field Work Tasks DR	SC	EX	Comments
D15-8 (cont.)									
C**	Modified/paved depression								surface midden; dates for site (N=7) range AD 1480-1857, additional features suggest possible burials, esp. Fea. M; midden deposits dense in Fea. D-H area; evidence of looting activities on the site
D**	Cave shelter								
E**	Terrace								
F**	Wall								
G**	Cave shelters (2)								
H**	Midden piles								
I**	Platform								
J**	Rubble-filled depression								
K**	Paved depression								
L**	Cave shelter								
M**	Cairn on platform								
D15-16	High-walled enclosure	Animal pen	M	H	M	None			Associated with D15-17, which is 12.7 m west of this structure; walls are relatively well-preserved
D15-17	Platform	Habitation	M/H	M	M	+	+	+	Associated with D15-16
D15-18	Complex (4)	Ceremonial	H	H	H	+	+	+	Interpreted by Cordy as prob. <u>heiau</u>; not tested; associated features directly across jeep road; Site T-62 is prob. also associated; these may be burial platforms
A	Enclosed platform								
B**	Platform								
C**	Platform								
D**	Platform								
D15-19	Complex (6)	Ceremonial/ historic habitation	H	H	H	+	+	+	Fea. A is poss. <u>heiau</u>; four volcanic glass dates range AD 1590-1720; Cordy suggests historic-period house site on Fea. A platform; Fea. B is confirmed burial mound; other features may contain burials as well; Fea. A is well-preserved and relatively unaltered
A	Platform								
B**	Pavement								
C**	Low-walled shelter								
D**	Rubble piles								
E**	Rock mound								
F**	Filled depression								

APPENDIX O

ARCHAEOLOGICAL SURVEY UPDATE

Paul H. Rosendahl, Ph.D., Inc.

PHRI
Paul H. Rosendahl, Ph.D., Inc.
Archaeological • Historical • Cultural Resource Management Studies & Services
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893-092690 September 26, 1990

Kahala Capital Corporation
75-5751 Kuakini Highway, Suite 201
Kailua-Kona, Hawaii 96740

Attention: Ms. Toni Fortin
Vice President and Director of Hawaii Operations

Subject: ***Status of Historic Preservation Concerns***
Ooma II Project Area
Land of Ooma 2nd, North Kona District
Island of Hawaii (TMK:3-7-3-09:4)

Dear Ms. Fortin:

At your request, Paul H. Rosendahl, Ph.D., Inc. (PHRI) has reviewed the archaeological work conducted previously in connection with the above subject project to provide you with a summary of the current status of historic preservation concerns. Our review is based primarily upon the following: (a) the final report on archaeological survey and testing conducted by PHRI in 1986 (Donham 1987); (b) various letters contained within PHRI project files relating to agency consultations and review of PHRI's 1986 work; and (c) a recent status check with the Department of Land and Natural Resources-Historic Preservation Program/State Historic Preservation Office (DLNR-HPP/SHPO).

In July 1986, PHRI conducted a program of archaeological survey and testing within the c. 314 ac Ooma II project area situated between the shoreline and the Mamalahoa Trail in the Land of Ooma 2nd, North Kona District, Island of Hawaii (TMK:3-7-3-09:4). The scope of this program, which was formulated in consultation with and approved by the Department of Land and Natural Resources/State Historic Preservation Office (DLNR/SHPO), consisted of a high intensity pedestrian reconnaissance (inventory-level) survey of the immediate coastal zone (shoreline to 300 m inland), and intensive survey (detailed recording with test excavations or controlled surface collections) of ten previously identified sites situated within the inland portion of the project area. Twenty-seven sites with 130 component features were newly identified during the reconnaissance survey phase, and 54 new features were found at previously recorded sites. These new findings resulted in a cummulative total of 74 sites with 279 component features identified to date within the project area.

Fifteen permanent habitation site complexes were identified within the coastal zone. Nine of these sites had been previously tested and temporal and functional interpretations offered (Cordy 1981). Thirty-four temporary habitation sites were also identified within the project area, in addition to four footpath segments, six possible burial sites, two shrines, and a high-walled enclosure. Volcanic glass hydration rind age determinations from 15 sites (69 age determinations) indicate a temporal range of AD 1430-1855 for habitation of sites within the project area.

Based on the findings of the 1986 PHRI survey and testing, additional archaeological work in the form of further data collection was recommended for 24 sites assessed as significant for their information content. For nine sites, further data collection was considered sufficient treatment and no continued preservation would be necessary. Preservation with some level of interpretive development was recommended for five of the 24 sites assessed as significant additionally as good examples of site types and/or for cultural values, while preservation with protection only ("as is") was recommended for ten of these sites assessed as significant additionally as good examples of site types and/or for potential cultural values as possible burial and/or religious sites. No further work or preservation in any form was recommended for the remaining 50 sites which were assessed as significant for information content only and for which sufficient data collection had been completed.

The Department of Land and Natural Resources-Historic Preservation Program/State Historic Preservation Office (DLNR-HPP/SHPO) reviewed and concurred with the general significance assessments and general mitigation treatments recommended by PHRI and summarized here (letter of 19 September 1986 to A. Lyman, Hawaii County Planning Department). A recent check with DLNR-HPP/SHPO confirmed that the general significance assessments have not changed.

Subsequent to completion of the survey and testing within the Ooma II project area, the configuration of the project area was modified by a land exchange made with the State of Hawaii. A section of approximately 83 ac on the north side of the project area was exchanged for a similar sized section on the inland end of the project area (see Figure 1, at end). This exchange results in the deletion of 32 sites from consideration with regards to further development. Table 1 (at end) summarizes general significance assessments and recommended general mitigation treatments for the 42 sites affected by the revised project area.

Based on the revision to the project area, additional archaeological work in the form of further data collection is needed for 13 sites assessed as significant for their information content. For four sites, further data collection would be sufficient treatment and no continued preservation would be necessary. Preservation with some level of interpretive development is recommended for three of the 13 sites assessed as significant additionally as good examples of site types and/or for cultural values, while preservation with protection only ("as is") is recommended for six of these sites assessed as significant additionally as good examples of site types and/or for potential cultural values as possible burial and/or religious sites. No further work or preservation in any form is needed for the remaining 29 sites which were assessed as significant for information content only and for which sufficient data collection had been completed.

While the recent check with DLNR-HPP/SHPO confirmed that the general significance assessments had not changed, it should be noted that requirements for dealing with possible burial sites have changed, due to recent amendments to State Historic Preservation law (Chapter 6E). Current DLNR-HPP/SHPO procedures now require consultation with the Hawaii Island Burial Council to determine treatment of any sites and features containing human burial remains. In-place preservation of confirmed burial sites and features is the treatment preferred by the Burial Council. Any proposed development involving the disinterment and reinterment of human burials would involve close negotiations with the Burial Council, which would be facilitated by having acommplished in advance (a) determination of the confirmed presence of any human burial remains at specific sites and features, and (b) a search for any individuals claiming to be direct lineal descendents of any such identified remains.

Based on the above, we would recommend that the feasibility of in-place preservation of all features potentially containing human burial remains be strongly considered. If appropriate, further archaeological testing to determine the definite presence or absence of human burial remains could be conducted to facilitate decisions regarding preservation or disinterment. Site and feature-specific mitigation treatments would then be modified as needed.

Please note that no further work needs to be done prior to a petition to the State Land Use Commission for a land use boundary amendment to change the portion of the revised project area presently designated as conservation lands. However, any supporting documentation submitted with such a petition would have to reflect the revised general significance assessments and recommended general mitigation treatments summarized in Table 1 (at end).

I hope this review of archaeological work conducted previously in connection with the subject project provides you with a summary of the current status of historic preservation concerns sufficient for your immediate needs. Should you have any questions or comments, please contact me at our main Hilo office (808/969-1763).

Sincerely yours,

Paul H. Rosendahl, Ph.D.
President and Principal Archaeologist

References Cited

Cordy, R.H.

1981 A Study of Prehistoric Social Change: The Development of Complex Societies in the Hawaiian Islands. New Yor: Academic Press. (Virtually identical to author's 1978 Ph.D. dissertation [Anthropology, University of Hawaii], with addition of an epilogue.)

Donham, T.K.

1987 Archaeological Survey and Testing, Ooma II Resort Project Area, Land of Ooma II, North Kona, Island of Hawaii (TMK:3-7-3-09:4). PHRI Report 254-081286. Prepared for Helber, Hastert, Van Horn & Kimura (Honolulu). (April)

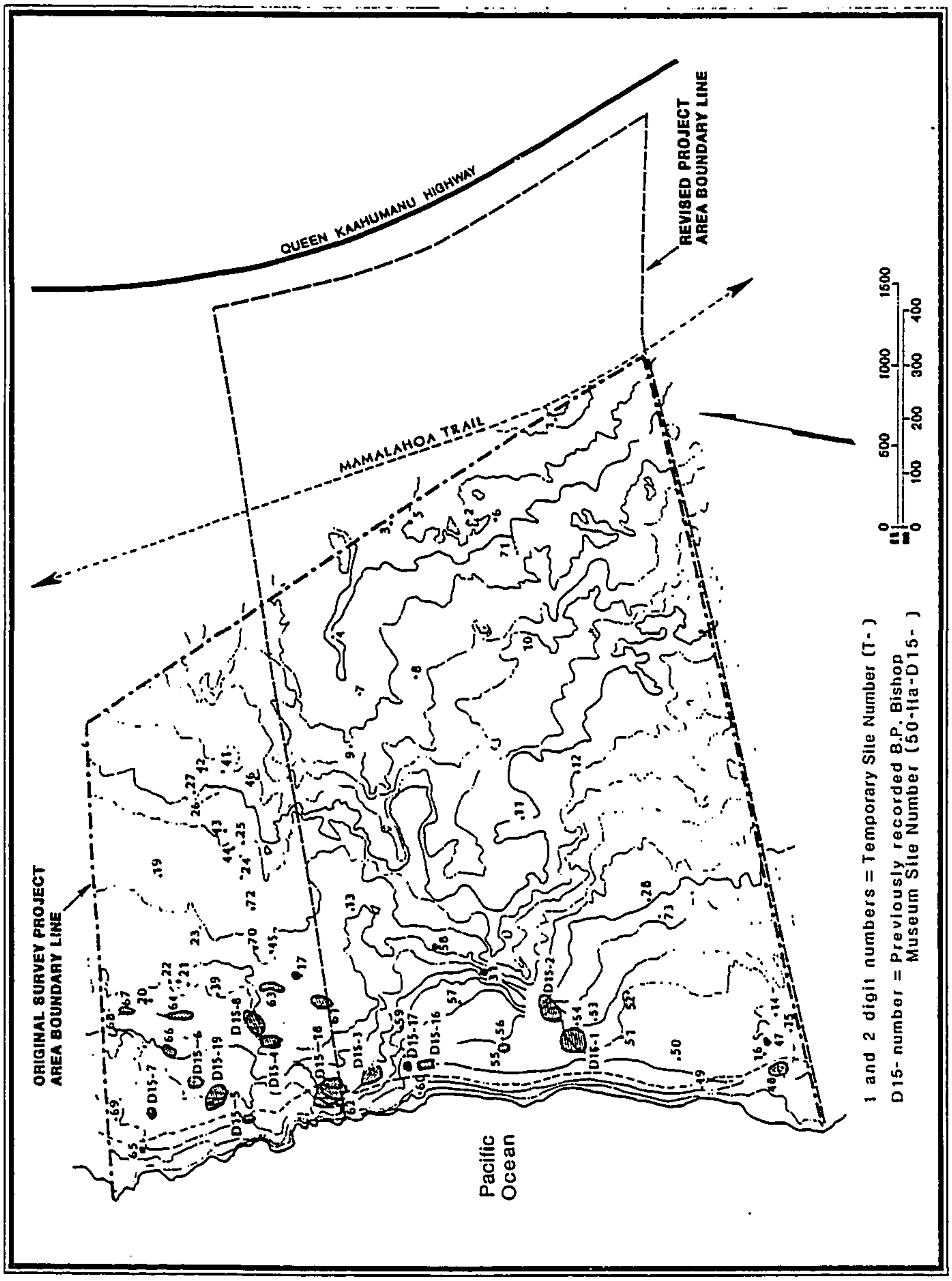

Figure 1. SITE LOCATION MAP - REVISED OOMA II PROJECT AREA

Table 1.

SUMMARY OF GENERAL SIGNIFICANCE ASSESSMENTS AND RECOMMENDED GENERAL TREATMENTS REVISED OOMA II PROJECT AREA

Site\Fea. Number	Significance Category				Recommended Treatment			
	A	X	B	C	FDC	NFW	PID	PAI
D15-2	+	-	-	-	+	-	-	-
D15-17	+	-	-	-	+	-	-	-
T-61	+	-	-	-	+	-	-	-
T-71	+	-	-	-	+	-	-	-
Subtotal: 4	4	0	0	0	4	0	0	0
T-48	+	-	-	*	+	-	-	*
D15-3	+	-	-	*	+	-	-	*
T-14	+	-	-	*	+	-	-	*
T-62	+	-	-	*	+	-	-	*
Subtotal: 4	4	0	0	4	4	0	0	4
T-15	+	-	+	-	+	-	+	-
Subtotal: 1	1	0	1	0	1	0	1	0

General Significance Categories:

A = Important for information content, further data collection necessary (PHRI=research value);
X = Important for information content, no further data collection necessary (PHRI=research value, SHPO=not significant);
B = Excellent example of site type at local, region, island, state, or national level (PHRI=interpretive value); and
C = Culturally significant (PHRI=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 archaeological clearance recommended, no preservation potential;
PID = Preservation with some level of interpretive development recommended (including appropriate related data recovery work);
PAI = Preservation "as is", with no further work (and possible inclusion into landscaping), or minimal further data collection necessary.

* Provisional assessment, definite assessment pending further collection (i.e., testing for presence/absence of skeletal remains)

Table 1. (cont.)

Site\Fea. Number	Significance Category				Recommended Treatment			
	A	X	B	C	FDC	NFW	PID	PAI
D15-1	+	-	+	+	+	-	+	-
D15-18	+	-	+	+	+	-	+	-
Subtotal: 2	4	0	2	2	2	0	2	0
T-13	+	-	-	+	*	-	-	+
T-31	+	-	-	+	*	-	-	+
Subtotal: 2	2	0	0	2	2	0	0	2
All others	-	+	-	-	-	+	-	-
Subtotal: 29	0	29	0	0	0	29	0	0
Total: 42	13	29	3	10	13	29	3	6

APPENDIX P

ECONOMIC AND FISCAL IMPACT ASSESSMENT

KPMG Peat Marwick

KPMG Peat Marwick

Management Consulting

Economic and Fiscal Impact Assessment for the O'oma II Ocean Science and Recreation Community

North Kona, Hawaii

Prepared for

KAHALA CAPITAL CORPORATION

February 1991

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February 26, 1991

Ms. Toni Fortin
Vice President, Hawaii
Operations
Kahala Capital Corporation
75-5751 Kuakini Highway
Kailua-Kona, Hawaii 96740

Dear Ms. Fortin:

We are pleased to present the attached report entitled, "Economic and Fiscal Impact Assessment for the O'oma II Ocean Science and Recreation Community."

The report is organized into five chapters as follows:

I. Introduction and Summary
II. Regional Economic and Demographic Setting
III. Economic Impacts
IV. Population and Housing Impacts
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Thank you for this opportunity to work with you and your development team in planning this interesting project.

Very truly yours,

KPMG Peat Marwick

Economic and Fiscal Impact Assessment for the O'oma II Ocean Science and Recreation Community

North Kona, Hawaii

Prepared for

KAHALA CAPITAL CORPORATION

February 1991

KAHALA CAPITAL CORPORATION

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I - INTRODUCTION AND SUMMARY

This chapter presents the background and objectives of the assistance provided to Kahala Capital Corporation (Kahala Capital) in this engagement and summarizes the study's conclusions. More detailed findings and conclusions are presented in subsequent chapters.

PROJECT DESCRIPTION AND STUDY OBJECTIVES

Title to the O'oma II property is held by the American Trust Co. of Hawaii, Inc., as trustee for Kona Oceanfront Properties, a Hawaii limited partnership. Kahala Capital is the managing general partner of Kona Oceanfront Properties and is the developer of the O'oma II project. The property is located south of Keahole Airport in the district of North Kona on the island of Hawaii, as shown in Exhibit I-A. Kahala Capital seeks to develop the site as a master-planned residential and recreational community named O'oma II (sometimes refereed to as simply O'oma).

O'oma is planned to enhance the west Hawaii region's emergence as a:

- Center for ocean science research and technology
- Visitor destination area
- High-quality residential community

O'oma is planned to be a recreational and residential community, linked to the neighboring Natural Energy Laboratory of Hawaii Authority (NELHA) project through its ocean science center and professional meetings facility.

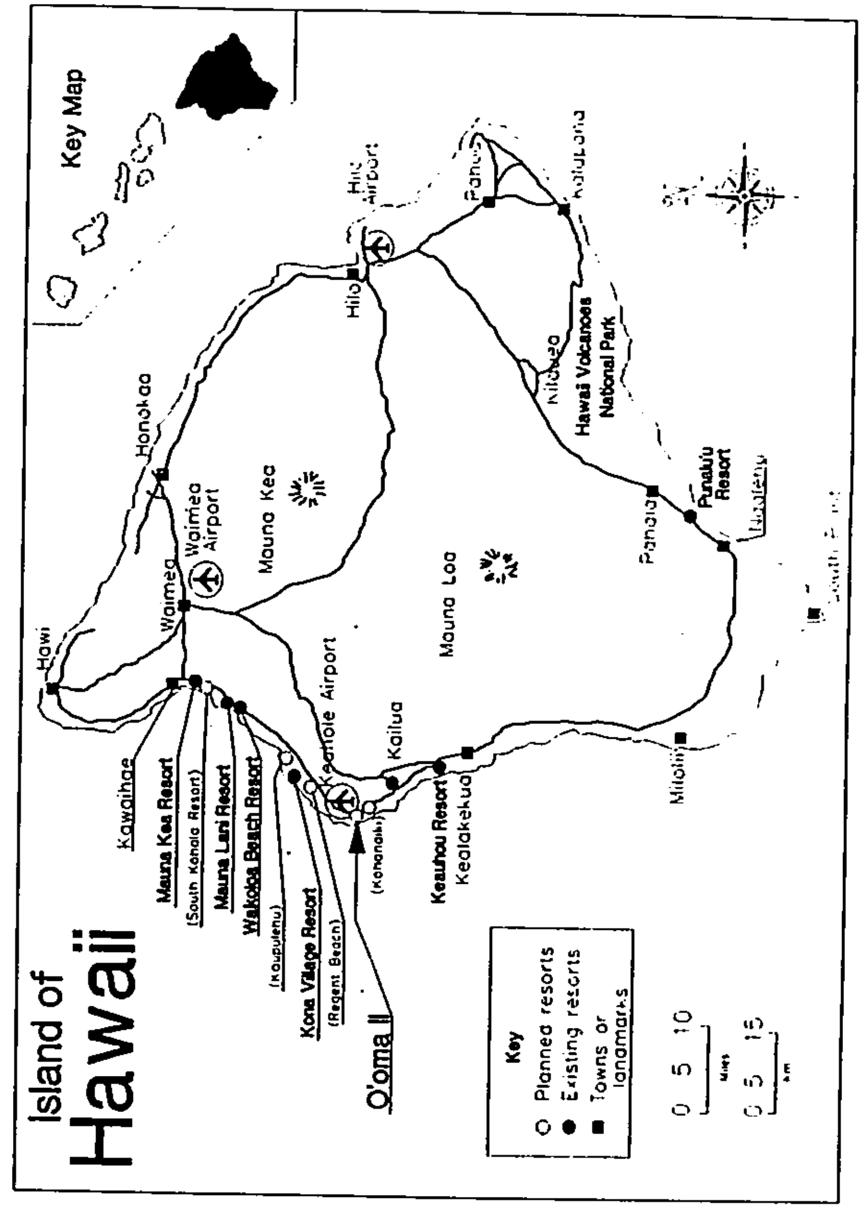
Key elements of the development plan include the following:

- Ocean science center featuring educational and scientific exhibits.
- Water recreation park offering active water-based amusement.
- Professional conference center catering to scientific community and small-to-mid-sized corporate meetings.
- An 18-hole golf course, a clubhouse and a lodging inn of about 50 rooms.
- Up to 100 residential lots situated within two private communities fronting the golf course.
- Up to 230 condominium units with golf course frontage.
- Small retail center located along planned lagoons.
- Oceanfront first-class hotel providing 550 rooms on an extensive salt water lagoon.

Exhibit I-A

KAHALA CAPITAL CORPORATION

Island of Hawaii Map



In total, the master plan includes up to 330 residential units and 600 visitor units, for a total project density of 3.1 units per acre as shown in Exhibit I-B. For purposes of projecting the economic and fiscal impacts of the development, however, this study assumes a mid-range development of 150 condominium units and 70 lots as referred to in the December 1990 market study. These mid-range figures are considered appropriate for portraying the impacts of the development because they avoid over-estimation of the economic and fiscal benefits and/or under-estimation of the population impacts of the project.

Assuming development approvals are obtained by 1993, a first phase of development, including all the community elements, could be operational by late 1995 or 1996. Completion of all elements, except build-out of owner-built homes on the single-family lots, would be anticipated within the following five years.

All major community infrastructure would be expected to be completed by project opening in 1996.

KPMG Peat Marwick was engaged for the following purposes:

- To assess the market potential of the planned land uses at O'oma.
- To assess the economic and fiscal impacts of the proposed development.

"Market assessment conclusions are presented in a separate report entitled, Market Assessment for the O'oma II Ocean Science and Recreation Community", dated December 12, 1990.

ECONOMIC IMPACTS

Development of O'oma could be expected to impact the economy by generating additional visitor expenditures, jobs in construction and operation of facilities, additional personal income and possible population growth.

Visitor Expenditures

Development of the professional conference center, the ocean science center, water recreation park, hotel, condominium and single-family residential units at the community would contribute to additional visitor spending, to the extent that these units are used by visitors. The average daily population of visitors in the hotel and residential units is projected to reach about 1,130 persons by 2010. Direct spending by these persons is expected to represent about $88 million per year by 2010.

Considering multiplier effects throughout the state's economy, this could lead to total expenditures of up to 122 million by 2010.

Construction Employment

Community development would generate employment in construction of facilities over the period corresponding to the development program. Completion of the plan is estimated to require nearly 1,300 person-years of construction labor between 1993 and 2010. This could represent an annual average of about 270 person years between 1993 and 1996, the period of greatest facility development, tapering to less than 10 by 2006 to 2010.

Exhibit I-B

KAHALA CAPITAL CORPORATION

O'oma II Project Development Summary

	Land area (acres)	Maximum number of units	Maximum per acre	Description
Ocean science center	12	-	-	300,000 to 600,000 gallon capacity, indoor and outdoor tanks, tide pools and archeological reserves, retail space; food and beverage service.
Professional conference center	3	-	-	State-of-the-art conference facility catering to scientific community associated with NELH/HOST and to other meeting groups; 100 parking stalls.
Water recreation park	19(1)	-	-	Includes a variety of water park activities and services centered on 7-acre swimming lagoon.
Golf course	176	-	-	18-hole, par 72 semiprivate course with clubhouse.
Golf inn	5	50	10.0	Japanese-style ryokan with restaurant and tennis court.
Residential lots	24	100	4.2	10,000 square foot lots with central recreation facility, pool and tennis courts.
Condominium units	10	230	23.0	1,200 to 1,500 square foot units in 2- and 3-story buildings, with central recreation facility, pool and tennis courts.

Exhibit I-8, Continued

KAHALA CAPITAL CORPORATION

O'oma II Project Development Summary, Continued

	Land area (acres)	Maximum number of units	Maximum per acre	Description
Retail center	8(1)	-	-	35,000 square feet of gross leasable area; 350 parking stalls.
Hotel	22(1)	550	26.2	First-class meeting- and family-oriented hotel with restaurants, tennis courts, pool, spa and other recreational facilities, 8,250 square feet of retail space.
Other infrastructure:				
Maintenance/STP	6	-	-	
Spine road	15	-	-	
Total/average	300	930	3.1	

(1) With lagoon allocation.

Source: Discussions with Kahala Capital Corporation representatives.

Total employment associated with construction of the community, including induced and indirect positions, could total about 2,300 person-years over the 1993 to 2010 projection period.

Operational Employment

Permanent jobs at the community would be generated as facilities are completed and occupied. Direct operational jobs at O'oma are projected to consist of about 700 full-time equivalent positions.

Total employment, including indirect and induced jobs, could represent nearly 1,300 full-time equivalent positions.

Personal Income

Wages and salaries paid to those directly employed in community development and operations are expected to represent about $24 million per year in 1996, or about $14 million by 2010. These benefits decline over the projection period, as the highly paid construction positions are replaced by permanent operational positions.

Wage and salary income figures do not include potential wages paid to holders of indirect and induced jobs associated with the project, nor do they reflect income of proprietors whose businesses serve the project. Total household income, which does consider the latter, is expected to be about $46 million per year by 2010.

Population

Development of the O'oma community could add to the population of Hawaii County in several ways:

- Visitors staying at the community would add to the de facto population of the county.
- Full- and part-time residents living on-site could increase the county's resident population.
- To the extent that the island's available labor supply proves insufficient to fill new operational jobs, in-migrants would be needed.
- Temporary increases in resident population could also be associated with in-migration of construction workers during project development.

By 2010, population impacts of the community could be as summarized below:

- On-site:
  - Average daily visitors: 1,130 persons
  - Average daily residents: 180 (estimated 135 from off-island) persons
- Total new residents to county: On-site 135; Off-site 845; Total 980

Housing

Community development could also impact west Hawaii's housing situation in several ways. First, development will require temporary housing for construction workers brought to the island during the construction period. Second, operational employment would trigger additional housing demand for in-migrant and other employees. The affordability, and therefore type, of housing employees would demand is primarily determined by household income.

Construction workers could require an average of about 70 rental units during the most active construction period, between 1993 and 1996. At peak times within this period, up to 140 rental units could be demanded.

Operational employees could require close to 260 housing units in 1996, peaking at about 280 units by 2010.

Based on individual employees' ability and preferences in selecting ownership versus rental housing, it is estimated that about 40% to 50% could seek to purchase homes.

Among those seeking to buy, approximately 45% could require some form of affordable housing. For those employees that choose to rent, about 81% could require below market, or subsidized rents. In total, about 65% of the total housing demand could require financial assistance.

FISCAL IMPACTS

The fiscal impacts of the O'oma community are estimated by comparing anticipated government revenues from the project with the government service costs associated with the additional population the project may attract to the state or county.

Fiscal benefits are anticipated to exceed additional operating expenses for both the county and state governments. The ratio of projected government revenues to expenditures in 2010 are summarized below:

- County of Hawaii:
  - Annual net additional revenues: $0.8 million
  - Revenue/expenditure ratio: 1.7
- State of Hawaii:
  - Annual net additional revenues: $3.9 million
  - Revenue/expenditure ratio: 2.1

II - REGIONAL ECONOMIC AND DEMOGRAPHIC SETTING

This chapter reviews economic and demographic trends in the west Hawaii region that are pertinent to the outlook for development in this area.

REGIONAL ECONOMIC BASE

The O'oma site is located in the North Kona district, part of the west Hawaii region which also includes North and South Kohala. Coffee production and ranching provided Kona's economic base through much of this century, while Kohala depended upon sugar and ranching. In the years following statehood and the introduction of jet service to the islands, the west Hawaii region began to host an increasing number of visitors.

In the 1960s and 1970s, North Kona fueled a building boom that spread to South Kohala and resulted in hundreds of new hotel and condominium units and residential dwellings. Today the region is primarily supported by its real estate and visitor industries. The Kona and Kohala districts have ideal weather conditions, a black lava coastline with scattered white sandy beaches and important historical sites. The availability of large parcels of land under single ownership and the establishment of horizontal property regime laws have further encouraged high quality development in several resort areas along this coast.

The North Kona district includes the Kailua-Kona resort area and two master-planned resorts, as shown previously in Exhibit I-A:

- Keauhou Resort
- Kona Village Resort

Three master-planned resorts currently exist in the neighboring South Kohala district:

- Waikoloa Beach and Village Resorts
- Mauna Kea Resort
- Mauna Lani Resort

Both districts include planned resort developments, as also shown in Exhibit I-A.

Through the NELHA project, located adjacent to O'oma, and other efforts, the state of Hawaii and various private interests also seek to establish the North Kona district as a center for ocean-, marine- and aquaculture-related research and industry.

POPULATION

Population is considered in terms of resident population, those who customarily live in an area and de facto population, which excludes residents temporarily absent but includes visitors temporarily present.

Resident Population

The resident population of North Kona and North/South Kohala was estimated at 21,600 in 1980, as shown in Exhibit II-A. From 1970 to 1980, the resident population for the area increased at an annually compounded rate of 7.5% per year, or nearly twice the 3.8% rate for the county as a whole. Within the region, the North Kona district experienced the most rapid population growth at 11% per year, followed by the South Kohala district, at 7.1% per year.

Since 1980, resident population growth on the island has been more gradual and continues to be most rapid in the North Kona and South Kohala districts. Between 1980 and 1989, the population grew 5.9% and 7.7% per year in North Kona and South Kohala, respectively, compared to about 2.4% for the island, as also shown in Exhibit II-A.

De Facto Population

Growth in the island's de facto population, including visitors present but excluding residents absent, has also slowed since the 1970s. De facto population grew about 3.8% per year between 1980 and 1989, compared to 4.2% per year during the 1970s, as also shown in the exhibit.

EMPLOYMENT PATTERNS

Employment patterns of the county of Hawaii and the regions closest to O'oma are evaluated in terms of historical labor force characteristics and current estimates of labor force size.

Labor Force Characteristics

Labor force participation rates increased significantly in the North Kona district between 1970 and 1980, but declined in North and South Kohala, as shown in Exhibit II-B. Overall declines in labor force participation in the two Kohala districts were due to their declining rates in male labor force participation over the period. This is attributed primarily to erosion of Kohala's traditionally male-dominated economic bases of sugar cultivation and processing and ranching, coupled with the rise of resort and tourism-related centers of employment in North Kona and South Kohala which provided many new work opportunities for women. Thus, female labor force participation has increased throughout the region, with increases ranging from 18.5 percentage points over the ten year period in North Kona to 4.3 and 2.7 percentage point increases in North and South Kohala, respectively.

Current Labor Force Estimates

Information on labor force characteristics since 1980 is not available by district, but the State of Hawaii, Department of Labor and Industrial Relations (DLIR) prepares labor force estimates for the county as a whole. The DLIR estimates that in the 1980s, the civilian labor force increased 3% per year to about 56,900 persons in 1989, as shown in Exhibit II-C. The county averaged a 3.9% unemployment rate in 1989, or less than 2/3 that of 1980. As of December 1990, unemployment was estimated at 3.1%, up from 2.1% in December 1989. With

Exhibit II-A

KAHALA CAPITAL CORPORATION

Resident and De Facto Population of the North Kohala, South Kohala and North Kona Districts and County of Hawaii

1970 to 1989

	April 1 1970	April 1 1980	July 1, 1989	Average annual percent change 1970 to 1980	Average annual percent change 1980 to 1989
Resident population:					
North Kohala	3,326	3,249	3,900	(.2)%	2.0%
South Kohala	2,310	4,607	9,000	7.1	7.7
North Kona	4,832	13,748	23,000	11.0	5.9
Total region	10,468	21,604	35,900	7.5%	5.8%
County of Hawaii:					
Resident population	63,468	92,053	122,300	3.8%	2.4%
De facto population(1)	65,700	98,700	138,000	4.2	3.8

(1) Includes all persons physically present in area; includes visitors present but excludes residents who are temporarily absent.

Sources: U. S. Bureau of the Census, 1980 Census of Population, Number of Inhabitants, Hawaii, PC80-1-A13 (October 1981), Table 4; Federal-State Cooperative Program for local population estimates and Hawaii State Data Center.

Exhibit II-B

KAHALA CAPITAL CORPORATION

Labor Force Characteristics of
Selected Judicial Districts and County of Hawaii

1970 and 1989

	North Kona (census tracts 215 and 216) 1970	North Kona (census tracts 215 and 216) 1980	North Kohala (census tract 218) 1970	North Kohala (census tract 218) 1980	South Kohala (census tract 217) 1970	South Kohala (census tract 217) 1980	County of Hawaii 1970	County of Hawaii 1980
Potential labor force (age 16+)	3,262	10,115	2,240	2,286	1,446	3,290	43,075	67,205
Civilian labor force	2,022	7,292	1,355	1,355	951	2,110	25,889	41,006
Percentage distribution:								
Armed services	-%	.1%	1.1%	1.0%	-%	-%	.4%	.3%
Civilian labor force	62.0	72.1	60.5	59.3	65.8	64.1	60.1	61.0
Not in labor force	38.0	27.8	38.4	39.7	34.2	35.9	39.5	38.7
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Civilian labor force participation rates:								
Male	78.5	82.0	71.6	66.6	84.4	78.3	63.6	70.5
Female	43.5	62.0	47.8	52.1	46.3	49.0	36.4	51.3
Average	62.0%	72.1%	60.5%	59.3%	65.8%	64.1%	60.1%	61.0%

Sources: U. S. Bureau of the Census, Census of Population and Housing, 1970, Census Tracts (Final Report, PHC(1)88, Honolulu, Hawaii, SMSA), 1972; and Summary Tape Files 1-A and 3-A, 1980; and State of Hawaii, Department of Planning and Economic Development, Community Profiles for Hawaii, 1973; and The Geographic Distribution of Hawaii's Racial Groups, 1970 and 1980 (SR #152), 1982.

Exhibit II-C

KAHALA CAPITAL CORPORATION

Average Annual Labor Force Estimates for the
County of Hawaii

1980 to 1989

	1980	1989	Average annual percent change 1980 to 1989
Civilian labor force	43,550	56,900	3.0%
Percent unemployed	6.2%	3.9%	
Nonagricultural wage and salary jobs by industry:			
Construction	1,800	2,400	3.2
Manufacturing	2,800	2,350	(1.9)
Transportation, communications and utilities	1,950	2,400	2.3
Trade	6,850	11,400	5.8
Wholesale	1,250	1,750	3.8
Retail	5,600	9,650	6.2
Finance, insurance and real estate	1,200	2,050	6.1
Services and miscellaneous	7,050	12,500	6.6
Hotels	3,150	6,000	7.4
Health and other services	3,900	6,500	5.8
Government	6,550	8,000	2.2
Total	28,200	41,100	4.3%

Sources: State of Hawaii, Department of Labor and Industrial Relations, Labor Force Data Book (March 1978), as revised annually through April 1990.

the increase in the county civilian labor force to 60,100 persons by the end of 1990, this slight rise in unemployment represented about 200 more unemployed persons, and 1,900 more employed persons compared to 12 months prior.

Job losses between 1980 and 1989 occurred only in the manufacturing sector, while significant increases in jobs were noted in the areas of retail trade, services, finance, insurance and real estate, as also shown in Exhibit II-C.

Since 1986, construction employment has increased greatly. The Hyatt Regency Hotel at Waikoloa spurred construction employment, which has been sustained through increases in residential, commercial and industrial development. In addition, several other major developments to be built in the west Hawaii region should further strengthen the county's construction labor pool in the years ahead.

SOCIAL CHARACTERISTICS

Exhibit II-D summarizes regional population characteristics in terms of education, ethnicity and age in 1970 and 1980. All three districts of the region have exhibited increasing levels of educational achievement over the intercensal decade, as shown in the exhibit. This change was most pronounced in North Kona and South Kohala, where development during the 1970s brought new economic opportunities. All districts also showed increases in the share of population of working force age; North Kohala and South Kohala also showed relative growth in the population aged 65 or older.

Comparison of 1970 and 1980 U. S. Census data on ethnicity, unfortunately, is not productive because of significant differences in the methods of classifying ethnicity at the two census periods.

ECONOMIC AND DEMOGRAPHIC OUTLOOK

On the island of Hawaii, much of the future economic growth is expected to occur in the west Hawaii region. It has been estimated that over one billion dollars will be spent on developing new hotels and resort areas in this region. Hotel employment would be a major component of this growth, with an estimated 7,700-person hotel work force increasing at a strong annual growth rate of 5.8% to 13,500 by the end of the century, as shown in Exhibit II-E.

The County of Hawaii employment projections reflect this overall strength with total job counts growing at a projected 4.7% annual rate from 58,000 in 1990, to 92,000 by the year 2000. Accordingly, the Hawaii General Plan projects a 60% increase in the island's resident population by 2000 from 129,000 in 1990 to a projected 212,000, as also shown in Exhibit II-E.

In summary, the west Hawaii region is expected to lead the growth that the island of Hawaii is anticipated to experience in the years ahead. The major capital investments planned for existing and new master-planned areas will help support this growth.

KAHALA CAPITAL CORPORATION

Social Characteristics of the Kona and Kohala Districts and County of Hawaii

1970 and 1980

	North Kona (census tracts 215 and 216) 1970	1980	South Kona (census tracts 213 and 214) 1970	1980	North Kohala (census tract 218) 1970	1980	South Kohala (census tract 217) 1970	1980	County of Hawaii 1970	1980
Total population	4,832	13,748	4,004	5,914	3,326	3,249	2,310	4,607	63,468	92,053
Education (aged 25+)(1):										
Less than 8 years	28.8%	8.0%	48.0%	23.6%	44.2%	29.0%	24.1%	8.6%	37.2%	20.1%
12 years	66.0	40.9	45.7	33.8	30.0	39.0	34.2	37.0	31.6	35.5
16 or more years	8.8	18.8	6.3	12.4	5.9	8.1	13.1	20.7	7.5	15.2
Ethnicity(1):										
Hawaiian	19.3	22.1	14.7	23.5	15.3	24.7	26.5	28.5	12.3	18.8
Japanese	23.1	11.8	39.6	27.5	23.8	16.1	24.4	14.6	37.5	26.6
Caucasian	44.0	53.8	17.7	30.0	25.6	27.8	39.2	46.5	28.8	35.0
Chinese	3.7	1.6	.8	.8	4.3	1.0	1.3	1.4	2.9	1.7
Filipino	8.4	7.2	26.3	13.0	29.2	23.9	6.6	5.6	16.5	13.9
Other	1.5	3.5	.9	5.2	1.8	6.5	2.0	3.4	2.0	4.0
Age:										
Under 5 years	9.1	9.1	8.5	9.8	10.0	9.2	9.3	10.0	8.6	9.1
5 to 17 years	27.0	20.3	26.6	17.2	29.4	22.9	28.3	23.6	27.8	21.5
18 to 64 years	55.7	63.9	55.3	62.4	51.1	54.3	56.0	58.6	54.4	59.2
65 or older	8.2	6.7	9.6	10.6	9.5	13.6	6.4	7.6	9.2	10.2

(1) Estimates based on 15% sample.

Sources: U. S. Bureau of the Census, Census of Population and Housing, 1970, Census Tracts (Final Report, PHC(1)88, Honolulu, Hawaii, SMSA), 1972; Census of Population and Housing, 1980, Census Tracts (PHC 80(2)13), 1983; and Summary Tape Files 1-A and 3-A, 1980; and State of Hawaii, Department of Planning and Economic Development, Community Profiles for Hawaii, 1973; and The Geographic Distribution of Hawaii's Racial Groups, 1970 and 1980 (SR #152), 1982.

Exhibit II-E

KAHALA CAPITAL CORPORATION

Population and Employment Projections for the County of Hawaii

1990 to 2000

	Resident population	Employment: Hotel industry	Employment: Total jobs
1990	129,000	7,700	58,000
1995	167,000	11,000	76,900
2000	212,000	13,500	92,000

Source: County of Hawaii, Hawaii General Plan.

III - ECONOMIC IMPACTS

The proposed O'oma community is expected to generate significant positive economic benefits to the county and state of Hawaii. This chapter describes the expected impacts in terms of expenditures, employment and resident income.

DEVELOPMENT AND UTILIZATION ASSUMPTIONS

Assuming County and State development approvals are obtained in a timely manner, a first phase of development, including all or most of all elements of the O'oma community, is anticipated to be completed and available for use by about 1996. Thereafter, there could be further phases of condominium units and single-family lots, and on-going development of individual homes by the single-family lot buyers.

The development and operational schedule assumed for purposes of projecting the economic and fiscal impacts of the community are shown in Exhibit III-A. Compared to the maximum potential development presented in Exhibit I-B, this schedule assumes a mid-range development of 150 condominium units and 70 single-family lots, to avoid over-estimation of economic and fiscal benefits, and/or under-estimation of population impacts and therefore public costs. Major infrastructure, including the primary roads and a sewage treatment plant, would be expected to be in place by the time of first operations at the community, projected for 1996.

VISITOR EXPENDITURES

The subsections below summarize the projected direct, indirect and induced impacts of O'oma on consumer spending in the state. Most of this may be attributed to spending by visitors attracted to O'oma, who would make direct expenditures for food, lodging, gift items and other goods and services. These expenditures would, in turn, require those establishments serving these demands to purchase goods and services from other establishments in the state. The latter expenditures are considered indirect effects of the original expenditures. Induced expenditures are those made by employees and proprietors with income derived from establishments benefiting from these new direct and indirect expenditures.

Direct Expenditures

Expenditures generated by O'oma within the state or county of Hawaii are estimated based on the community's ability to attract new visitors to Hawaii. This may be considered a conservative statement of the potential benefits of O'oma because it neglects potential new expenditures by:

- Full- and part-time residents of the community who move from outside of the state, and thus bring new income and resources with which to make consumer expenditures on the island of Hawaii as well as throughout the state.

- Full-time residents of O'oma who move from Oahu or other islands, such as for retirement. Expenditures by such persons would be new for the county of Hawaii, although not for the state.

Exhibit III-A

KAHALA CAPITAL CORPORATION

O'oma II Community Development and Operational Assumptions

1996 to 2010

	1996	2000	2005	2010
Ocean science center and water recreation park admissions(1):				
O'oma visitors	376,000	492,000	569,000	615,000
Island residents	7,000	8,000	9,000	11,000
Total admissions	383,000	500,000	578,000	626,000
Conference center usage:				
Available function area(2)	18,000	18,000	18,000	18,000
Projected utilization	40%	50%	65%	65%
Average daily golf rounds(3):				
O'oma II residents	5	5	10	10
O'oma II visitors	75	85	100	100
Island residents	50	50	50	50
Total rounds	130	140	160	160
Golf Inn:				
Available rooms	50	50	50	50
Projected occupancy	65%	75%	85%	85%
Single-family lot sales and home development (cumulative)(4):				
Homes completed	0	24	46	58
Unbuilt sold lots	30	46	24	12
Total sold lots	30	70	70	70
Condominium unit sales (cumulative)	50	150	150	150
Retail areas distribution(5):				
Retail center	35,000	35,000	35,000	35,000
Ocean science center	2,000	3,000	3,000	3,000
Hotel shops	8,250	8,250	8,250	8,250
Total gross leasable area	45,250	46,250	46,250	46,250
Hotel:				
Available rooms	550	550	550	550
Projected occupancy	65%	75%	85%	85%

(1) As indicated in market study, Exhibit III-E.
(2) In square feet. Does not include "back of house" and support facilities.
(3) Based on data presented in market study, Exhibit VI-K, rounded.
(4) Based on 12% of sold lots being improved per year, as shown in market study, Exhibit VI-F.
(5) In gross leasable square feet, based on information shown in market study, Exhibit VII-K.

Source: Discussions with representatives from Kahala Capital Corporation; Information in the report entitled "Market Assessment for the O'oma II Ocean Science and Recreation Community," December 1990.

Exhibit III-B

KAHALA CAPITAL CORPORATION

Projected Direct Annual Visitor Expenditures
Attributable to O'oma II

1996 to 2010

(1990 dollars)

Expenditure source	Basis per unit	1996	2000	2005	2010
		In millions			
Ocean science center and water recreation park admissions:					
Annual visitor admissions(1)		376,000	492,000	569,000	615,000
Subtotal expenditures	$15/person	$5.6	7.4	8.5	9.2
Conference center rental:					
Average occupied function area(1)		7,200	9,000	11,700	11,700
Subtotal, expenditures	35¢/sq ft	0.9	1.1	1.5	1.5
Golf fees and related:					
Average annual guest rounds(1)		27,375	31,025	36,500	36,500
Subtotal expenditures	$15/round	0.4	0.5	0.5	0.5
Golf Inn guests:					
Average daily visitors(2)		65	75	85	85
Subtotal expenditures(3)	$250/visitor	5.9	6.8	7.8	7.8
Single-family home and condominium visitors:					
Average daily visitors(2)		23	108	158	157
Subtotal expenditures(3)	$140/visitor	1.2	5.5	8.1	8.0
Projected retail center sales(4)		7.3	10.2	11.9	12.1
Hotel guests:					
Average daily visitors(2)		679	784	888	888
Subtotal expenditures(3)	$150/visitor	37.2	42.9	48.6	48.6
Total annual expenditures		$58.6	74.5	86.9	87.8

(1) Based on data shown in Exhibit III-A.
(2) As shown in Exhibit IV-A.
(3) Average daily per person/day expenditure based on adjusted 1990 spending estimates as follows: westbound hotel visitors, $130; westbound condominium and resort single-family guests, $110; eastbound guests, $295. Mix of guests assumed to represent 25% westbound for golf inn, and 85% for other accommodations. Party size and other assumptions as shown in Exhibit IV-A.
(4) Based on projected sales reported in market study, adjusted to exclude resident expenditures, and for development of 50 condominium units by 1996.

Direct expenditure impacts would occur on-site, at the ocean science center, golf course, retail center and other commercial components of the community, as well as off-site, when the visitors and residents attracted to Hawaii by O'oma make day trips within the county and state.

Total visitor expenditures directly attributable to O'oma's development are estimated to increase from about $59 million in 1996, to nearly $88 million by 2010, as shown in Exhibit III-B.

Indirect, Induced and Total Expenditures

The Hawaii State Department of Business, Economic Development and Tourism (DBED) Input/Output Model estimates the economic activity generated in the state by various types of visitor-related direct expenditures. The all-industries 1989 multiplier of $1.39 total expenditures for every $1.00 of direct visitor expenditures is used.

Thus, the direct expenditures generated by O'oma could be expected to generate indirect and induced expenditures throughout the state amounting to $23 million by 1996 or $34 million by 2010 in 1990 dollars, as shown in Exhibit III-C.

Total expenditures attributable to the community including direct, indirect and induced effects, are also shown in Exhibit III-C and could amount to about $81 million statewide in the initial year of operations, and up to $122 million per year by 2010, in 1990 dollars.

EMPLOYMENT IMPACT

Development of O'oma would generate short-term employment during the construction of new facilities and long-term employment in the operation and support of those facilities.

Employment effects may also be classified as being direct, indirect or induced:

- Direct employment is that supported by expenditures generated by the community, such as the employment at facilities that serve visitors and residents. Most of the direct employment effects would occur on-site at the visitor-serving, recreational and conference facilities.

- Indirect and induced employment is that resulting off-site due to employment multiplier effects. As an example, new employment may occur in the public services sector, such as for teachers, police, and health care workers, to support new in-migrants working on-site. Such employment could occur throughout the state's economy.

This section projects the direct, indirect and induced effects of the proposed development on construction and operational employment.

Exhibit III-C

KAHALA CAPITAL CORPORATION

Projected Indirect, Induced and Total Annual Expenditures
Attributable to O'oma II Visitors

1996 to 2010

(1990 dollars in millions)

Spending type	1996	2000	2005	2010
Direct(1)	$58.6	74.5	86.9	87.8
Indirect and induced	22.8	29.0	33.9	34.2
Total(2)	$81.4	103.5	120.8	122.0

(1) From Exhibit III-B.
(2) Projected at $1.39 per one dollar of direct visitor expenditures based on 1989 ratios derived from the DBED Input-Output Model and Hawaii Econometric Model, as published in the "Hawaii State Data Book," 1990.

Direct Construction Employment

Direct construction employment is that which would be supported directly by the construction of the various facilities. Such employment includes on-site laborers, operatives and craftsmen, as well as professional, managerial, sales and clerical workers whose usual places of employment may be elsewhere on the island or in the state.

Construction employment requirements would be greatest during the 1993 to 1996 period, when all the major infrastructure and most of the facilities of the community are anticipated to be developed. In this period, average construction employment could represent nearly 270 full-time equivalent jobs per year, as shown in Exhibit III-D.

Indirect, Induced and Total Construction Employment

Direct construction employment stimulates additional purchases of goods and services on the island and elsewhere in the state. For O'oma, these indirect and induced employment effects could be expected to amount to about 210 person-years per year until 1996, tapering off to less than 10 per year by the 2006 to 2010 period, as shown in Exhibit III-E. Much of these multiplier effects could be expected to occur on Oahu or elsewhere in the state, due to leakages from the island's economy.

Including direct, indirect and induced effects, statewide employment supported by the construction of O'oma could represent over 2,300 person-years, mostly during the pre-opening years, about 1993 to 1996.

Direct Operational Employment

Operations of the planned commercial and residential facilities at O'oma would also generate significant permanent employment. The direct operational employment effects are estimated based on the nature and scope of facilities planned at O'oma and on surveys and observation of comparable other facilities. Direct impacts are estimated at about 700 full-time equivalent positions by project completion, as shown in Exhibit III-F.

In addition to the retail, hotel, golf and other types of employment common in other commercial developments in Hawaii, O'oma could support a variety of new types of positions, including some which might be located off-site. These less familiar types of employment are discussed as follows:

- Ocean science center - Would require an executive and assistant director for overall facility/program planning and management, as well as employees to collect fish and other marine species, to conduct research, provide aquarium maintenance and management, veterinarian services, laboratory analyses, groundskeeping, sales and administration, food and beverage preparation and service, janitorial services, building maintenance, and the like. Several positions would require advanced education and training in ocean, marine and related sciences. The center could also support community relations and charitable fund- raising coordinators.

Exhibit III-D

KAHALA CAPITAL CORPORATION

Projected Direct Employment for Facility Construction
O'oma II Community

1993 to 2010

Facility type	Average annual person years: 1993-1996	1997-2000	2001-2005	2006-2010	Total person-years
Ocean science center and water recreation park(1)	19	--	--	--	75
Conference center(2)	10	--	--	--	40
Golf course(3)	10	--	--	--	40
Golf inn(4)	13	--	--	--	50
Single-family homes:					
Lot development(5)	4	--	--	--	15
Home construction(6)	--	12	9	5	115
Condominiums(7)	14	28	--	--	165
Retail center(8)	11	0	--	--	45
Hotel(4)	138	--	--	--	550
Infrastructure(9)	49	--	--	--	195
Total	266	40	9	5	1,290

(1) Calculated at 75 person-years and a one year construction period.
(2) Calculated at 2 persons per thousand square feet, and construction period of a year and a half.
(3) Person-years assumes labor cost is 50% of construction cost and average two-year cosntruction period.
(4) Calculated at 1 person-year per room based on similar developments.
(5) Calculated at 0.2 person-years per year per home, and an average one-year construction period per lot.
(6) Calculated at 2 person-years per year per home, and an average one-year construction period per home.
(7) Calculated at 1.1 person-years per condominium unit.
(8) Calculated at 1 person-year per 1,000 square feet.
(9) Based on a construction cost estimate provided by Kahala Capital Corporation of $39.2 million and full-time equivalent jobs calculated at 5 person years per million dollars of cost.

Exhibit III-E

KAHALA CAPITAL CORPORATION

Projected Total Employment for Facility Construction
O'oma II Community

1993 to 2010

Type of employment	Average annual person years 1993-1996	1997-2000	2001-2005	2006-2010	Total person-years
Direct employment(1)	266	40	9	5	1,290
Indirect and induced:					
On-island(2)	80	12	3	2	387
Elsewhere in State	133	20	5	3	645
Subtotal	213	32	8	5	1,032
Total(3)	479	72	17	10	2,322

(1) From Exhibit III-D.
(2) Estimated at 30% of direct employment.
(3) Total direct, indirect and induced effect estimated at 1.8 full-time equivalent positions per direct position, based on 1989 ratios from the DBED Input-Output Model and Hawaii Econometric Model, as presented in the Department of Business and Economic Development, "The Hawaii State Data Book," 1990.

Exhibit III-F

KAHALA CAPITAL CORPORATION

Projected Direct Operational Employment Impacts of the
O'oma II Community

1996 to 2010

(Full-time equivalent positions)

Facility type	1996	2000	2005	2010
Ocean science center(1)	90	110	125	125
Water recreation park(1)	20	25	25	25
Conference center(2)	8	10	10	10
Golf course(3)	40	40	40	40
Golf inn(4)	50	50	50	50
Single-family and condominium rentals(5)	4	12	12	12
Retail center(6)	100	100	100	100
Hotel(7)	330	330	330	330
Facilities administration(8)	5	10	10	10
Total (rounded)	650	690	700	700

(1) Includes park staff, administration, maintenance, and food and beverage.
(2) Based on industry ratios.
(3) Based on comparable local and national clubs. Includes clubhouse, food and beverage, and retail facilities as well as course management and maintenance.
(4) Estimated at 1 per room.
(5) Estimated at 0.15 jobs per unit kept in rental pool (estimated at 50% of condominium units and 10% of single-family).
(6) Estimated at 1 per 350 square feet of leasable space.
(7) Estimated at 0.6 per room.
(8) Category includes resort administration, property development, sales and management and other groundskeeping and maintenance of developed facilities and infrastructure.

- Water recreation park - Would require groundskeeping (shared with ocean science center), sales/clerical services (may share with ocean science center), beach services, ocean sport training, life guard services, food and beverage service and overall management. The park would also require sophisticated management of its water engineering systems, some of which might be handled on a contract basis.

- Conference center - Could require an executive and assistant director as well as sales managers, accountants, receptionist/secretaries, event supervisors and coordinators, and building and grounds maintenance personnel. Many of the positions would require training and experience in group sales and/or meetings/conference management. Although conferences could frequently include food and beverage services, the employment attributed to these service is allocated to the ocean science center and the hotel in the projections shown on Exhibit III-F.

Indirect, Induced and Total Operational Employment

The direct operational positions created would also indirectly generate employment beyond the community site. Considering the multiplier effects associated with the various types of work expected, O'oma could be expected to support up to 1,280 positions throughout the state by stabilization of its operations by 2000, as shown in Exhibit III-G.

This would include about 580 full-time equivalent positions supported as indirect and induced effects of the community's direct employment. These employment opportunities would be expected to occur in diverse fields, at sites located throughout the state.

RESIDENT INCOME

The O'oma community would generate resident income in the form of employee wages, salaries and benefits, and income to business proprietors. The income effects of the development are summarized in Exhibit III-H.

Personal Income

Personal income effects of O'oma are estimated as the wages and salaries paid to the direct construction and operational employees of the development. Personal income is projected on the basis of average industry wages and salaries for the various types of employment anticipated and on the projected future employment demand.

Considering the levels of direct employment shown previously in Exhibit III-F, and Hawaii full-time equivalent 1990 wages and salaries representative of the types of employment anticipated, O'oma could be expected to provide direct personal income ranging from about $14 million to $24 million per year in 1990 dollars, as shown in Exhibit III-H.

Personal income declines over the projection period as the relatively highly paid construction work phases out.

Exhibit III-G

KAHALA CAPITAL CORPORATION

Projected Total Operational Employment Impacts of the O'oma II Community

1996 to 2010

(Full-time equivalent positions)

Type of employment	1996	2000	2005	2010
Direct employment(1)	650	690	700	700
Indirect and induced employment:				
Ocean science center(2)	61	75	85	85
Water recreation park(2)	14	17	17	17
Conference center(3)	7	9	9	9
Golf course(2)	27	27	27	27
Golf Inn(3)	47	47	47	47
Single-family and condominiums rentals(3)	3	11	11	11
Retail center(4)	63	63	63	63
Hotel(3)	307	307	307	307
Facilities administration(3)	5	9	9	9
Subtotal (rounded)	530	560	580	580
Total	1,180	1,250	1,280	1,280

(1) As shown in Exhibit III-F.
(2) Estimated at 1.68 full-time equivalent positions per direct position.
(3) Estimated at 1.93 full-time equivalent positions per direct position.
(4) Estimated at 1.63 full-time equivalent positions per direct position.

Reference: DBED Input-Output Model and Hawaii Econometric Model as published in the "Hawaii State Data Book," 1990.

Exhibit III-H

KAHALA CAPITAL CORPORATION

Projected Direct Personal and Total Household Income from Direct Employment Associated with the O'oma II Community

1996 to 2010

(1990 dollars)

Type of direct employment	Full-time equivalent wages(1)	In millions 1996	2000	2005	2010
Personal income(2)					
Construction(3)	$41,350	$11.0	1.6	0.4	0.2
Operational:					
Amusement & recreation(4)	19,820	3.0	3.5	3.8	3.8
Retail trade(5)	16,830	1.7	1.7	1.7	1.7
Hotel(6)	19,820	7.8	8.0	7.9	7.9
Administrative(7)	17,870	0.1	0.2	0.2	0.2
Subtotal operational income		12.6	13.4	13.6	13.6
Total annual personal income		$23.6	15.0	14.0	13.8
Household income(8)		$30.5	38.7	45.2	45.6

(1) 1990 salaries. Adjusted full-time equivalent salaries based on a 40-hour work week.
(2) For direct employment effects only.
(3) Average state wage for category multiplied by average number of construction workers for period shown in Exhibit III-D.
(4) Average state wage for category multiplied by number of ocean science center, water recreation park and golf course employees, as shown in Exhibit III-F.
(5) Average state wage for category multiplied by number of retail center employees, as shown in Exhibit III-F.
(6) Average state wage for category multiplied by number of hotel, golf inn, rental, and conference center employees, as shown in Exhibit III-F.
(7) Average state wage for category multiplied by number of facilities administration employees, as shown in Exhibit III-F.
(8) Based on an estimate of $0.52 total household income for each direct dollar spent by visitors to the state of Hawaii (1989 ratios).

References: Department of Labor and Industrial Relations, "Labor Area News," July 1990; DBED Input-Output Model and Hawaii Econometric Model, as reported in the "State of Hawaii Data Book," 1990.

These figures exclude the wages and salaries that would be associated with the indirect and induced employment benefits of O'oma.

Household Income

The dispersion of indirect and induced employment effects among many industries make it difficult to project the total income effects of the proposed development. However, estimates of total household income, which includes rents, proprietary and unearned income effects of the visitor expenditures at O'oma permits a perspective on the statewide income benefits that could result from the community.

Based on the latest (1989) ratios available from DBED, each direct dollar spent by visitors generates an estimated $0.52 in total income to households in the state. Thus, based on the annual direct expenditures of community visitors shown previously in Exhibit III-B, household income from the development could exceed $45 million by 2010, in 1990 dollars, as shown in Exhibit III-H.

IV - POPULATION AND HOUSING IMPACTS

This chapter describes the projected impact of the proposed O'oma II community on population growth. It further describes the potential impact this growth may have on housing demand in the west Hawaii region.

POPULATION IMPACTS OF DEVELOPMENT

The O'oma II community could contribute to population increase at the project site and elsewhere on the island. People would be residing during most or parts of each year in the residential portion of the community, while visitors at the hotel, inn and rental accommodations would contribute to the average daily population at O'oma. Operational and construction employees could also add to the population of the region and the island, although they would likely reside away from the project site.

On-site Population Impact

On-site visitor population projections are derived from the planned facilities as previously shown in Exhibit III-A and unit usage, average occupancy and party size assumptions are as listed in Exhibit IV-A.

Based on these assumptions, on an average day, visitors staying at the community could be as shown in Exhibit IV-B, or ranging from about 770 persons in 1996, to 1,130 persons by 2010.

Considering the anticipated mix of fulland part-time use of the single-family and condominium homes at O'oma, on-site resident population could be expected to grow from a daily average of about 30 persons in 1996, to nearly 180 by 2010, as also shown in Exhibit IV-A. In total, the on-site population of O'oma could range up to about 1,300 persons by 2010, in terms of households. The full- and part-time residents of O'oma could represent about 15 occupied homes per day in 1996, and nearly 80 per day by 2010, as shown in Exhibit IV-C.

Off-site and Total Population Impacts

O'oma could also impact population outside of its boundaries, principally in nearby west Hawaii communities. For the island of Hawaii, this would be a result of operational and construction employees who move to the island because of the employment opportunities at O'oma, and from the dependents that may accompany these in-migrants. During the construction phases, these impacts would be temporary, while there would be long-term impacts from the new residents associated with operational positions at the community.

The off-site population impacts of O'oma are estimated to range from about 920 persons in 1996, to about 840 by 2010, as shown in Exhibit IV-D. Thus, in total, on- and off-site effects of the development could represent up to 2,100 additional persons on the island by the end of the projection period, as also shown in the exhibit.

Exhibit IV-A

KAHALA CAPITAL CORPORATION

Unit Usage Assumptions for
On-Site Population Projections

Source of population impact	Number of units(1)	Percent distribution by use	Projected occupancy rate(2)	Persons per unit
Single-family homes:				
Visitor rentals		10%	50	2.5
Part-time residences		30	20	2.0
Full-time residences		60	95	2.4
Total	60(3)	100		
Condominium units(4):				
Visitor rentals		50	37% 50 80%	2.5
Part-time residences		25	20	2.0
Full-time residences		25	95	2.2
Total	150	100		
Golf inn guests	50	100	65% to 85%	2.0
Hotel guests	550	100%	65% to 85%	1.9

(1) At assumed completion.

(2) Vary with projection year for visitor rental units.

(3) Homes projected to be completed within projection period. Based on 12% of available vacant lots developed per year as shown in market study, Exhibit VI-F.

(4) About 50 condominium units anticipated to be available in 1996, remainder by 2000.

Exhibit IV-B

KAHALA CAPITAL CORPORATION

Projected Average Daily Resident and Visitor Population
at the O'oma II Community

1996 to 2010

	1996	2000	2005	2010
Community residents:				
Full-time-				
Single-family home	--	33	63	79
Condominium	26	77	77	77
Subtotal	26	110	140	156
Part-time-				
Single-family home	--	3	6	7
Condominium	5	15	15	15
Subtotal	5	18	21	22
Total daily residents	31	128	161	178
Community visitors:				
Golf Inn	65	75	85	85
Single-family home	--	3	6	7
Condominium	23	105	152	150
Hotel	679	784	888	888
Total daily visitors	767	967	1,131	1,130
Total O'oma II community daily population	798	1,095	1,292	1,308

Source: Exhibits VI-G through VI-I of "Market Assessment for the O'oma II Ocean Science and Recreation Community," KPMG Peat Marwick, December 1990.

Exhibit IV-C

KAHALA CAPITAL CORPORATION

Projected Average Resident Households
at the O'oma II Community

1996 to 2010

	1996	2000	2005	2010
Community residents:				
Full-time-				
Single-family home	--	14	26	33
Condominium	12	35	35	35
Subtotal	12	49	61	68
Part-time-				
Single-family home	--	1	3	3
Condominium	3	7	7	7
Subtotal	3	8	10	10
Total resident households	15	57	71	78

Source: Exhibit VI-H of "Market Assessment for the O'oma II Ocean Science and Recreation Community," KPMG Peat Marwick, December 1990.

Exhibit IV-D

KAHALA CAPITAL CORPORATION

Total Projected Additional In-migrant Resident Population to the County of Hawaii

1996 to 2010

In-migrant type	1996	2000	2005	2010
On-site community residents(1)	23	96	121	134
Off-site community residents:				
Temporary-				
Construction employees(2)	93	14	3	2
Dependents(3)	47	7	2	1
Permanent-				
Operational employees(4)	390	414	420	420
Dependents(5)	390	414	420	420
Subtotal	920	849	845	843
Total in-migrant population impact (rounded)	940	940	970	980

(1) As shown in Exhibit IV-B. An estimated 75% of community residents are expected to come from off-island.
(2) An estimated 35% of direct construction workers from Exhibit III-D are expected to come from off-island. Represents average annual person years.
(3) Projected at 0.5 additional persons per construction worker. Represents average annual person-years.
(4) An estimated 60% of direct operational workers from Exhibit III-F are expected to come from off-island.
(5) Dependents are projected at 1 additional person per operational worker.

HOUSING IMPACTS

Development of the O'oma II community could affect west Hawaii's housing situation in several ways. Temporary housing could be needed to house workers brought to the island during project construction. Operational employment at the community would also trigger additional housing demand, to accommodate in-migrant employees and their dependents.

Construction Employee Housing Demand

Construction employment is temporary, and therefore does not generate the long-term housing demands associated with community operational employment. However, in-migrating construction workers could be expected to seek shortto medium-term rental units in the general market.

It is assumed that an average of 35% of construction workers could have to be attracted from off-island, that 90% of these workers could require rental housing, and that construction workers would share housing at a ratio of 1.25 workers per household. Thus, the average daily rental unit requirements for construction workers could range from about 70 homes in the period of maximum development activity, 1993 to 1996. Thereafter, these temporary housing needs could decline to become almost negligible, as the project is built-out, as shown in Exhibit IV-E.

Because of the nature of labor needs during development of real estate projects, construction employment could fluctuate significantly from month to month and even week to week within any year. Thus, considering the anticipated timing of individual construction projects within O'oma the associated temporary housing needs could represent up to about 140 rental units during peak activity weeks in the 1993 to 1996 period, and could phase out thereafter.

Operational Employee Housing Demand

O'oma II operational employees and their dependents who come from off-island would require long-term housing on the island. Also, new household formation among prior island residents who work at the community could create demands for new housing units. The projected housing demand associated with operational employees, shown in Exhibit IV-F, is discussed as follows:

- Those workers drawn from the available area resident labor supply, consisting of the unemployed, underemployed and new labor force entrants, are expected to already be housed on the island. However, n w housing demand might occur, due to rising income, the desire to live closer to work, or the opportunity to live independently or start a family. Thus, a 15% new household formation factor is used to measure housing demand of workers recruited from available area resident labor.
- About 60% of permanent positions at O'oma could generate in-migration to the island, based on anticipated continuation of the tight labor market conditions on Hawaii island. Thus, in-migrants constitute the largest source of potential housing demand.

Exhibit IV-E

KAHALA CAPITAL CORPORATION

Projected Rental Units Required for Off-Island Construction Workers

1993 to 2010

	1993-1996	1997-2000	2001-2005	2006-2010
At average employment level:				
Average annual employment(1)	266	40	9	5
Off-island construction workers(2)	93	14	3	2
Workers requiring rental units(3)	84	13	3	2
Rental units required(4)	67	10	2	1
At peak employment level:				
Peak employment(5)	545	44	11	6
Off-island construction workers(2)	191	16	4	2
Workers requiring rental units(3)	172	14	4	2
Rental units required(4)	137	11	3	2

(1) From Exhibit III-D.
(2) Estimate based on 35% of construction workers originating from off-island.
(3) Estimate based on 90% of workers requiring rental units.
(4) Projected at 1.25 construction workers per rental unit.
(5) Estimated at an average of 1.9 times average employment based on project timing and development schedule provided by Kahala Capital Corporation.

Exhibit IV-F

KAHALA CAPITAL CORPORATION

Direct Operational O'oma II Employees Projected to Demand Additional Housing

1996 to 2010

Housing demand source	1996	2000	2005	2010
Availablable island labor force(1)	260	276	280	280
New island households(2)	23	25	25	25
In-migrants(3)	390	414	420	420
New in-migrant households(4)	234	248	252	252
Total demand (rounded)	260	270	280	280

(1) Island labor force estimated at total operational employees (Exhibit II-F) less in-migrant employees (Exhibit IV-C).
(2) New household formation projected based on 15% of projected operational employment, with 1.7 employees sharing each household.
(3) As shown in Exhibit IV-C.
(4) Projected at 1.7 employees sharing each household.

- Due to the high incidence of multiple resort worker households identified at west Hawaii resorts in a 1987 survey conducted by Community Resources, Inc. (CRI), the housing demand assessment is based on 1.7 operational workers per household.

Based on these standards, Exhibit IV-F shows housing demand related to resort operational employment of about 260 units in 1996, increasing to about 280 units by 2010.

Price and Tenure of
Required Employee Housing

The household income distribution of west Hawaii resort workers is based on findings of the 1987 CRI Survey, adjusted to 1990 dollars, as shown in Exhibit IV-G. The exhibit also indicates the affordability of housing for each income group, as measured by the maximum monthly mortgage or rent payment afforded by income.

The household income distribution is also used to estimate the percentage of each group that could be expected to seek to purchase as opposed to rent units, based on:

- Maximum home purchase price affordable.
- Percentage of owner households, estimated from historical observations for the island.
- Ownership percentages are adjusted upward to reflect the potential availability of affordably-priced units.
- Application of ownership percentages to the projected income distribution.

Based on historical buying patterns during periods of lower housing market prices, if affordably-priced units could be made available, nearly 46% of the 280 new O'oma community worker households could represent demand for ownership units. Remaining demand could be accommodated with rental housing.

Housing Affordability

By observing local market prices for household ownership and rental, the minimum gross monthly income required for homeownership in the unassisted market is approximately $2,750, which would afford mortgaging a home of about $145,000, assuming $29,000 in savings that could be applied to a downpayment. For rentals, a minimum monthly income of about $2,500 could permit rental of about 50% of the condominium units listed for long-term rent in west Hawaii in October 1990. Thus, these income levels serve as measuring points for home ownership and rental affordability. The calculation of this affordability measuring point assumes the following:

- Housing affordability standards used by the State Housing Finance and Development Corporation.

KAHALA CAPITAL CORPORATION

Projected Income and Housing Tenure Distribution of O'oma II Community Workers

Gross monthly household income in 1987(1)	1990 maximum monthly household income(2)	Percent distribution	Maximum housing payment(3) Own	Maximum housing payment(3) Rent	Maximum purchase price(4)	Potential market for O'oma II worker households Own	Rent	Total(5)//	Estimated potential owners
Less than $1,000	$ 1,191	6%	$ 417	$ 357	$ 59,000	-	17	17	-%
$1,001 to $1,250	1,489	10	521	447	74,000	4	24	28	15
$1,251 to $1,500	1,787	9	625	536	88,000	5	20	25	20
$1,501 to $1,750	2,084	9	729	625	103,000	6	19	25	25
$1,751 to $2,000	2,382	11	834	715	118,000	11	20	31	35
$2,001 to $2,500	2,978	15	1,042	893	147,000	19	23	42	45
$2,501 to $3,000	3,573	15	1,251	1,072	177,000	25	17	42	60
$3,001 to $3,500	4,169	10	1,459	1,251	206,000	21	7	28	75
More than $3,500	-	15	-	-	-	38	4	42	90
Total		100%				129	151	280	46%

(1) From 1987 surveys of South Kohala resort workers conducted by Community Resources, Inc.

(2) Adjusted for annual income increases of 7.6% and 10.7% in 1988 and 1989, respectively.

(3) Assuming maximum 1990 household incomes as shown and 35% of income for owner and 30% for renter households dedicated to housing payments.

(4) Assuming maximum 1990 household incomes as shown and 20% downpayment, 10% interest rate and 30-year mortgage amortization period.

(5) Maximum housing required for O'oma II operational workers, as shown in Exhibit IV-G, rounded.

- For ownership, maximum purchase price is based on typical prevailing terms for a 30-year, fixed-rate conventional mortgage loan; these include a 20% downpayment and 10% interest rate.
- For rentals, 30% of gross monthly income available for rent payments.

Exhibit IV-H projects the percentage mix of the type of housing demanded by applying the income level indicated above to the observed income distribution shown previously in Exhibit IV-G. The exhibit indicates that for the total potential employee housing required:

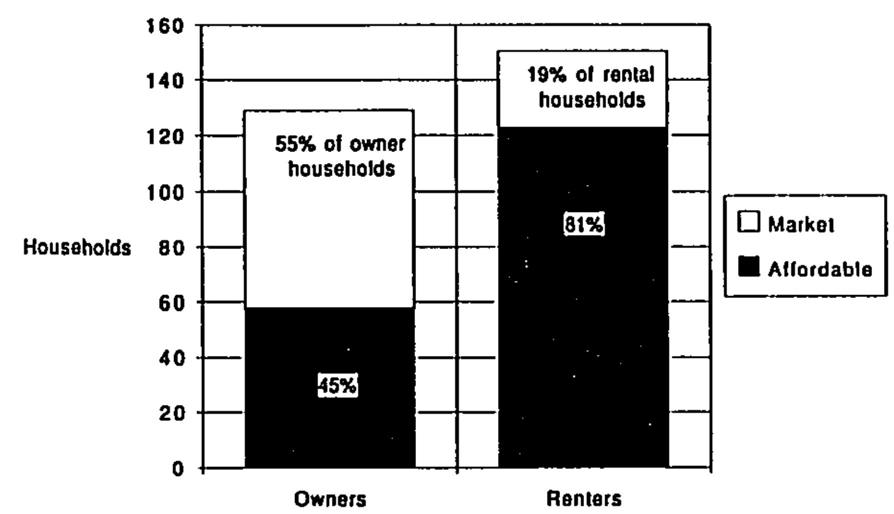
- Affordable housing assistance could be required by 45% of those seeking to own and by 81% of those seeking to rent. This could represent about 58 owner and 123 renter households.
- Conversely, 55% of potential owners and 19% of potential renters are expected to be able to find market housing. This indicates a need for an additional 71 owner and 28 rental households on the island.

Thus, affordable housing alternatives could be required for about 60% of all new households generated by the operation of the O'oma II community. The majority of these households would be renters.

Exhibit IV-H

KAHALA CAPITAL CORPORATION

Affordability Mix for
Potential Housing Market Demand at the
O'oma II Community



Source: Total households as shown in Exhibit IV-H with affordability determined by the gross monthly income level of $2,750 for owner and $2,500 for renter households.

V - FISCAL IMPACTS

The proposed O'oma community is expected to generate significant positive fiscal benefits for the county and state of Hawaii. These fiscal impacts are evaluated by comparing the tax revenues and government operating expenditures projected to result from project development and operations.

GOVERNMENT REVENUES

Development of O'oma II would bring additional tax revenues to the county and state governments. County government revenues would be principally in the form of real property taxes on the developed acreage and new facilities. Revenues to the state government would be composed principally of general and specific excise taxes and personal income taxes paid by new state residents, and the general excise tax on sales revenues and transient accommodations tax attributable to visitors.

The following sections project the additional revenues that could be generated for county and state governments as a result of the O'oma II development.

County Revenues

Commercial and unimproved real property in the county of Hawaii is currently taxed at $8.50 and $10.00 per $1,000 of assessed value for the improvements and land, respectively. Improved residential property is taxed at $8.50 per $1,000 total (land and building) assessed value.

Considering O'oma's current property tax burden of approximately $36,000, and potential owner-occupant exemptions the community could be expected to generate net new property tax revenues of about $1.5 million per year by its opening in 1996, or up to $1.9 million by 2010, as shown in Exhibit V-A.

State Revenues

O'oma II visitors would generate new revenues to the state government through the general excise tax on their direct, indirect and induced expenditures and through the tax on rental of transient accommodations.

These new revenues could amount to $3.4 million per year in 1996, and up to $6 million by 2010, as shown in Exhibit V-B.

In addition, new residents attracted to the state by the employment or residential opportunities of the project would bring in additional excise sales taxes, individual income taxes and other state taxes such as liquor, tobacco, fuel, inheritance, estate and conveyance taxes. In 1990, these individual income and other taxes are estimated at $2,460 for the average resident and $3,950 for high income ($100,000 household income) persons. Thus, new total tax revenues to the state government attributable to the residents and in-migrant employees of the community are estimated at $1.3 million by 1996 and $1.6 million by 2010, as shown in Exhibit V-C.

In summary, the additional state tax revenues attributable to the total visitor and resident population impacts of O'oma are estimated to increase from about $4.7 million in 1996, to $7.6 million by 2010, as also shown in Exhibit V-C.

Exhibit V-A

KAHALA CAPITAL CORPORATION

Projected Real Property Tax Revenues
to the County Government Attributable to the O'oma II Community

1996 to 2010

(1990 dollars in millions)

Source of property tax revenue	1996	2000	2005	2010
Ocean science center(1)	$0.16	0.16	0.16	0.16
Water recreation park(2)	0.13	0.13	0.13	0.13
Conference center(3)	0.07	0.07	0.07	0.07
Golf course and club house(4)	0.08	0.08	0.08	0.08
Golf Inn(5)	0.07	0.07	0.07	0.07
Single-family lots(6):				
Improved lots(7)	0.00	0.10	0.19	0.24
Unimproved lots	0.18	0.12	0.06	0.03
Condominiums(7)(8)	0.14	0.43	0.43	0.43
Retail center(9)	0.05	0.05	0.05	0.05
Hotel(10)	0.63	0.63	0.63	0.63
Other undeveloped land(11)	0.01	0.00	0.00	0.00
Total new property tax revenues	1.50	1.83	1.86	1.88
Less current property taxes(12)	0.04	0.04	0.04	0.04
Net new property tax revenues	$1.47	1.79	1.83	1.85

(1) Based on assessments of $15 million for improvements and $250 thousand/acre for land.
(2) Based on assessments of $10 million for improvements and $250 thousand/acre for land.
(3) Based on assessments of $7 million for improvements and $250 thousand/acre for land.
(4) Based on assessments of $3 million for improvements and $30 thousand/acre for land.
(5) Based on assessments of $5 million for improvements and $500 thousand/acre for land.
(6) Based on assessed values of $250 thousand per home and $250 thousand per lot.
(7) Owner-occupant tax exemption based on a $20 thousand reduction per unit in assessed improvement value for each owner. Qualified occupants are assumed at 33%.
(8) Based on a total estimated value of $340 thousand per unit.
(9) Assessment values estimated at $100 per gross leasable square foot for improvements and a $200 thousand/acre for land.
(10) Based on assessments of $55 million for improvements and $750 thousand/acre for land.
(11) Includes infrastructure and other undeveloped land estimated at $20 thousand per acre.
(12) Current property tax is $36,068, as reported by Kahala Capital Corporation.

Exhibit V-B

KAHALA CAPITAL CORPORATION

Projected Annual Revenues to the State
Government Attributable to O'oma II Visitors

1996 to 2010

(1990 dollars)

Revenue source	Basis per unit	In millions 1996	2000	2005	2010
General excise tax on direct visitor spending(1):					
Ocean science center and water recreation park		$0.24	0.31	0.36	0.38
Conference center		0.04	0.05	0.06	0.06
Golf course		0.02	0.02	0.02	0.02
Golf inn		0.25	0.29	0.32	0.32
Single-family and condominiums		0.05	0.23	0.34	0.33
Retail center		0.30	0.43	0.50	0.50
Hotel		1.55	1.79	2.03	2.03
Subtotal		2.44	3.11	3.62	3.66
General excise tax on indirect and induced visitor spending(1)		0.95	1.21	1.41	1.43
Transient accommodations tax(2):					
Golf inn	$90/room	0.06	0.06	0.07	0.07
Single-family	$200/room	0.00	0.00	0.01	0.01
Condominium	$150/room	0.03	0.08	0.08	0.08
Hotel	$120/room	0.82	0.95	1.08	1.08
Subtotal		0.01	0.94	1.23	1.33
Total revenues		$3.40	4.06	5.46	5.99

(1) Based on a general excise tax of 4.17%. Direct, indirect and induced spending as shown in Exhibits III-B and III-C.
(2) Based on a transient accommodations tax of 5.25% on estimated visitor rental revenues.

Exhibit V-C

KAHALA CAPITAL CORPORATION

Projected Total Annual Revenues to the State
Government Attributable to O'oma II Visitors, Residents and Employees

1996 to 2010

(1990 dollars)

Revenue source	Basis per unit	In millions 1996	2000	2005	2010
Visitors(1)		$3.40	4.06	5.46	5.99
In-migrant residents:					
On-site-					
Number of persons(2)		23	96	121	134
State tax revenues(3)	$3,950 per person	0.09	0.38	0.48	0.53
Off-site-					
Number of persons(2)		483	428	423	422
State tax revenues(3)	$2,460 per person	1.19	1.05	1.04	1.04
Subtotal resident revenues		1.28	1.43	1.52	1.56
Total state revenues		$4.69	5.49	6.98	7.55

(1) As shown in Exhibit V-B.
(2) From Exhibit IV-C.
(3) Includes general excise, income tax, etc.

GOVERNMENT OPERATING EXPENDITURES

New visitors and residents attracted to O'oma would also necessitate additional expenditures of state and county public resources.

In-migrant residents would incur public costs in terms of public safety, maintenance of highways, recreational facilities and natural resources, health and sanitation measures, special cash capital improvements, education, retirement and pension funds, public welfare and other government functions.

Visitors would also increase the average daily population of the community and would require public expenditures in terms of public safety, maintenance of highways, health and sanitation, recreation and special cash capital improvements.

County Operating Expenditures

The various county government operating expenditures for fiscal year 1989 were analyzed with respect to the relevant population served by each of the government functions. This analysis indicates that Hawaii County government expenditures in fiscal year 1989 totaled about $590 per resident and $400 per visitor, as shown in Exhibit V-D. Adjusting for a 7.2% rise in the Honolulu Consumer Price Index between second quarters of 1989 and 1990, these expenditures in 1990 dollars are estimated at about $630 and $430 per capita for residents and visitors, respectively.

Based on these county government outlays, public expenditures by the county on behalf of the population impacts of O'oma are as shown in Exhibit V-E representing about $0.9 million in 1996, and about $1 million in 2010.

State Operating Expenditures

A similar analysis of state government operating expenditures and the relevant populations for the various government services indicate that expenditures in fiscal year 1989 totaled about $2,860 per resident and $810 per visitor, as shown in Exhibit V-F. This is equivalent to about $3,070 per resident and $870 per full-time equivalent visitor when adjusted to 1990 dollars.

Based on these operating costs, state government operating expenditures attributable to O'oma are projected as shown in Exhibit V-G, representing an additional $3.3 million in 1996 and up to $3.6 million by 2010. These projections may overstate potential state costs in that they assume all operational employees and their dependents who move to Hawaii island to work at O'oma are new residents for the state.

REVENUE AND EXPENDITURE ANALYSIS

The net fiscal impacts of the resort on county and state operating budgets are estimated by comparison of the projected additional new revenues and expenditures for each government entity.

Exhibit V-D

KAHALA CAPITAL CORPORATION

County of Hawaii Per Capita Government Expenditures

Fiscal Years 1989 and 1990

Function	Total expenditures FY'89 (000's)(1)	Service population(2)	Annual expenditure: Per resident	Per visitor
General government	$11,045	119,800	$92	--
Public safety	30,499	132,000	231	231
Highways	5,173	132,000	39	39
Health and sanitation	4,282	132,000	32	32
Economic and urban development	3,257	119,800	27	--
Recreation	6,362	132,000	48	48
Interest	4,900	132,000	37	37
Bond redemption	2,967	119,800	--	--
Retirement and pension	6,034	119,800	50	--
Mass transit	482	132,000	4	4
Cash capital improvements	1,092	132,000	8	8
Miscellaneous	2,439	119,800	20	--
Total 1989 dollars	$78,531		$590	400
Total 1990 dollars, rounded(3)			$630	430

(1) County government operating expenditures for fiscal year ended June 30, 1989 as reported in Tax Foundation of Hawaii, "Government in Hawaii," 1990.
(2) Resident or de facto population estimates for the county as of January 1, 1989.
(3) Adjusted to 1990 dollars based on a 7.2% increase in the Consumer Price Index between 2nd quarter 1990 and year earlier; as reported by Bank of Hawaii Information Center, 1990.

Exhibit V-E

KAHALA CAPITAL CORPORATION

Projected Annual County Government Expenditures
Associated with the O'oma II Community

1996 to 2010

(1990 dollars in millions)

Population and expenditure type	1996	2000	2005	2010
New service population (average annual persons)(1):				
Average daily visitors	767	967	1,131	1,130
Community residents	23	96	121	134
In-migrant employees & dependents(2)	920	849	845	843
Total	1,710	1,912	2,096	2,106
Expenditures (millions)(3):				
Visitors	$0.33	0.42	0.49	0.49
Community residents	0.01	0.06	0.08	0.08
In-migrant employees & dependents	0.58	0.53	0.53	0.53
Total expenditures	$0.92	1.01	1.09	1.10

(1) As shown in Exhibit IV-C.
(2) Including construction and operational employees.
(3) Based on per capita expenditures, as shown in Exhibit V-D.

Exhibit V-F

KAHALA CAPITAL CORPORATION

State of Hawaii Per Capita Government Expenditures

Fiscal Years 1989 and 1990

Function	Total expenditures FY'89 (000's)(1)	Service population(2)	Annual expenditure Per resident	Per visitor
General government	$287,802	1,105,300	$260	--
Public safety	119,991	1,240,900	97	97
Highways	76,911	1,240,900	62	62
Natural resources	38,327	1,240,900	31	31
Health and sanitation	120,440	1,240,900	97	97
Hospitals and institutions	147,452	1,105,300	133	--
Public welfare	396,944	1,105,300	359	--
Education	986,588	1,105,300	893	--
Recreation	27,025	1,240,900	22	22
Utilities and other enterprise	174,257	1,240,900	140	140
Debt service	248,062	1,240,900	200	200
Retirement and pension	85,727	1,105,300	78	--
Employees' health insurance	584	1,105,300	1	--
Unemployment compensation	49,112	1,105,300	44	--
Grants-in-aid to counties	42,348	1,240,900	34	34
Urban redevelopment and housin-	263,908	1,105,300	239	--
Cash capital improvements	155,598	1,240,900	125	125
Miscellaneous	46,921	1,105,300	42	--
Total 1989 dollars	$3,267,999		$2,860	810
Total 1990 dollars, rounded(3)			$3,070	870

(1) State government operating expenditures for fiscal year ended June 30, 1989 as reported in Tax Foundation of Hawaii, "Government in Hawaii," 1990.
(2) Resident or de facto population estimates for the state as of January 1, 1989.
(3) Adjusted to 1990 dollars based on a 7.2% increase in the Consumer Price Index between 2nd quarter 1990 and year earlier; as reported by Bank of Hawaii Information Center, 1990.

Exhibit V-G

KAHALA CAPITAL CORPORATION

Projected Annual State Government Expenditures
Associated with the O'oma II Community

1996 to 2010

(1990 dollars in millions)

Population and expenditure type	1996	2000	2005	2010
New service population (average annual persons)(1):				
Average daily visitors	767	967	1,131	1,130
Community residents(2)	19	77	97	107
In-migrant operational employees & dependents(3)	828	764	760	758
Total	1,614	1,808	1,988	1,995
Expenditures (millions)(3):				
Visitors	$0.67	0.84	0.98	0.98
Community residents	0.06	0.24	0.30	0.33
In-migrant employees & dependents	2.54	2.35	2.33	2.33
Total expenditures	$3.27	3.42	3.61	3.64

(1) As shown in Exhibit IV-C.
(2) Not including 20% of in-migrants to the county estimated to have relocated from elsewhere in the state.
(3) Not including 10% of in-migrants to the county estimated to have relocated from elsewhere in the state.
(4) Based on per capita expenditures, as shown in Exhibit V-F.

County Cost/Benefit

The county government could expect positive fiscal benefits from O'oma, representing a net additional $0.5 million in revenues in 1996, or about $0.8 million by 2010, as shown in Exhibit V-H.

The analysis also indicates that the additional county government revenues generated could approach two times county operating expenditures.

State Cost/Benefit

Based on a similar analysis, net fiscal benefits to the state government in 1990 dollars are estimated at $1.4 million in 1996, increasing to $3.9 million by 2010, as shown in Exhibit V-I.

The additional state government revenues attributable to O'oma could slightly exceed two times the additional operating expenditures incurred by the state, as also shown in Exhibit V-I.

Exhibit V-H

KAHALA CAPITAL CORPORATION

Summary of County Government Revenue and Expenditures Associated with the O'oma II Community

1996 to 2010

(1990 dollars)

	1996	2000	2005	2010
New revenues(1)	$1.47	1.79	1.83	1.85
New expenditures(2)	0.92	1.01	1.09	1.10
Net additional revenues	$0.54	0.78	0.73	0.75
Revenue/expenditure ratio(3)	1.6	1.8	1.7	1.7

(1) As shown in Exhibit V-A.
(2) As shown in Exhibit V-E.
(3) New revenues divided by new expenditures.

Exhibit V-I

KAHALA CAPITAL CORPORATION

Summary of State Government Revenue and Expenditures Associated with the O'oma II Community

1996 to 2010

(1990 dollars)

	1996	2000	2005	2010
New revenues(1)	$4.69	5.49	6.98	7.55
New expenditures(2)	3.27	3.42	3.61	3.64
Net additional revenues	$1.42	2.07	3.36	3.91
Revenue/expenditure ratio(3)	1.4	1.6	1.9	2.1

(1) As shown in Exhibit V-C.
(2) As shown in Exhibit V-F.
(3) New revenues divided by new expenditures.

APPENDIX Q

MARKET ANALYSIS

KPMG Peat Marwick

KPMG Peat Marwick

Management Consulting

Market Assessment for the O'oma II Ocean Science and Recreation Community

North Kona, Hawaii

Prepared for

KAHALA CAPITAL CORPORATION

December 1990

KPMG Peat Marwick

PO Box 4150
Honolulu, HI 96812-4150

Telephone 808 531 7286
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Telecopier 808 541 9320
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December 12, 1990

Ms. Toni Fortin
Vice President, Hawaii
Operations
Kahala Capital Corporation
75-5751 Kuakini Highway
Kailua-Kona, Hawaii 96740

Dear Ms. Fortin:

We are pleased to present the attached report entitled "Market Assessment for the O'oma II Ocean Science and Recreation Community."

The report is organized into eight chapters as follows:

I. Introduction and Executive Summary
II. Hawaii Island Visitor Industry Overview
III. Ocean Science Center and Water Recreation Park Market Assessment
IV. Residential Lot Market Assessment
V. Condominium Market Assessment
VI. Golf Course Market Assessment
VII. Retail Market Assessment
VIII. Hotel Market Assessment

Thank you for this opportunity to work with you and your development team in planning this interesting project.

Very truly yours,

KPMG Peat Marwick

KAHALA CAPITAL CORPORATION

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KAHALA CAPITAL CORPORATION

Table of Contents, Continued

I - INTRODUCTION AND EXECUTIVE SUMMARY

This chapter introduces the market assessment for development of the O'oma II ocean science and recreation community. The development site and project are described, as are the objectives and scope of assistance of KPMG Peat Marwick. Study conclusions are summarized at the end of the chapter.

PROJECT DESCRIPTION

This section summarizes characteristics of the O'oma II site and describes the project planned by Kahala Capital Corporation (Kahala Capital).

Site Characteristics

The O'oma II community is planned for a site of about 300 acres located in the North Kona district of the island of Hawaii. The property's general location is shown in Exhibit I-A.

The O'oma II property has a central location in regard to future employment centers and visitor movements within the west Hawaii region. It is within four miles of Keahole airport, and lies between the airport and the Kailua-Kona commercial and service center. This should provide a high-traffic location, outstanding visibility for uses at the O'oma II site and a residential setting environment for work, shopping and cultural amenities.

The property is situated between the oceanfront and Queen Kaahumanu Highway and adjoins the site of the planned Kohanaiki resort and the State of Hawaii's Natural Energy Laboratory of Hawaii/Hawaii Ocean Science Technology Park (NELH/HOST) complex.

Site characteristics of particular significance include the following:

- Relatively flat configuration, with some upslope from the ocean frontage to the road and numerous small depressions and rocky outcroppings.
- Extensive coastal area with pristine off-shore water quality conditions.
- Location near Keahole airport and within the aircraft approach and departure path, producing potential noise impacts on planned uses.

Planned Project Description

A project is envisioned at O'oma II which could enhance the west Hawaii region's emergence as:

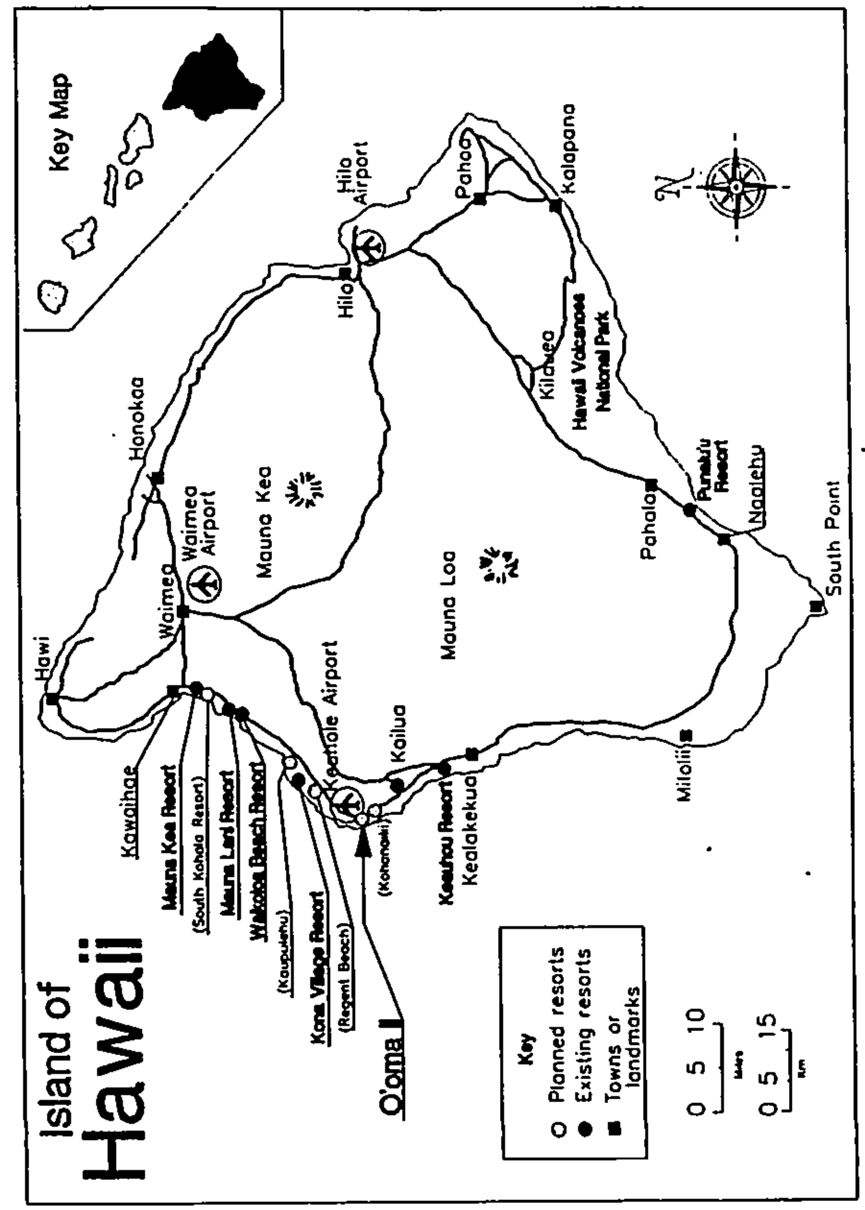
- Center for ocean science research and technology
- Visitor destination area
- High-quality residential community

O'oma II is planned to be a high-activity recreational and residential community, linked to the neighboring NELH/HOST park project through its ocean science center and professional meetings facility.

Exhibit I-A

KAHALA CAPITAL CORPORATION

Island of Hawaii Map



The O'oma II property, with extensive ocean frontage and central location in the west Hawaii region, provides an excellent setting for a community designed to serve both residents and visitors. The development plan, as shown in Exhibit I-B, would create a distinctive mixed-use community with a variety of amenities.

Key elements of the development plan, as shown in Exhibit I-B, include the following:

- A major marine complex, designed to serve as a visitor attraction and a center for ocean science research.
  - Marine complex elements are planned to include:
    - -- Ocean science center featuring educational and scientific exhibits.
    - -- Water recreation park offering active water-based amusement.
    - -- Professional meetings center catering to the scientific community and group-travel corporate markets.
- An 18-hole golf course with clubhouse and lodging inn of about 50 rooms.
- From 70 to 100 residential lots.
  - Lots would be situated within two private communities fronting the golf course.
- From 130 to 230 condominium units.
  - Condominiums would also have golf course frontage.
- Small retail center located along planned lagoons.
- Oceanfront first-class hotel providing 550 rooms.

STUDY OBJECTIVES AND REPORT ORGANIZATION

KPMG Peat Marwick was retained to assess potential development markets for the O'oma II mixed-use community and to assess the economic and fiscal impacts of development under the master plan formulated by Helber Hastert Kimura.

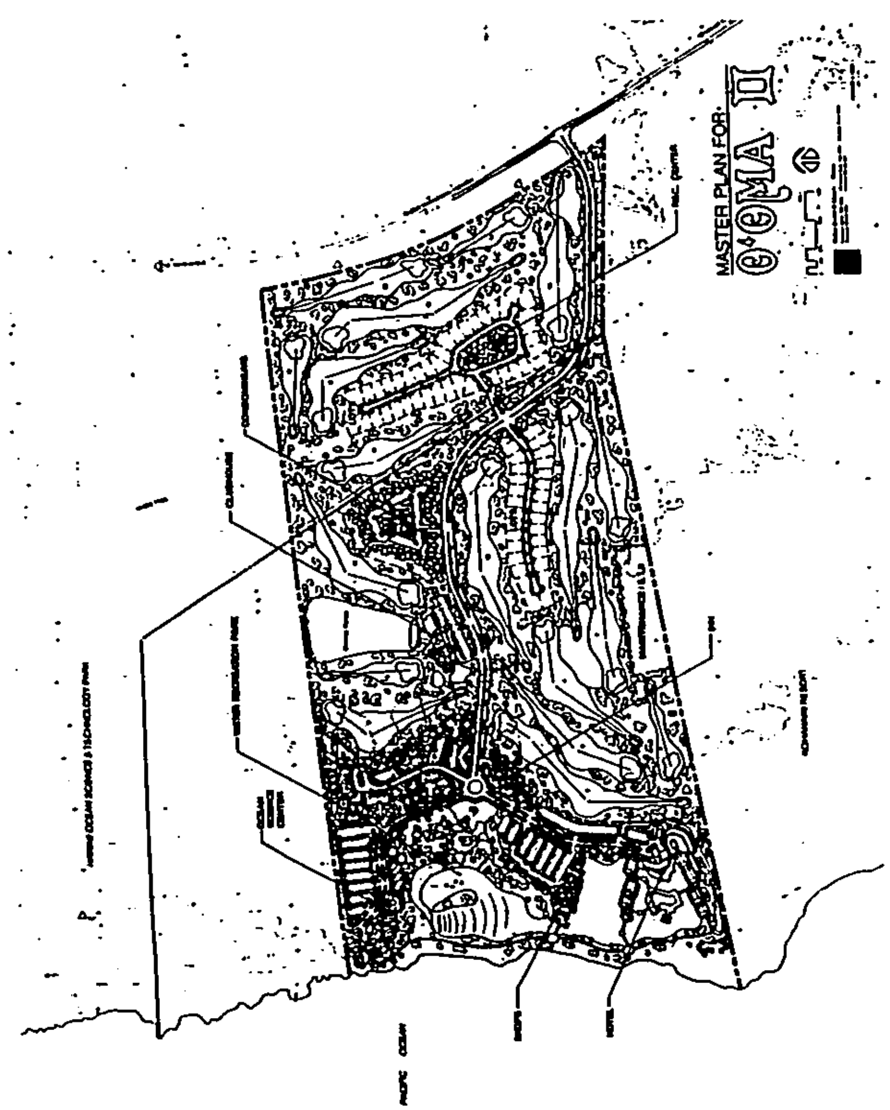
The economic and fiscal impact assessment is presented in a separate report.

This report is organized into eight chapters, as follows:

I. Introduction and Executive Summary
II. Hawaii Island Visitor Industry Overview
III. Ocean Science Center and Water Recreation Park Market Assessment
IV. Residential Lot Market Assessment
V. Condominium Market Assessment
VI. Golf Course Market Assessment
VII. Retail Market Assessment
VIII. Hotel Market Assessment

KAHALA CAPITAL CORPORATION

O'oma II Master Plan Map



EXECUTIVE SUMMARY

The major analysis and conclusions, presented in detail in the following chapters, are summarized in this section.

Visitor Industry Overview

The neighbor islands have attracted an increasing share of Hawaii's westbound visitors, as the industry has matured in the 1970s and 1980s. Growing numbers of visitors from Japan represent a potential new market of neighbor island travelers.

Projections by the State Department of Business and Economic Development (DBED) indicate that visitors to the state could increase from 6.6 million in 1989 to 9.1 million in 2000 and 11.5 million in 2010.

The share of westbound visitors traveling to the island of Hawaii has increased rapidly since 1988. More rapid development of hotels, visitor facilities and amenities is expected to contribute to further increases in the share of visitors going to the island in the future. Island arrivals, which reached 1 million in 1989, could increase to 2.4 million in 2000 and 3.8 million in 2010.

Ocean Science Center and Water Recreation Park Market Assessment

The marine attraction at O'oma II is planned to include an ocean science center with an aquarium, as well as an active water recreation park. The combination of active and passive entertainment opportunities is expected to make the facility a full-day recreation opportunity, in a region which lacks large-scale commercial attractions. Market support for the park was assessed based on comparable facilities in other visitor destinations and on market experience of major off-resort visitor attractions on Oahu. Admissions at the O'oma II facility are projected to reach about 380,000 in 1995 and more than 600,000 by 2010. About 95% of patrons are anticipated to be visitors to the island, with primary markets targeted to be families with children and first-time visitors from Japan.

Residential Lot Market Assessment

Under the O'oma II project concept, from 70 to 100 residential lots could be developed in two areas of the property's mauka area. Lots would be relatively small, averaging about 10,000 square feet, and would have golf course frontage. Based on a review of comparable lot subdivisions, O'oma II is determined to have potential strength among U. S. mainland investors, and in the Hawaii investor and owner-occupant markets. Residential lots at O'oma II are anticipated to command prices of $250,000 to $300,000, or $22 to $28 per square foot. Sales absorption of 30 to 40 lots per year could by achieved at O'oma II.

Golf Course Market Assessment

The golf course at O'oma II is planned to include a large clubhouse and Japanese-style inn with lodging units for the use of members. Market analysis indicates that on-property guests could constitute the largest source of demand for golf at O'oma II. Sufficient capacity is projected to be available, however, to accommodate play by on-property residents as well by a limited number of private members. Golf demand from on-property guests and residents is projected at about 160 rounds per day in 2005. With on-property play at this level and reservation of rounds for public play, about 300 private memberships could be offered.

Condominium Market Assessment

Support for condominium units at the O'oma II community is assessed based on comparable projects adjusted for the anticipated market position and planned development characteristics of O'oma II. Strong market support is expected for medium-sized, moderate-density golf-frontage units as planned at O'oma II. Sales absorption of 40 to 50 units per year is anticipated. Anticipated sales prices could range from $250 to $280 per square foot, for unit prices of $340,000 to $375,000.

Retail Market Assessment

Commercial facilities at O'oma II are expected to be patronized by on-property residents and visitors, general visitors to the region and those visiting the ocean science center and water recreation park. Facility concepts were assessed using centers comparable in location, market mix and size of on-property market segments.

While a considerable inventory of commercial space is planned in the west Hawaii region, the O'oma II community center is considered to have particular strength in terms of its on-property market and the potential patronage associated with the marine theme attraction. Based on anticipated on-property population and the ocean science center's market performance, total retail spending at O'oma II is projected as follows:

- $10.0 million in 1996
- $13.4 million in 2000
- $16.2 million in 2010

Island visitors are estimated to represent more than 90% of retail spending at O'oma II, mostly by guests at on-property visitor accommodations. Spending at these levels could support hotel shops, limited commercial space at the ocean science center and water recreation park, and a free-standing retail center of more than 50,000 square feet by 2010.

Hotel Market Assessment

A first-class hotel, with recreation and group meeting facilities, is planned at the O'oma II site. The facility could offer above-average accommodations to a broad range of visitor markets with particular emphasis on the family vacation and business traveler markets. Visitor unit demand is projected to be strong on the island of Hawaii, in particular after the large number of luxury and upscale units are absorbed between 1991 and 1995.

Market performance of the O'oma II hotel is expected to exceed the projected islandwide occupancy level in 2000 and succeeding years. Occupancy is projected at 65% in 1995, increasing to 75% by 2000. Average achieved room rates are anticipated to be $120 to $140 per room, with rates ranging from $120 to $250 per night for standard rooms.

II - HAWAII ISLAND VISITOR INDUSTRY OVERVIEW

This chapter summarizes trends and characteristics in visitor arrivals to the island of Hawaii.

ISLAND OF HAWAII VISITOR ARRIVAL TRENDS

This section discusses historical and projected visitor arrivals.

Historical Arrivals

Historically, Hawaii County's visitor growth has been slower than the other neighbor islands, as shown in Exhibit II-A. This can be attributed to its relatively slower facility development, resulting in a less prominent market image among westbound travelers. However, the island has gained market momentum with the recent and imminent openings of major new hotels including the Hyatt Regency Waikoloa and Ritz-Carlton Mauna Lani.

Visitor arrivals to the island were stable at about 780,000 per year from 1986 through 1988, as shown in Exhibit II-B. This level was higher than in 1985, which was influenced by the United Airlines strike. Arrivals increased to almost 960,000 in 1989 -- an increase of 23% -- and are projected to further increase by 13% in 1990. The island attracted 24% of westbound visitors to the state in the first six months of 1990.

The island of Hawaii attracted 16% of total state arrivals in 1989, up from 14% in the previous year. Increases were reflected in improved visitor unit occupancies in both of the island's main destination areas, Hilo and west Hawaii:

- Hilo-area visitor unit occupancy rose from 50% in 1988 to 54% in 1989. Contributing factors included:
  - Increased volcanic activity
  - More effective marketing of east Hawaii attractions
  - Historic reduction in visitor unit inventory
- West Hawaii visitor unit occupancy increased from 58% in 1988 to 65% in 1989. This increase has been attributed to development of high visibility "signature" hotels and greater recognition of the region as a destination area.

Projected Visitor Arrivals

Substantial visitor arrivals growth is projected for the island of Hawaii through the year 2010. Factors supporting growth include:

- Continuing increases in visitor arrivals to the state through expanded markets in continental North America, Japan, the Asian Pacific Rim, South Pacific and Europe.
- Development of high visibility hotels and destination resorts.

Exhibit II-A

KAHALA CAPITAL CORPORATION

Westbound Visitors to the Neighbor Islands

1970 to 1990

		Neighbor island counties			
	Oahu	Hawaii	Maui(1)	Kauai	Total
1970	1,200,493	446,370	449,763	412,102	1,308,235
1971	1,311,426	522,162	554,869	472,550	1,549,581
1972	1,572,380	637,562	710,050	565,386	1,912,998
1973	1,785,485	694,170	766,790	590,475	2,051,435
1974	1,877,845	742,839	852,204	601,703	2,196,746
1975	1,889,792	769,779	931,863	632,821	2,334,463
1976	2,169,849	817,514	1,110,726	699,275	2,627,515
1977	2,295,313	839,008	1,257,142	740,501	2,836,651
1978	2,494,893	908,983	1,403,054	837,712	3,149,749
1979	2,542,717	860,940	1,419,773	825,366	3,106,079
1980	2,398,737	761,103	1,378,189	781,409	2,920,701
1981	2,398,477	672,683	1,389,892	757,811	2,820,386
1982	2,589,190	678,170	1,550,080	733,295	2,961,545
1983	2,590,980	714,030	1,645,720	692,130	3,051,880
1984	2,901,320	760,940	1,854,690	814,590	3,430,220
1985	2,828,640	697,380	1,831,110	832,580	3,361,070
1986	3,146,030	786,930	2,001,870	1,014,650	3,803,450
1987	3,078,500	782,550	1,908,780	1,032,840	3,724,170
1988	3,013,850	782,360	1,884,050	1,043,710	3,710,120
1989	3,134,000	959,890	2,036,060	1,177,260	4,173,210
1990(2)	2,437,630	737,330	1,511,910	850,800	3,100,040
Compound annual percent increase:					
1970 to 1989	5.2%	4.1%	8.3%	5.7%	6.3%
1980 to 1989	3.0	2.6	4.4	4.7	4.0

(1) Includes the islands of Molokai and Lanai.
(2) As of September 1990.

Source: Hawaii Visitors Bureau, Westbound Visitors to Hawaii by Island, annual.

Exhibit II-B

KAHALA CAPITAL CORPORATION

Historical and Projected Visitor Arrivals
to the State and Island of Hawaii

1985 to 2010

	Westbound			Eastbound			Total(4)		
	State(1)	Island(2)	Percent of state total	State(1)	Island(2)	Percent of state total	State arrivals(2)	Island arrivals	Percent of State total
Historical:									
1985	3,708,610	697,380	18.8%	1,175,500	80,841	6.9%	4,884,110	778,221	15.9%
1986	4,256,390	786,930	18.5	1,350,590	90,850	6.7	5,606,980	877,780	15.7
1987	4,204,010	782,550	18.6	1,595,820	90,444	5.7	5,799,830	872,994	15.1
1988	4,264,730	782,360	18.3	1,877,690	102,319	5.4	6,142,420	884,679	14.4
1989	4,705,320	959,890	20.4	1,936,500	110,678	5.7	6,641,820	1,070,563	16.1
Annualized growth rate - 1985 to 1989	6.1%	8.3%		13.3%	8.2%		8.0%	8.3%	
Projected(4):									
1990	4,863,000	1,084,000	22%	2,119,000	127,000	6%	6,982,000	1,211,000	17%
1995	5,638,000	1,534,000	27	2,386,000	276,000	12	8,024,000	1,810,000	23
2000	6,441,000	1,939,000	30	2,655,000	517,000	19	9,096,000	2,456,000	27
2005	7,287,000	2,405,000	33	2,931,000	728,000	25	10,218,000	3,133,000	31
2010	8,245,000	2,976,000	36	3,236,000	845,000	26	11,481,000	3,821,000	33
Annualized growth rate - 1990 to 2010	2.7%	5.2%		2.1%	9.9%		2.5%	5.9%	

(1) Historical arrivals from Hawaii Visitors Bureau, annual reports; projected based on estimate of non-Japanese visitor growth in DBED, Population and Economic Projections for the State of Hawaii to 2010 (Series M-K), 1988.

(2) Hawaii Visitors Bureau, Annual Research Report.

(3) 1990 projections from DBED&T (actual January through June 1990) applied against 1989 performance rate for balance of year (July through December).

(4) DBED, ibid., 1988.

- Growth in visitor attractions and accommodations on the island, centering in the west Hawaii region.
- Greater interest in the neighbor islands among Japanese visitors, who in the prior stages of market growth have stayed primarily at Waikiki accommodations.
- Increasing numbers of repeat visitors to the state seeking new destinations and experiences.

Projected visitor arrivals on the island of Hawaii are shown in Exhibit II-B. As shown in the exhibit:

- The island's relative share of westbound visitors grew from 18% to more than 20% from 1985 to 1989 at an annual rate of more than 80%. As visitor attractions and accommodations increase, the percentage of westbound visitors going to the island could grow by an annual rate of 2.7%, reaching 36% of westbound visitors by 2010. In that event, westbound visitors would increase from about 960,000 in 1989 to 1.9 million in 2000 and almost 3.0 million in 2010.
- Historically, eastbound visitors have been far less likely than their westbound counterparts to visit the neighbor islands. From 1985 to 1989, 5% to 7% of eastbound visitors traveled to the island of Hawaii. Substantial growth in eastbound visitors is expected in the future with increases in visitor attractions and repeat travelers from Japan. The annualized growth rate for eastbound activity is projected at 9.9% over the next 20 years. This yields a 26% capture of total state eastbound visitors by Hawaii County by 2010, based on a trend similar to that for westbound visitors.
  - Eastbound visitor arrivals to the island could increase from about 110,000 in 1989 to more than 500,000 in 2000 and nearly 850,000 in 2010.
- Total visitor arrivals to the island could increase from about 1.1 million in 1989 to 3.8 million in 2010, at a 5.9% annual growth rate.

ISLAND OF HAWAII VISITOR CHARACTERISTICS

This section discusses travel patterns, characteristics and expenditures of westbound and eastbound visitors to the island of Hawaii.

Visitor Travel Patterns

Visitor travel patterns are summarized as follows:

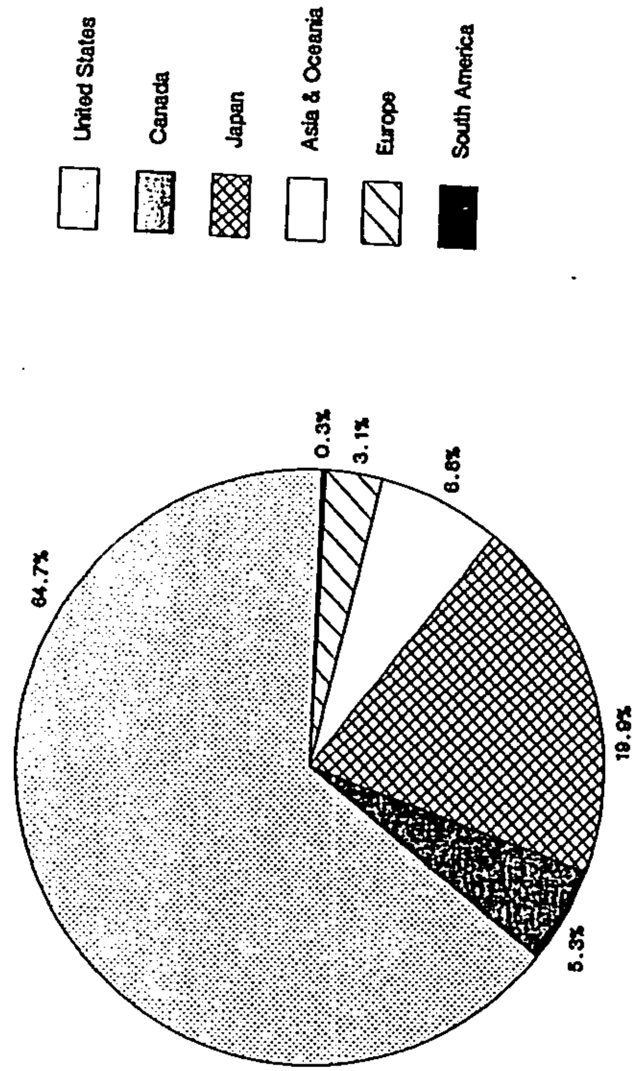
- Place of origin - In 1989, about 70% of all visitors to the state resided in the continental United States and Canada, as shown in Exhibit II-C. About 20% of the state's visitors were from Japan.
- Purpose of trip - Visitors to the state tend to be primarily vacationers. In 1988, about 84% of westbound travel to the state was for pleasure, while 95% of Japanese travel was for pleasure, as shown in Exhibit II-D. About 85% of the visitors to the island of Hawaii were traveling for pleasure.

Exhibit II-C

KAHALA CAPITAL CORPORATION

State of Hawaii Visitor Origins

1989



Source: Hawaii Visitors Bureau, Eastbound Visitors to Hawaii, 1989.

Exhibit II-D

KAHALA CAPITAL CORPORATION

Visitor Travel Patterns and Demographic Characteristics

1988

	Island of Hawaii westbound visitors	Visitors to the state of Hawaii: Westbound visitors	Visitors to the state of Hawaii: Japanese visitors
Pleasure trip (percent of total)	85.3%	84.3%	94.5%
Accommodation usage (percent of total):			
Hotel	54.6	59.4	91.9
Condominium	16.3	20.7	5.6
Hotel and condominium	12.2	10.2	1.5
Other	16.9	9.7	1.0
Length of stay (days)	5.0	10.0	6.0
Travel status (percentage distribution):			
Free independent traveler (FIT)	82.4%	85.9%	10.0%
Group inclusive tours (GIT)	17.6	14.1	45.4
Package visitors	-	-	44.6
Total	100.0%	100.0%	100.0%
Average party size	1.9	1.8	2.5
Median age	45	40	31
Occupation (percent distribution):			
Professional and technical	40.2	39.3	24.0
Business, managerial, official	24.4	25.8	20.0
Clerical, office, sales	7.0	8.7	28.0
Retired	18.7	12.7	4.0
Other	9.7	13.5	24.0
Total	100.0%	100.0%	100.0%
First-time visitors (percent of total)	44.1%	48.0%	77.4%

Source: Hawaii Visitors Bureau, Study of Japanese Visitors to Hawaii, 1988 (1989); 1988 Westbound Visitors to Hawaii by Island: Oahu, Maui, Kauai, The Big Island and Molokai (January 1990).

- Accommodation usage - Hotels serve the majority of visitors:

    - In 1988, about 60% of westbound visitors to the state and about 55% of westbound visitors to the island of Hawaii stayed in hotels.

    - Japanese travelers' use of hotels, at 92%, was higher than westbound visitors.

- Travel status - Most westbound visitors to the state (86%) were free and independent travelers (FITs) while only 10% of the Japanese visitors were FITs in 1988. Most of the Japanese visitors (45%) were on group inclusive tours (GIT) and package tours (45%). Island of Hawaii westbound visitors were primarily FITs at 82% with about 18% GIT visitors.

- Average length of stay - The average length of stay in the state was about 10 days for westbound travelers and 6 days for Japanese visitors in 1988:

    - Average length of stay varies per island, as shown for westbound visitors in Exhibit II-E.

    - Average length of stay is still longer on Oahu and Maui; however, stays on the island of Hawaii showed a larger increase from 1988 to 1990 than other neighbor islands.

Visitor Characteristics

Characteristics of visitors to the state were previously shown in Exhibit II-D and summarized below:

- Average party size - On average, westbound visitors traveled in smaller groups (1.8 persons per party) than Japanese visitors (2.5 persons). The island of Hawaii's westbound party size is slightly higher than average at 1.9.

- Age - The median age of westbound travelers to the state, about 40, has changed little in the last decade and a half. The island of Hawaii's westbound visitors are older at an average of 45 years. In 1988, the median age of the Japanese traveler was 31.

- Occupation - The state's visitors include large proportions of higher-salaried professional/technical and business/managerial household heads, representing 39% and 26% of all westbound visitors to the state, respectively.

    - In contrast, the distribution of Japanese visitors is more evenly spread among professional, executive, clerical and other occupational categories.

    - Another notable difference between westbound and Japanese travelers is the greater number of westbound travelers who are retired (13% as opposed to 4% of the Japanese). However, this segment of Japanese visitors is expected to increase in the future.

Exhibit II-E

KAHALA CAPITAL CORPORATION

Average Length of Stay of Westbound Overnight and Longer Visitors by Island

1970 to 1989

	Oahu	Hawaii	Maui	Kauai
1970	6.03	2.94	2.97	2.68
1975	5.97	3.08	3.42	2.85
1980	5.78	3.46	4.08	3.40
1981	5.91	3.56	4.13	3.48
1982	5.77	3.62	4.26	3.51
1983	6.96	4.52	5.61	4.22
1984	7.49	3.64	6.47	4.91
1985	7.24	4.21	6.20	5.03
1986	7.25	4.58	6.26	5.34
1987	7.25	4.76	6.48	5.48
1988	7.15	5.00	6.58	5.75
1989	7.00	6.00	6.90	5.80
Compound annual increase from 1980 to 1989	2.2%	6.3%	6.0%	6.1%

Source: Hawaii Visitors Bureau, Westbound Visitors to Hawaii by Island, annual.

- **Accommodation usage** - Hotels serve the majority of visitors:
  - In 1988, about 60% of westbound visitors to the state and about 55% of westbound visitors to the island of Hawaii stayed in hotels.
  - Japanese travelers' use of hotels, at 92%, was higher than westbound visitors.
- **Travel status** - Most westbound visitors to the state (86%) were free and independent travelers (FITs) while only 10% of the Japanese visitors were FITs in 1988. Most of the Japanese visitors (45%) were on group inclusive tours (GIT) and package tours (45%). Island of Hawaii westbound visitors were primarily FITs at 82% with about 18% GIT visitors.
- **Average length of stay** - The average length of stay in the state was about 10 days for westbound travelers and 6 days for Japanese visitors in 1988:
  - Average length of stay varies per island, as shown for westbound visitors in Exhibit II-E.
  - Average length of stay is still longer on Oahu and Maui; however, stays on the island of Hawaii showed a larger increase from 1988 to 1990 than other neighbor islands.

Visitor Characteristics

Characteristics of visitors to the state were previously shown in Exhibit II-D and summarized below:

- **Average party size** - On average, westbound visitors traveled in smaller groups (1.8 persons per party) than Japanese visitors (2.5 persons). The island of Hawaii's westbound party size is slightly higher than average at 1.9.
- **Age** - The median age of westbound travelers to the state, about 40, has changed little in the last decade and a half. The island of Hawaii's westbound visitors are older at an average of 45 years. In 1988, the median age of the Japanese traveler was 31.
- **Occupation** - The state's visitors include large proportions of higher-salaried professional/technical and business/managerial household heads, representing 39% and 26% of all westbound visitors to the state, respectively.
  - In contrast, the distribution of Japanese visitors is more evenly spread among professional, executive, clerical and other occupational categories.
  - Another notable difference between westbound and Japanese travelers is the greater number of westbound travelers who are retired (13% as opposed to 4% of the Japanese). However, this segment of Japanese visitors is expected to increase in the future.

Exhibit II-E

KAHALA CAPITAL CORPORATION

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	Oahu	Hawaii	Maui	Kauai
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1982	5.77	3.62	4.26	3.51
1983	6.96	4.52	5.61	4.22
1984	7.49	3.64	6.47	4.91
1985	7.24	4.21	6.20	5.03
1986	7.25	4.58	6.26	5.34
1987	7.25	4.76	6.48	5.48
1988	7.15	5.00	6.58	5.75
1989	7.00	6.00	6.90	5.80
Compound annual increase from 1980 to 1989	2.2%	6.3%	6.0%	6.1%

Source: Hawaii Visitors Bureau, Westbound Visitors to Hawaii by Island, annual.

- The island of Hawaii generally attracts similar occupations as compared to the state, except that the island tends to attract more retired westbound visitors.

- Number of visits - Slightly less than half of the state's westbound visitors in 1988 were first-time visitors to the state. The share of Japanese travelers visiting the state for the first time was 77%.

Visitor Expenditures

Visitor expenditures differ greatly between westbound and Japanese visitors, as shown in Exhibit II-F. In 1989, statewide westbound daily visitor expenditures averaged $126.57 as compared to $588.92 for Japanese visitors. Japanese expenditures increased 13.7% per year from 1980 to 1989, whereas westbound visitor expenditures increased 7%.

Westbound visitor expenditures are significantly higher on the neighbor islands than on Oahu. Average daily expenditures on the neighbor islands were $145.76 versus the statewide average of $126.57 noted previously. Lodging represents the largest expenditure, as shown in Exhibit II-G.

A current comparable breakdown of Japanese expenditures is not available; however, based upon 1985 data, Japanese spend significantly more than westbound visitors on lodging, clothing, dining, entertainment, and gifts, as shown in Exhibit II-H. Japanese spending patterns include lodging and dining expenditures that are about 50% higher than westbound expenditures, and gift/souvenir purchases that are almost 9 times higher.

The differences between spending patterns of westbound and Japanese visitors, as well as the growth rate of Japanese expenditures are significant observations. Possible factors to explain these are as follows:

- The Japanese visitors typically stay for a shorter period than the westbound visitors. As a result, the daily average spending figure is increased by fixed cost items such as ground transportation and tours which do not vary significantly with the length of stay.

- Japanese visitors spend heavily on gifts and souvenirs observing the custom of omiyage, wherein the traveler returns with presents for family and friends.

- Japanese spend more on nondurable goods.

- High domestic prices in Japan and the additional purchasing power of the yen has made dollar denominated prices in Hawaii increasingly attractive to Japanese visitors during recent years.

  - A strengthening of the American dollar relative to the yen could depress Japanese visitor spending. This situation, in 1989, contributed to Japanese daily visitor spending remaining stable, as shown previously in Exhibit II-F.

Exhibit II-F

KAHALA CAPITAL CORPORATION

Average Daily Visitor Expenditures

1980 to 1989

Year	Westbound visitors	Japanese visitors
1980	$ 71.24	$ 185.00
1983	85.88	227.32
1985	98.17	250.33
1986	95.40	257.40
1987	102.49	366.63
1988	118.66	586.00
1989	126.57	588.92
Average annual percentage increase:		
1980 to 1989	6.6%	13.7%
1983 to 1989	6.7%	17.2%

Source: Hawaii Visitors Bureau, Visitor Expenditure Survey, annual; Study of Japanese Visitors to Hawaii 1987 and 1988; and Eastbound Visitors to Hawaii, 1989.

Exhibit II-G

KAHALA CAPITAL CORPORATION

Westbound Visitor Expenditures by Type

1989

Expenditure type	Neighbor island expenditures
Food:	
Restaurants	$ 21.71
Dinner shows	0.86
Night clubs	1.75
Groceries	3.20
Subtotal	27.52
Entertainment:	
Attractions	7.69
Other entertainment	3.50
Subtotal	11.19
Transportation:	
Ground transportation	0.53
U-drive cars	9.36
Interisland travel	16.06
Sightseeing tours	1.74
Subtotal	27.69
Lodging and other purchases:	
Clothing	7.50
Gifts and souvenirs	8.60
All other(1)	4.97
Lodging	56.00
Adjustment factor amount(2)	2.29
Subtotal	79.36
Total	$ 145.76

(1) Includes miscellaneous items such as telephone, beauty and barber shop, stamps, laundry, gasoline, photo supplies, etc.

(2) A per day estimate made by each visitor concerning the dollar amount that he or she may have neglected to include in the listed categories.

Source: Hawaii Visitors Bureau, Visitor Expenditure Survey, 1989.

Exhibit II-H

KAHALA CAPITAL CORPORATION

Statewide Daily Visitor Expenditures by Type

1985

	Westbound	Japanese	Japanese as a percentage of westbound
Lodging	$ 36.71	$ 56.42	154%
Clothing	6.81	10.40	153
Food and beverage	24.07	60.46	251
Neighbor island travel	2.63	17.97	683
Entertainment	5.31	9.55	180
Transportation	8.70	4.90	56
Gifts and souvenirs	8.11	72.45	893
Other	5.83	18.18	312
Total(1)	$ 98.17	$ 250.33	255%

(1) Does not include air transportation to Hawaii.

Source: Hawaii Visitors Bureau, Highlights of Japanese Tourism to Hawaii, 1985, 1986.

III - OCEAN SCIENCE CENTER AND WATER RECREATION PARK MARKET ASSESSMENT

This chapter assess market support for the proposed ocean science center and water recreation park at the O'oma II community. The following sections review comparable attractions with respect to their characteristics and market performance. Based on this overview, the chapter presents the market assessment for the O'oma II marine complex in terms of the development concept, target markets, projected admissions pricing.

A major marine entertainment and research complex is planned for a site of about 20 acres within the O'oma II community. The complex would include three principal elements:

- Ocean science center
- Water recreation park
- Professional meetings center

Ocean Science Center

The ocean science center would be designed to give visitors a greater understanding of and appreciation for Hawaii's marine environment. Facilities in developments similar in concept to the O'oma II ocean science center include:

- Aquarium - walk through facilities bringing the visitor down into the depths for a "fish eye" view of a simulated ocean environment. The aquarium is viewed from either panoramic windows along descending ramps wrapping around the tank, or clear plexiglass tunnels that extend through the tank. Such exhibits typically contain the marine plants and animals endemic to the ocean nearby. Animal feeding periods and guided tours are particularly popular with visitors.
- Scientific exhibits - allow visitors to gain a better understanding of the different ecosystems and animal behaviors that are found in the ocean nearby. Such exhibits may include:
    - Dangerous marine animals - exhibits, which demystify marine life that many visitors may fear due to a lack of understanding, such as sharks, rays, eels and jellyfish.
    - Microaquariums - allowing visitors to focus close-up on smaller marine life. These aquariums may be fit with micro-scanning video cameras attached to robotic arms that allow the aquarium subject to be magnified many times.
    - Touch pools - giving visitors a chance to interact with tidal life such as crabs, snails and starfish.

Water Recreation Park

The water recreation park would be designed to provide a variety of marine experiences within a safe, supervised and enjoyable setting. Activities could include:

- Pedal boating

- Swim-through tropical reef lagoons - allowing visitors to see local marine environments while experiencing snorkeling or S.C.U.B.A. diving under professional supervision.
- Artificial wave generators - giving visitors an opportunity to learn how to surf year-round.
- Artificial islands and sunning rafts - designed as visual points of interest for park visitors to explore and sun. May also include slide and flume rides.
- Children activity pools - including water toys and shallow waters under close lifeguard supervision for younger visitors.

Professional Meetings Center

A professional meetings center is planned in conjunction with the ocean science center. The meetings center would be designed to service professional gatherings of a scientific and technical nature and feature:

- Function rooms readily subdividable into spaces of varying size.
- Advanced communications technology permitting teleconferencing and satellite reception.
- High-quality audiovisual capacity.

The professional meetings center could provide a focus for conference activity catering to the general corporate market NELH/HOST park tenants and scientific community. The meetings center could also be developed in conjunction with a performing arts facility.

The meetings center could be served by the hotel's food and beverage staff. When not used for professional meetings, the center could operate as an additional hotel group function site.

Relation of Marine Complex to Other Community Elements

While a marine activity complex could conceivably be developed at a single-use location, development within a mixed-use community with the O'oma II property's central location offers a number of advantages in relation to other project elements:

- Hotel and inn properties, together with the golf course and retail shops offer ready, convenient accommodations and services for professional meetings center users.
- Increased daily visitor population supplied by the marine complex and meetings center could expand support for retail facilities also serving O'oma II residents.

COMPARABLE FACILITIES REVIEW

This section reviews selected marine theme parks in terms of their respective development and market characteristics.

The O'oma II ocean science center and water recreation park would be unique in combining active and passive recreational elements. Facilities were selected for review based on comparability in terms of location, scale of facilities and commercial orientation. Most of these attractions, however, emphasize viewing of the marine environment and do not also offer water recreational activities and attractions.

Facilities reviewed include the following:

- Coral World Bahamas, Bahamas
- Coral World St. Thomas, St. Thomas, U. S. Virgin Islands
- Monterey Bay Aquarium, Monterey, California
- Sea Life Park, Oahu, Hawaii
- Kelly Tarlton's Underwater World, San Francisco, California

Development Characteristics

Three of the selected comparable facilities (Coral World Bahamas, Coral World St. Thomas and Sea Life Park) are located in popular island resort and vacation destinations. These locations are characterized by a predominantly tourism-based economy and lack of substantial heavy industry.

The selected comparable facilities maintain aquarium capacity ranging from 130,000 to 716,000 gallons, as shown in Exhibit III-A. Most of the attractions contain underwater observatories allowing the visitor to descend on land beneath the water surface to view aquatic life, and other exhibits designed around the indigenous coral and sea environment. The facilities with activities encourage visitor participation such as stingray and fish feeding and other marine encounter exhibits.

Comparable facilities are summarized as follows:

- Sea Life Park - on the island of Oahu is the oldest facility, established in 1964.
  - Aquarium facilities have a capacity of 300,000 gallons.
  - Contains other related exhibitions in its shark gallery, Hawaiian canoe and home area and whaling museum spread over 11 acres.
  - Facilities include small retail and restaurant operations.
- Coral World Bahamas - opened in 1987 and contains many underwater viewing platforms.
  - Facilities contain 250,000 gallons of aquarium capacity and one of the largest live coral reef displays in the world.
  - Related visitor accommodations include 22 private villa rooms opened in 1988.

Exhibit III-A

KAHALA CAPITAL CORPORATION

Development Characteristics of Selected Marine Parks

1990

	Coral World Bahamas	Coral World St. Thomas	Monterey Bay Aquarium	Sea Life Park	Underwater World in San Francisco, California(1)
Site location	Nassau, Bahamas	Koki Point, Charlotte	Monterey, California	Oahu, Hawaii	San Francisco, California
Year opened	1987	1978	1984	1964	1991 (planned)
Site area (acres)	16	5	1.6(2)	11	0.87
Total aquarium capacity (gallons)	250,000	130,000	716,000(3)	300,000	N/A
Exhibits: Number	8	9	3	6	N/A
Size (square feet)	*	*	9,000	2,000	N/A
Nonaquarium facilities	Restaurant, Bars, Villas, Retail	Duty-free shops	Restaurant, Retail, Research labs, Auditorium	Retail	N/A

* Confidential information.
N/A Not available.
(1) Under construction.
(2) Excludes parking.
(3) Includes three multistory tanks and excludes outdoor tide pools and up to 100 small exhibits.

Source: Based on interviews with representatives of the respective facilities.

- Coral World St. Thomas - opened in 1978 and is the smallest of the operating comparable facilities.
    - An 80,000 gallon aquarium was added to the original 50,000 gallon aquarium in 1989 for a total capacity of 130,000 gallons.
    - The facility contains nine ocean science exhibits including the aquariums and retail operations on a five-acre site.
- Monterey Bay Aquarium - is located in the popular visitor area known as "Cannery Row."
    - Total aquarium capacity is 716,000 gallons contained in three multistory tanks, the largest of the selected facilities.
    - Research laboratories, retail and restaurant operations are also included.
    - The financial structure of the Monterey Bay Aquarium differs from the other facilities. The aquarium was established with private donations, and is supported primarily through over 76,000 private memberships as well as through admission fees.
- Underwater World - plans to develop a facility near San Francisco's Pier 39 visitor retail center.
    - Existing facilities operated by the same group are located in Singapore and New Zealand.
    - Underwater World has developed a proven and profitable concept using compact networks of underwater tubes through which visitors can pass while viewing aquatic life in their natural environments.

Market Characteristics

Several major factors affect market support for a marine theme attraction. These include attendance, admission mix between visitors and regional residents and admission fees.

- Attendance - was the highest at the Monterey Bay Aquarium which hosted over 1.7 million guests in 1989. Operators report that attendance at the other selected comparable aquariums ranged from 215,000 to 740,170 guests. Underwater World in San Francisco is not yet open to the public.
- Admission mix - at the selected comparable aquariums is comprised primarily of visitors to the area rather than regional residents. Operators report that between 60% and 90% of the admissions mix is made up of visitors, as shown in Exhibit III-B. Some operators report that most visitors tend to be independent travelers rather than groups.
- Admission fees - range between $3.50 and $8.00 for children and $4.50 and $12.95 for adults. The Monterey Bay Aquarium has a special rate for students and senior citizens. Fees at most facilities include admittance to the aquarium facility and other exhibits.

Exhibit III-B

KAHALA CAPITAL CORPORATION

Market Characteristics of Selected Marine Parks

1990

	Coral World		Monterey Bay Aquarium	Sea Life Park	Underwater World in San Francisco California(1)
	Bahamas	St. Thomas			
Admissions mix:					
Visitors	*	*	59.7%	85.0%	N/A
Regional residents	*	*	40.3	15.0	N/A
Total	100.0%	100.0%	100.0%	100.0%	N/A
Attendance:					
1985				655,000	
1986				684,530	
1987			1,697,000	637,889	
1988	*	*	1,716,000	739,041	
1989	*	*	1,716,000	740,170	N/A
Admission fees:					
Adult	$ 12.00	12.00	8.00	12.95	N/A
Students and seniors	N/A	N/A	5.75	8.50	N/A
Children	8.00	8.00	3.50	4.50	N/A

* Confidential information.
N/A Not available.

(1) Under construction.
(2) Senior citizen rate.

Source: Based on interviews with representatives of the respective aquariums.

MARKET ASSESSMENT FOR THE O'OMA II OCEAN SCIENCE CENTER AND WATER RECREATION PARK

This section assesses the market for the proposed O'oma II ocean science and water recreation park in terms of the development concept, target markets, projected visitor count and admission pricing. The assessment is based on the experience of selected comparable facilities as adjusted for the O'oma II project location and development concept.

Projected Aquarium Capacity

Aquarium capacity at the O'oma II marine attraction could reasonably range from 300,000 to 400,000 gallons in 6 to 8 tanks, in addition to other marine related exhibits:

- Aquarium capacity at the selected comparable aquariums ranges from 130,000 gallons to 716,000 gallons, as shown previously in Exhibit IV-A.
- Site areas vary widely between approximately 1 acre to 16 acres and the selected facilities include 3 to 9 tanks.
  - The smallest sites, such as Underwater World, are self-contained structures within urban commercial areas.
  - The larger sites provide a more park-like, open-air setting consistent with the visitor experience desired at neighbor island attractions.

The larger size of the O'oma II site provides additional space for development of the water amusement facilities, parking, restaurant and retail uses to complement the operations of the ocean science center.

Attendance at Selected Comparable Attractions

Attendance at the proposed ocean science center and water recreation park is projected based on the patronage at selected Oahu commercial attractions and anticipated visitor and resident population levels in the west Hawaii region. Projections of admissions to the theme park on the island of Hawaii are based on the following:

- Fewer commercial attractions are available on the island of Hawaii than on Oahu.
- Also, the island of Hawaii can be expected to attract more pleasure travel and less business travel than Oahu. Therefore, expected capture rates of visitors to Hawaii island commercial attractions could be higher than on Oahu.
- The following Oahu attractions provide a basis for projected capture rates for an attraction on the island of Hawaii, as shown in Exhibit III-C:

Exhibit III-C

KAHALA CAPITAL CORPORATION

Attendance at Selected Oahu Commercial Attractions

1986 to 1989

	1986		1987		1988		1989	
	Number of visitors	Percent of Oahu visitors(1)	Number of visitors	Percent of Oahu visitors(1)	Number of visitors	Percent of Oahu visitors(1)	Number of visitors	Percent of Oahu visitors
Island of Oahu	3,146,030	100.0%	3,078,500	100.0%	3,013,850	100.0%	3,134,000	100.0%
Sea Life Park	684,530	21.8	758,978	24.7	739,041	24.5	740,170	23.6
Polynesian Cultural Center	870,000	27.7	1,001,708	32.5	881,500	29.2	850,185	27.1
Paradise Cove Luau Park	239,767	7.6	307,603	10.0	298,198	9.9	264,743	8.4
Waimea Falls Park	601,477	19.7	672,835	21.9	654,896	2.7	580,020	18.5
Range		7.6% - 27.7%		10.0% - 32.5%		9.9% - 29.2%		8.4% - 27.1%

(1) Approximately 5% to 7% of attendance consists of kamaaina visitors.

Source: Department of Business and Economic Development, 1989.

Attraction	Admissions as percentage of Oahu visitors 1989
Sea Life Park	24%
Polynesian Cultural Center	27
Paradise Cove Luau Park	8
Waimea Falls Park	19

- The selected Oahu attractions are similar in that they are located outside of the Waikiki visitor center and accessible primarily by organized tour bus and by rental car. However, compared to the existing Oahu facilities, the O'oma attraction would be significantly closer to its target visitor markets. These facilities also command admission fees of approximately $5 per person or higher.

Projections of eastbound visitor admissions to the marine theme park are based on capture rates ranging from 20% to 30% for the Pacific Islands Club and Cocos Island, two major water-theme attractions on the island of Guam, as shown in Exhibit III-D.

Projected Admissions at the O'oma II Marine Attraction

Projected admissions at the proposed O'oma II marine attraction could exceed 380,000 in 1995 and 625,000 by 2010, as shown in Exhibit III-E.

- Estimates are based on the following projections of total island of Hawaii visitor arrivals, as previously shown in Exhibit II-B:

	Total island of Hawaii visitor arrivals
1995	1,810,000
2000	2,456,000
2005	3,133,000
2010	3,821,000

- The following capture rates of total island of Hawaii visitor arrivals were used to derive projected admissions:

	Westbound capture rate	Eastbound capture rate
1995	20%	25%
2000	19	24
2005	17	22
2010	15	20

- Eastbound visitors to the island of Hawaii are expected to consist predominantly of Japanese tourists.

Exhibit III-D

KAHALA CAPITAL CORPORATION

Fees and Attendance at Popular Optional Tours for Japanese Visitors to Guam

Activity	1989 Attendance	Estimated capture of Guam visitors(1)	Entrance fees
Cocos Island	201,000	30%	$ 55
Dinner cruises	134,000	20	40 - 50
Atlantis Submarine	134,000	20	50 - 85
Pacific Islands Club	134,000	20	65 - 90
Shooting	100,000	15	30 - 60
Golf	67,000	10	49 - 82
Typical	128,000		$ 60

(1) Based on discussions with managements of respective tour agents.

Exhibit III-E

KAHALA CAPITAL CORPORATION

Projected Visitor and Resident Admissions
at the O'oma Ocean Science Center and Water Recreation Park

1995 to 2010

	Westbound visitors			Eastbound visitors			Island resident visitor		Projected admissions	
	Island of Hawaii visitor arrivals(1)	Marine theme park capture rate(2)	Theme park visitors	Island of Hawaii visitor arrivals(1)	Marine theme park capture rate(3)	Theme park visitors	Total island residents(4)	Theme park visitors(5)	Total	Percent-age change
1995	1,534,000	20%	307,000	276,000	25%	69,000	142,500	7,000	383,000	-%
2000	1,939,000	19	368,000	517,000	24	124,000	160,400	8,000	500,000	23.4
2005	2,405,000	17	409,000	728,000	22	160,000	180,800	9,000	578,000	13.5
2010	2,976,000	15	446,000	845,000	20	169,000	206,100	11,000	626,000	7.7

(1) As shown in Exhibit II-B.

(2) Estimated from Exhibit III-C.

(3) Estimated from Exhibit III-D.

(4) Based on resident population projections for the County of Hawaii estimated by the State of Hawaii Department of Business and Economic Development, Population and Economic Projections to 2010 (Series M-K), November, 1988.

(5) Estimated at 50 kamaaina visitors per 1,000 Hawaii island residents.

- The majority of kamaaina visitors are expected to be residents of the island of Hawaii. These visitors are projected at approximately 50 annual visits per 1,000 residents based on experience of the comparable Oahu commercial attractions. Kamaainas could include visitors from other islands, school groups and special community groups, such as groups with special education needs.

  - Kamaaina visitors are expected to represent a larger share of total visitors than projected, in that admission for community program and group functions would be either discounted or free of charge.

- Capture rates are expected to decline based on the experience of the selected comparable Oahu commercial attractions, due to expected decreases in the rate of growth in first-time visitors and the market penetration patterns common to many attractions.

The proposed O'oma II ocean science center and water recreation park appears to have adequate market support in terms of attendance based on the following factors:

- Substantial growth expected in the island of Hawaii visitor population.

- An increasing proportion of eastbound visitors, particularly the Japanese who tend to be highly attraction-oriented.

- A greater number of first-time visitors to the island of Hawaii.

- A relative lack of major theme attractions of the type and scale proposed at O'oma II throughout the neighbor islands.

- A separate admission fee structure could be considered for the ocean science center and water recreation park attractions. In this situation, admission charges could be as follows:

  - From $4.00 to $6.00 for children and from $7.50 to $12.50 for adults for the ocean science center.

  - From $5.00 to $6.00 for children and from $7.50 to $10.00 for adults for the water recreation park.

Projected Admissions Mix

The guest mix of the proposed O'oma II marine attraction can be expected to be composed primarily of resort visitors. Visitors will likely comprise around 90% to 95% of the total paid admissions mix with the remaining 5% made up of local island residents due to the following factors:

- Admissions mixes of the selected comparable aquarium facilities in 1989 range from about 60% to 90% for visitors and 10% to 40% for regional residents, as reported by operators and shown previously in Exhibit III-B.

- The proposed O'oma II attraction can be expected to have a lower percentage of local resident admissions because the resident population base of the island of Hawaii is much smaller than Oahu's.
- Sea Life Park on Oahu can draw from a larger local resident base within driving proximity than can island of Hawaii attractions.

Island residents could represent from 20% to 25% of total attendance, where special events, school programs and other functions are included.

Projected Admission Fees

The proposed O'oma II marine attraction could be expected to support fees ranging from $8 for children to $20 for adults.

- Admission fees at the selected comparable aquariums range from $8.00 to $12.95 for adults and $3.50 to $8.00 for children, as shown previously in Exhibit IV-B.
- The total site area of the proposed O'oma II marine attraction is planned to occupy more space than some of the selected comparable aquariums. Thus, the facility can be expected to house more exhibits, aquariums, retail and restaurant uses than comparable facilities.
- By offering both active and passive recreational elements, the ocean science center and water recreation park could develop broader market appeal and establish itself as a full- rather than half-day attraction, justifying a higher admission price.
- Therefore, the planned O'oma II attraction will be more like the Coral World facilities which can take up to a full day to visit, supporting higher admission fees than other comparable aquariums.

IV - RESIDENTIAL LOT MARKET ASSESSMENT

This chapter reviews development trends and market performance of selected comparable resort and estate lot subdivisions in Hawaii and presents conclusions regarding sales absorption and buyer mix at the O'oma II ocean science and recreation community.

RESORT LOT DEVELOPMENT TRENDS

While O'oma II is not a resort, it is planned to include a hotel, major visitor attraction, retail center and recreation facilities, all elements sometimes found in resort areas. Since the O'oma II lots are also planned to be similar in size to smaller resort lots, resort-oriented residential areas are selected as comparable projects for review.

Resort lots are differentiated from other residential lots by their integration within a master-planned and self-supporting community oriented towards recreational activities such as golf and tennis. In addition, homes built on resort lots are frequently used as secondary or vacation homes, although lower-priced resort lots may more often become primary residences.

To date, resort residential lots have been developed at all major neighbor island resorts except at the Waikoloa Beach Resort on the island of Hawaii and the Makena Resort on Maui. Due to the home customization possible, resort lots help expand the range and types of visitor and resident accommodations at a resort as well as contributing to a lower-density character.

Location and View Orientation

Resort residential lots may be categorized by their location and view orientation with respect to:

- Ocean frontage or views
- Golf course frontage or views
- Mountain or hillside views
- Interior locations providing limited or garden/amenity views

View orientation is also a primary consideration for buyers in this market and may compensate for locational disadvantages of a resort lot. For example, the many interior lots at Wailea and Mirage Princeville resorts command ocean or mountain views which compensate for their less desirable location. The importance of views is illustrated by the experience at the Wailea Golf Estates I where interior lots sold more quickly than fairway frontage lots due to superior ocean views and lower prices.

Historically, resorts have offered the better quality lots early in the resort's development and the less desirable interior lots later as the resort matures. This pattern is particularly evident at Princeville which developed the ocean and golf frontage lots from 1971 to 1975 and the interior lots after 1979. In contrast, Wailea Resort's strategy was to offer alternating quality lots in each successive subdivision, thus appealing to a range of buyer markets simultaneously.

Lot Sizes

Typical resort lots range from 9,500 to 20,000 square feet and average from about 10,000 to 14,000 square feet. They are thus larger than nonresort residential lots in Hawaii which generally range from about 6,000 to 10,000 square feet. In general, the higher-priced golf course lots are larger than the interior or hillside view lots because purchasers of golf-front lots are more willing to pay for the additional square footage.

Amenities

Private recreational facilities and security are major features of successful lot developments on the mainland United States. These features have generally not been incorporated in first-class resort subdivisions in Hawaii, however, an increasing number of masterplans include these facilities. Most of the existing subdivisions offer short-term, complimentary or voluntary memberships at the resorts' golf or tennis facilities.

COMPARABLE PROJECT REVIEW

This section summarizes characteristics of single-family developments considered comparable to lots planned at the O'oma II community.

Project Characteristics

Standards for comparability to O'oma II include:

- Lot size
- High-quality subdivision standards
- On-property golf course and recreation facilities
- Resident and visitor buyer interest

Single-family lot projects selected for comparison to the proposed project are:

- Island of Hawaii:
  - Keauhou Estates (Keauhou Beach Resort)
  - Waikoloa Village (Waikoloa Village Resort)
- Other neighbor islands:
  - Pineapple Hill (Kapalua Resort)
  - Wailea Kai (Wailea Resort)
  - Wailea Golf Estates (Wailea Resort)
  - Wailea Kialoa (Wailea Resort)
  - Kiahuna Golf Village (Poipu resort area)

The resort and estate lot projects are differentiated based upon lot size, location, view orientation and amenities, as follows:

- View Orientation - The resort lots contain a well-balanced mix of golf course, hill/mauka, and some ocean and interior lots with limited views, as shown in Exhibit IV-A.

Exhibit IV-A

KAHALA CAPITAL CORPORATION

Location and View Orientation of Selected Subdivisions

Subdivision	Primary view orientation	Location: Ocean Number	Ocean Percentage	Golf course Number	Golf course Percentage	Hill/mountain Number	Hill/mountain Percentage	Interior/limited Number	Interior/limited Percentage	Total lots Number	Total lots Percentage
Island of Hawaii:											
Keauhou Estates I and II	Hillside/ocean	-	-%	22	16%	113	84%	-	-%	135	100%
Waikoloa Village	Interior	-	-	16	2	952	98	-	-	968	100
Other:											
Pineapple Hill	Golf course	-	-	25	25	50	51	24	24	99	100
Wailea Kai	Interior	-	-	-	-	-	-	100	100	100	100
Wailea Golf Estates	Golf course	-	-	71	64	20	18	20	18	111	100
Wailea Kialoa	Interior	-	-	-	-	25	25	77	75	102	100
Kiahuna Golf Village	Golf course	23	26	45	50	-	-	22	24	90	100
Average			1%		11%		72%		15%		100%

Source: Based upon interviews with developers and brokers.

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Private recreational facilities and security are major features of successful lot developments on the mainland United States. These features have generally not been incorporated in first-class resort subdivisions in Hawaii, however, an increasing number of masterplans include these facilities. Most of the existing subdivisions offer short-term, complimentary or voluntary memberships at the resorts' golf or tennis facilities.

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- Other neighbor islands:
  - Pineapple Hill (Kapalua Resort)
  - Wailea Kai (Wailea Resort)
  - Wailea Golf Estates (Wailea Resort)
  - Wailea Kialoa (Wailea Resort)
  - Kiahuna Golf Village (Poipu resort area)

The resort and estate lot projects are differentiated based upon lot size, location, view orientation and amenities, as follows:

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Exhibit IV-A

KAHALA CAPITAL CORPORATION

Location and View Orientation of Selected Subdivisions

Subdivision	Primary view orientation	Ocean Number	Ocean Percent-age	Golf course Number	Golf course Percent-age	Hill/mountain Number	Hill/mountain Percent-age	Interior/limited Number	Interior/limited Percent-age	Total lots Number	Total lots Percent-age
Island of Hawaii:											
Keauhou Estates I and II	Hillside/ocean	-	-%	22	16%	113	84%	-	-%	135	100%
Waikoloa Village	Interior	-	-	16	2	952	98	-	-	968	100
Other:											
Pineapple Hill	Golf course	-	-	25	25	50	51	24	24	99	100
Wailea Kai	Interior	-	-	-	-	-	-	100	100	100	100
Wailea Golf Estates	Golf course	-	-	71	64	20	18	20	18	111	100
Wailea Kialoa	Interior	-	-	-	-	25	25	77	75	102	100
Kiahuna Golf Village	Golf course	23	26	45	50	-	-	22	24	90	100
Average			1%		11%		72%		15%		100%

Source: Based upon interviews with developers and brokers.

- Most of the projects have at least two of the above views to offer its buyers. However, some projects offer primarily interior views such as at Wailea Kai.

- All of the O'oma II lots are planned to have golf course frontage.

- Lot Size - The lots range in size from a 7,886 square foot lot at Wailea Kai to a 24,119 square foot lot at Pineapple Hill, as shown in Exhibit IV-B. The selected resort projects average lot size is 14,245 square feet (about 1/3 acre).

- Prices - Sales as of May 1990 at the selected seven comparable lot projects are discussed below:

  - Pricing of resort lot projects is influenced by the prestige of the resort, view orientation and lot size.

  - Prices of single-family lots at these selected resort projects range from $164,700 at Waikoloa Village to $736,000 at Wailea Golf Estates. The price per square foot ranges from $13 to $51 per square foot. Wailea Golf Estates lots command the highest prices with an average of $51 per square foot.

  - Lots with golf frontage command the second highest premium after oceanfront lots. However, there are relatively few oceanfront lots, as shown previously in Exhibit IV-A.

- Amenities - Amenities such as golf courses, tennis courts, swimming pools and lush landscaping differentiate the resort residential lots from other residential lots. Lot projects are generally located nearer to the coast, so that ocean views and water activities are readily accessible to resort guests. Dining, entertainment and resort shopping facilities are also available. Amenities of residential-oriented projects are varied and can include:

  - Common park and picnic areas
  - Tennis courts
  - Swimming pools
  - Clubhouse
  - Security devices
  - Gated community
  - Underground utilities

- Buyer Profiles - Many resort lot buyers are already property owners within a particular resort. This is especially true at the high end of the market. This suggests that the market for higher-priced and better-located lots will develop as the project matures and gains a broader existing ownership base. The typical resort lot buyer can be classified by geographic origin as follows:

  - U. S. mainland buyers are a large share of the total market representing 50% of the total market for the selected comparable projects, as shown in Exhibit IV-C.

KAHALA CAPITAL CORPORATION

Current Lot Sales Prices at Selected Subdivisions

January 1990 to May 1990

	Current sales price(1)			Typical lot size (square feet)			Price per square foot		
	Low	High	Average	Low	High	Average	Low	High	Average
Island of Hawaii:									
Keauhou Estates I and II	$ 450,000	950,000	700,700	16,000	24,000	20,000	$ 28	40	35
Waikoloa Village	101,500	227,900	164,700	10,500	15,794	13,147	10	14	13
Average	275,750	588,950	432,350	13,250	19,897	16,574	19	27	24
Other:									
Pineapple Hill	400,000	745,000	572,500	9,719	24,119	16,919	31	41	34
Wailea Kai	175,000	310,000	242,500	7,886	9,317	8,602	22	33	28
Wailea Golf Estates	472,000	1,000,000	736,000	13,000	16,000	14,500	36	63	51
Wailea Kialoa	180,000	865,000	522,500	8,670	22,865	15,768	21	38	33
Kiahuna Golf Village	295,000	500,000	397,500	9,592	11,965	10,779	31	42	37
Average	304,400	684,000	494,200	8,145	14,044	11,094	24	36	30
Total average	$ 296,214	656,843	476,529	10,767	17,723	14,245	$ 26	39	33

(1) Reflects prices through May 1990.

Source: Multiple Listing Service Hawaii, Inc.

Exhibit IV-C

KAHALA CAPITAL CORPORATION

Buyer Characteristics at Selected Subdivisions

1989 to 1990

	Buyer origin						Purchase motivation			
Subdivision	Hawaii	West Coast	Other U.S.	Japan	Other foreign	Total	Primary home	Second-ary home	Invest-ment	Total
Island of Hawaii:										
Keauhou Estates I and II	41%	30%	15%	14%	-%	100%	30%	30%	40%	100%
Waikoloa Village	20	45	20	10	5	100	N/A	N/A	N/A	100
Average	31	38	18	12	3	100	15	15	20	100
Other:										
Pineapple Hill	10	21	14	48	7	100	5	65	30	100
Wailea Kai	45	45	-	9	-	100	70	10	20	100
Wailea Golf Estates	40	26	20	8	6	100	10	40	50	100
Wailea Kialoa	48	24	18	6	3	100	65	15	20	100
Kiahuna Golf Village	23	30	19	5	-	100	1	89	10	100
Average	33	30	19	15%	3	100	30	44	26	100
Total	33%	32%	18%	14%	3%	100%	26%	36%	24%	100%

N/A Not available.

Source: Multiple Listing Service Hawaii, Inc. and interviews with brokers and developers.

-- Mainland U. S. resident buyers for lots at the seven resorts average 56% on the island of Hawaii and 49% on the island of Maui.

-- Waikoloa Village attracts the highest U. S. mainland buyer market at 65%. The 73% U. S. mainland market at Kiahuna Golf Village represents the highest market of the other island projects.

- Hawaii buyers were the second largest market accounting for 33% of the market among the selected subdivision projects. For the resort lots, in-state buyers average 31% on Hawaii and 33% on Maui.

- Buyers from Japan represent 14% of the selected comparable market. Maui and Hawaii island buyers from Japan represent 15% and 12% of the respective markets. Many developers are also beginning to market their projects in Japan. For example, at Pineapple Hill, 48% of the buyers were Japanese.

- Purchase Motivations - Historically, the majority of purchasers have been motivated to buy resort residential lots for future improvement as a vacation or retirement home, for investment or for speculative building.

  - Two projects that were principally bought for primary homes are Wailea Kai and Wailea Kialoa with such buyers representing 70% and 65%, respectively, as shown in Exhibit IV-D.

  - Most units at Pineapple Hill and Kiahuna Golf Village were purchased for second home use.

RESIDENTIAL LOT MARKET ASSESSMENT

This section assesses market support for single-family residential lot development at the O'oma II site, including anticipated buyer market segments and projected lot sales absorption for residential lots.

Development Characteristics

Residential lots as planned at the O'oma II community could have the following characteristics:

- Relatively small size, averaging about 10,000 square feet for the 70 to 100 planned lots
- Golf course frontage for almost all lots
- Limited ocean views

Exhibit IV-D

KAHALA CAPITAL CORPORATION

Original Lot Sales for Selected Subdivisions

1981 to 1990

Subdivision	Year devel-oped	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990(1)	Total	Annual average sales/project
Island of Hawaii:													
Keauhou Estates I	1985	-	-	-	-	12	32	21	20	-	-	85	21
Keauhou Estates II	1987	-	-	-	-	-	-	32	18	-	-	50	25
Waikoloa Village	1986	26	28	26	11	-	-	-	-	-	-	91	23
Total sales per year		26	28	26	11	12	32	53	38	-	-	226	N/A
Other:													
Pineapple Hill	1985	-	-	-	-	33	17	49	-	-	-	99	50
Wailea Kai	1980	10	16	16	16	16	16	10	-	-	-	100	25
Wailea Golf Estates	1982	-	1	11	12	17	12	6	-	-	-	59	12
Wailea Kialoa	1986	-	-	-	-	-	-	46	56	-	-	102	15
Kiahuna Golf Village	1981	85	-	-	-	5	-	-	-	-	-	90	45
Total sales per year		95	17	27	28	71	45	111	56	-	-	450	N/A
Total sales		121	45	53	39	83	77	164	94	-	-	676	

(1) Sales through May 1990.

Source: Multiple Listing Service Hawaii, Inc.

- Potential siting within two highly private communities with:
  - Gating for limited access
  - Low traffic cul-de-sac street pattern
  - Private recreation facilities, including tennis and swimming pool
- Access to on-property recreation, retail and entertainment entities, including the golf course.

Comparative Market Position

Residential lots at the O'oma II community are anticipated to generate market support from both out-of-state investors and Hawaii residents. O'oma II is not expected to compete with luxury resorts for non-Hawaii purchasers, but would be attractive for price and golf frontage.

Anticipated Buyer Market Segments

California buyers have shown a particular interest in projects on the island of Hawaii within the last four years. The volume of Hawaii buyers appears to be related to lower pricing, since locally-based purchasers are a greater share of projects featuring lower prices.

- U. S. mainland - The primary market for lots is expected to come from the west coast and other U. S. mainland areas from repeat visitors who seek a vacation or future retirement home. These purchasers could represent from 35% to 45% of total sales.
- Hawaii - residents together with the U. S. mainland market could encompass the largest target markets. The Hawaii market could represent 40% to 45% of total sales, due to golf frontage and lower pricing than at resorts. Island residents represent a potential market as owner-occupants.
- Japanese - buyers are increasing and are projected to continue to become a larger percentage of the buyers of residential real estate on the island of Hawaii. The Japanese market has the potential to represent 20% to 30% of the total market.

Lot Sales Absorption

The golf course frontage orientation of the O'oma II residential lots would put them in a somewhat better market position than the Waikoloa Village and Kiahuna Golf Village lots. Keauhou Estates and Wailea Golf Estates where absorption levels range between 12 and 25 lots per year, as shown in Exhibit IV-D, could be considered similar to the best lots at O'oma II.

The projected level of absorption for the subject lots would be between 30 to 40 sales per year and can be expected to outpace levels experienced at comparable sites based on the following factors:

- The greater number of repeat visitors to the Big Island expected during the next five years.

- The increasing perception of the Kona Coast as a luxury destination.
- The increasing population of the Big Island in need of housing due to strong local economic conditions.

Pricing

Average lot sales prices at O'oma II could be expected to range from $250,000 to $300,000, or $22 to $28 per square foot, based on sales experience at comparable projects and development characteristics of the site. Pricing factors include the following:

- Prices per square foot currently range from $13 to $51 at comparable residential lot projects.
- Keauhou Estates, with a per square foot price range of $28 to $40, is most similar to O'oma II. However, O'oma II lots can be expected to be priced somewhat lower due to their smaller size and superior ocean views at Keauhou Estates.
- Golf frontage at O'oma II could support prices in the $22 to $28 per square foot range, with lot prices in the range of $250,000 to $300,000.

V - CONDOMINIUM MARKET ASSESSMENT

This chapter assesses market support for condominium development at the O'oma II ocean science and recreation community. The sections below review condominium development trends, current and planned inventory of units on the island of Hawaii, comparable project characteristics and market trends relating to buyer profiles, absorption rates and sales prices. The last section of the chapter presents the condominium market assessment for the O'oma II community.

CONDOMINIUM DEVELOPMENT TRENDS

While O'oma II is not a resort destination area, the planned mix of recreational and community uses could appeal to both resident and second-home or investment purchasers, as resort condominiums do. Thus, resort condominium projects are selected for comparative analysis.

This section reviews multifamily housing unit authorizations and trends in resort condominium development.

Private Multifamily Authorizations

- Multifamily units authorized by building permit on the island of Hawaii numbered 455 units in 1989, as shown in Exhibit V-A. Multifamily development was slower in the early 1980s than in the 1975 to 1980 period due to weaker economic conditions, a substantial inventory of unsold units built during the earlier period, and both uncertainty among investors about tax treatment and ultimately reduced real estate tax benefits under the Tax Reform Act of 1986. Because the multifamily housing category includes both condominiums and rental units targeted at low- and moderate-income resident families, average building permit values shown in Exhibit V-A can change significantly from year to year.
- Since 1987, multifamily housing authorizations have increased substantially over pre-1986 levels. The number of units authorized in 1989 totaled 455 with an average value of $98,853 per unit.

Resort Condominium Development

Condominiums are an important force in the visitor industry and in some cases, are competitive with hotels as visitor accommodations. Currently, about 2,167 units, or about 27% of the island of Hawaii's total visitor units are condominium units reserved for transient visitor use as part of a rental pool, as shown in Exhibit V-B. Condominium units as a percentage of total visitor inventory on Kauai and Maui is higher than on the island of Hawaii because of the more rapid growth in visitor arrivals to Kauai and Maui during the 1970s and 1980s.

On the island of Hawaii, visitor-oriented condominium units are found in the resort destination areas at Keauhou, Waikoloa Beach, Mauna Kea and Mauna Lani. However, most of the island's condominium visitor rentals are located within projects in the Kailua-Kona area. The Kailua-Kona condominiums offer access to shopping and the town's night life, but generally lack the extensive amenities and sense of identity found in the established resort areas. Although condominium units as a percentage of total visitor inventory is low relative to other islands, the percentage is expected to increase in future years.

Exhibit V-A

KAHALA CAPITAL CORPORATION

Private Multifamily Housing Authorizations
County of Hawaii

1980 to 1989

Year	County of Hawaii Units(1)	County of Hawaii (000's)	County of Hawaii Average value(2)
1970	395	$ 5,736	$ 14,522
1971	858	12,741	14,850
1972	854	13,055	15,287
1973	479	8,597	17,948
1974	994	25,104	25,256
1975	507	13,695	27,012
1976	129	2,043	15,837
1977	133	3,430	25,789
1978	334	11,935	35,734
1979	734	34,865	47,500
1980	739	56,325	76,218
1981	285	26,942	94,533
1982	245	27,141	110,780
1983	96	13,629	141,969
1984	181	16,441	90,834
1985	190	25,342	133,379
1986	39	1,971	50,538
1987	361	15,916	44,089
1988	474	17,172	36,228
1989	455	44,978	98,853

(1) Duplexes counted as multifamily units.
(2) Value of permits granted for new construction, in current dollars.

Source: Bank of Hawaii, Construction in Hawaii, and First Hawaiian Bank, Economic Indicator, March/April 1990.

Exhibit V-B

KAHALA CAPITAL CORPORATION

Condominium Units Used as
Visitor Accommodations

1989

Island	Total visitor units	Condominium units	Condominium units as a percent of total visitor units
Hawaii	8,171	2,167	26.5%
Molokai	574	248	43.2
Kauai	7,251	2,932	40.4
Lanai	10	-	-
Maui	15,444	7,941	51.4
Oahu	36,739	5,931	16.1
	68,189	19,219	28.2%

Source: Hawaii Visitors Bureau, Visitor Plant Inventory, February 1989.

Reasons for the increase in the planned number of condominium units designated for visitor use include:

- Lower construction costs compared to hotel units due to relatively minimal amenities and common areas.
- Appeal to repeat and family visitors who seek more space, cooking facilities or longer occupancy.
- Ability to develop condominium units to the higher standards of discriminating buyers.

Due to these reasons and to the projected growth in repeat visitors and part-time residents to the state and island of Hawaii who often patronize these units, condominiums are expected to become a higher proportion of future visitor accommodations.

Facilities and Amenities

Upscale condominium developments have become increasingly competitive in the provision of recreational and other project amenities. Facilities of recently completed projects include amenities such as:

- Recreation centers
- Swimming pools
- Jacuzzis and saunas
- Tennis courts
- Meeting rooms
- Barbecue areas

A recent trend offered to buyers has been allowances for membership or preferential usage of the resort's recreational facilities such as golf and/or tennis.

COMPARABLE PROJECT REVIEW

This section classifies resort condominium sites and reviews the characteristics of selected comparable resort condominium developments in the state of Hawaii.

Resort Condominium Site Locations

Visitors to the state of Hawaii tend to associate the islands with ocean views, beaches, golf courses and lush landscaping. Thus, market performance for individual projects is strongly affected by their location with respect to these elements. As discussed in Chapter IV with regard to single-family residential lots, condominium sites are also classified as oceanfront, golf-front or interior.

Anticipated market performance for condominiums in the O'oma II community is assessed using projects comparable to those planned at O'oma II in terms of:

- Location within or near resorts
- Similar facilities and amenities
- Recent completion

The selected comparables represent 12 condominium projects in Hawaii and are listed as follows:

- Island of Hawaii:
  - Hale Kehau (Keauhou Resort)
  - Villas at Keauhou (Keauhou Resort)
  - Country Club Villas (Keauhou Resort)
  - Holua at Mauna Loa (Keauhou Resort)
  - Kanaloa at Keauhou (Keauhou Resort)
  - Shores at Waikoloa (Waikoloa Beach Resort)
  - Waikoloa Fairways (Waikoloa Village Resort)
- Island of Maui:
  - Kapalua Bay Villas (Kapalua Resort)
  - Kapalua Golf Villas (Kapalua Resort)
  - The Ridge (Kapalua Resort)
  - Grand Champions (Wailea Resort)
  - Wailea Ekolu (Wailea Resort)

Project Size and Unit Mix

The project size and unit mix for the selected comparable projects are discussed below:

- The selected projects range from 29 to 469 units with an average of 148 units, including one-, two- and three-bedroom units, as shown in Exhibit V-C.
- None of the projects selected for study include studio units.
- Overall, existing developments average about 29% one-bedroom, 54% two-bedroom and 15% three-bedroom units.

Unit Size

Unit sizes, excluding lanai and garage spaces, range as follows:

- One-bedroom units range from about 822 to 1,485 net square feet
- Two-bedroom units range from 1,000 to 1,899 net square feet
- Three-bedroom units range from 1,851 to 2,424 square feet

The Hale Kehau project offers the largest unit sizes at an average 2,320 square feet, due to its exclusively three-bedroom unit type as shown in Exhibit V-D. Wailea Ekolu on Maui offers the smallest units with an average of 1,071 square feet, partly a result of its lack of three-bedroom units.

Condominium Market Performance

This section reviews the market performance of selected comparable projects in terms of sales prices, absorption rates and buyer profiles.

- Average unit sales prices - Sales prices in the comparable resort condominium projects are reviewed in terms of general price levels associated with the project and the average pricing per square foot, as shown in Exhibit V-E.

CORRECTION

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

Reasons for the increase in the planned number of condominium units designated for visitor use include:

- Lower construction costs compared to hotel units due to relatively minimal amenities and common areas.
- Appeal to repeat and family visitors who seek more space, cooking facilities or longer occupancy.
- Ability to develop condominium units to the higher standards of discriminating buyers.

Due to these reasons and to the projected growth in repeat visitors and part-time residents to the state and island of Hawaii who often patronize these units, condominiums are expected to become a higher proportion of future visitor accommodations.

Facilities and Amenities

Upscale condominium developments have become increasingly competitive in the provision of recreational and other project amenities. Facilities of recently completed projects include amenities such as:

- Recreation centers
- Swimming pools
- Jacuzzis and saunas
- Tennis courts
- Meeting rooms
- Barbecue areas

A recent trend offered to buyers has been allowances for membership or preferential usage of the resort's recreational facilities such as golf and/or tennis.

COMPARABLE PROJECT REVIEW

This section classifies resort condominium sites and reviews the characteristics of selected comparable resort condominium developments in the state of Hawaii.

Resort Condominium Site Locations

Visitors to the state of Hawaii tend to associate the islands with ocean views, beaches, golf courses and lush landscaping. Thus, market performance for individual projects is strongly affected by their location with respect to these elements. As discussed in Chapter IV with regard to single-family residential lots, condominium sites are also classified as oceanfront, golf-front or interior.

Anticipated market performance for condominiums in the O'oma II community is assessed using projects comparable to those planned at O'oma II in terms of:

- Location within or near resorts
- Similar facilities and amenities
- Recent completion

The selected comparables represent 12 condominium projects in Hawaii and are listed as follows:

- Island of Hawaii:
  - Hale Kehau (Keauhou Resort)
  - Villas at Keauhou (Keauhou Resort)
  - Country Club Villas (Keauhou Resort)
  - Holua at Mauna Loa (Keauhou Resort)
  - Kanaloa at Keauhou (Keauhou Resort)
  - Shores at Waikoloa (Waikoloa Beach Resort)
  - Waikoloa Fairways (Waikoloa Village Resort)
- Island of Maui:
  - Kapalua Bay Villas (Kapalua Resort)
  - Kapalua Golf Villas (Kapalua Resort)
  - The Ridge (Kapalua Resort)
  - Grand Champions (Wailea Resort)
  - Wailea Ekolu (Wailea Resort)

Project Size and Unit Mix

The project size and unit mix for the selected comparable projects are discussed below:

- The selected projects range from 29 to 469 units with an average of 148 units, including one-, two- and three-bedroom units, as shown in Exhibit V-C.
- None of the projects selected for study include studio units.
- Overall, existing developments average about 29% one-bedroom, 54% two-bedroom and 15% three-bedroom units.

Unit Size

Unit sizes, excluding lanai and garage spaces, range as follows:

- One-bedroom units range from about 822 to 1,485 net square feet
- Two-bedroom units range from 1,000 to 1,899 net square feet
- Three-bedroom units range from 1,851 to 2,424 square feet

The Hale Kehau project offers the largest unit sizes at an average 2,320 square feet, due to its exclusively three-bedroom unit type as shown in Exhibit V-D. Wailea Ekolu on Maui offers the smallest units with an average of 1,071 square feet, partly a result of its lack of three-bedroom units.

Condominium Market Performance

This section reviews the market performance of selected comparable projects in terms of sales prices, absorption rates and buyer profiles.

- Average unit sales prices - Sales prices in the comparable resort condominium projects are reviewed in terms of general price levels associated with the project and the average pricing per square foot, as shown in Exhibit V-E.

Exhibit V-C

KAHALA CAPITAL CORPORATION

Size and Unit Mix of Selected Condominium Projects

	One-bedroom		Two-bedroom		Three-bedroom		Total	
	Number	Per-cent	Number	Per-cent	Number	Per-cent	Number	Per-cent
Hawaii island:								
Hale Kehau	-	-%	-	-%	29	100%	29	100%
Villas at Keauhou	-	-	20	34	38	66	58	100
Country Club Villas	-	-	116	100	-	-	116	100
Holua at Mauna Loa	240	51	217	46	12	3	469	100
Kanaloa at Keauhou	31	26	60	50	28	24	119	100
Shores at Waikoloa	35	31	68	60	10	9	113	100
Waikoloa Fairways	-	-	51	100	-	-	51	100
Maui island:								
Kapalua Bay Villas	92	65	49	35	-	-	141	100
Kapalua Golf Villas	94	51	92	49	-	-	186	100
The Ridge	105	65	56	35	-	-	161	100
Grand Champions Villas	54	29	134	71	-	-	148	100
Wailea Ekolu	40	27	108	73	-	-	148	100
Average	57	29%	81	54%	10	17%	148	100%

Source: Hawaii Condominium Guide, other published sources and interviews with developers, realtors and property representatives.

Exhibit V-D

KAHALA CAPITAL CORPORATION

Average Unit Size of Selected Condominium Projects

(interior square feet)(1)

	One-bedroom		Two-bedroom		Three-bedroom		
	Low	High	Low	High	Low	High	Average
Hawaii island:							
Hale Kehau	-	-	-	-	2,215	2,424	2,320
Villas at Keauhou	-	-	1,612	1,612	1,873	1,873	1,743
Country Club Villas	-	-	1,000	1,271	-	-	1,136
Holua at Mauna Loa	823	866	1,175	1,899	2,093	2,093	1,492
Kanaloa at Keauhou	1,248	1,336	1,639	1,858	-	-	1,520
Shores at Waikoloa	822	878	1,118	1,462	1,851	1,887	1,336
Waikoloa Fairways	-	-	1,368	1,368	-	-	1,368
Maui island:							
Kapalua Bay Villas	937	1,096	1,518	1,547	-	-	1,275
Kapalua Golf Villas	899	987	1,344	1,350	-	-	1,145
The Ridge	1,125	1,162	1,756	1,758	-	-	1,450
Grand Champions Villas	908	908	1,056	1,383	-	-	1,064
Wailea Ekolu	866	869	1,060	1,489	-	-	1,071

(1) Excluding garage and lanai areas.

Source: Multiple Listing Service Hawaii, Inc., Condominium Guide and interviews with realtors of respective projects.

KAHALA CAPITAL CORPORATION

Current Price Range for
Selected Condominium Projects

January to May 1990

Project	Unit price Low	Unit price High	Unit price Average	Unit area Low	Unit area High	Unit area Average	Price/square foot Low	Price/square foot High	Price/square foot Average
Hawaii Island:									
Hale Kehau	$ 650,000	786,500	718,250	2,215	2,424	2,320	$ 293	324	309
Villas at Keauhou	425,000	550,000	487,500	1,612	1,873	1,743	264	294	280
Country Club Villas	178,000	341,500	259,750	1,000	1,271	1,053	178	269	223
Holua at Mauna Loa	230,000	377,000	303,500	823	1,585	1,204	238	279	252
Kanaloa at Keauhou	175,000	470,000	322,500	1,104	1,571	1,338	159	299	241
Shores at Waikoloa	265,000	590,000	427,500	822	1,484	1,153	322	398	371
Waikoloa Fairways	389,000	449,000	419,000	1,368	1,368	1,368	284	328	306
Maui Island:									
Kapalua Bay Villas	377,900	1,000,000	688,950	995	1,547	1,271	380	646	542
Kapalua Golf Villas	342,500	574,000	458,250	1,344	1,344	1,344	255	427	341
The Ridge	320,000	490,000	405,000	1,162	1,778	1,470	275	276	276
Grand Champions Villas	240,000	420,000	330,000	908	1,383	1,146	264	304	288
Wailea Ekolu	230,000	492,000	361,000	866	1,069	968	266	460	373

Source: Multiple Listing Service Hawaii, Inc.

Exhibit V-E

- Average unit prices range from $259,750 at Country Club Villas to $718,250 at Hale Kehau. The relatively high prices achieved at Hale Kehau are attributed to its recent completion, large unit sizes and good ocean views. The Kapalua Bay Villas reports the highest sales price as of May of 1990 with one resale for $1,000,000.
- Average per square foot prices range from $233 at Country Club Villas to $542 at Kapalua Bay Villas. The Kapalua Bay Villas unit noted above achieved the highest single sale with a high of $646 per square foot.

- Sales absorption - Original unit sales at the selected projects have ranged from 5 to 148 per year per project with average annual sales of 7 to 148 units per year, as shown in Exhibit V-F.
  - The most rapid sales absorption occurred from 1976 to 1978; similar results occurred in 1988 and 1989.
  - The historical absorption rate has been affected by the inventory available, since none was available from 1980 to 1985. Sales rates have been high when inventory was available. This trend should continue as more inventory is expected to be built in the near future.
- Buyer origins - Origins of condominium buyers at the selected projects include a significant share of buyers from the western U.S. and Hawaii, as shown in Exhibit V-G. The following is a summary of the U.S. mainland, Hawaii, and foreign buyers of the selected comparable projects.
- The U.S. mainland market segment averages about 45% of the overall Hawaii and Maui condominium markets at the selected comparable projects.
  - Hawaii Island - Condominium buyers from the U. S. mainland average about 43% and are most significant at the Kanaloa at Mauna Loa project with 48% from the west coast and other U. S. mainland states.
  - Maui Island - Condominium buyers from the U.S. mainland compose 45% of the selected projects on Maui and represent the majority of the market at the Kapalua Bay Villas project.
- Hawaii state residents have high representation in the resort condominium market averaging about 23% of buyers at the selected projects. Local buyers include owner-occupants, as found at the Hale Kehau project.
  - Hawaii Island - Buyer interest typically comes from the island of Oahu, with some projects, such as Hale Kehau, able to capture buyers from its own island. Hawaii buyers represent the largest market share on the island of Hawaii with 35%.
  - Maui Island - Buyers from the state of Hawaii represent 15% of the total market. The largest Hawaii buyer interest among the selected projects on Maui is at 32% of the market at Wailea Ekolu.

KAHALA CAPITAL CORPORATION

Original Unit Sales for
Selected Condominium Projects

1975 to 1990

Project	Year developed	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	Total	Annual average sales/ project
Island of Hawaii:'																			
Hale Kehau	1986	-	-	-	-	-	-	-	-	-	-	-	5	9	9	6	-	29	7
Villas at Keauhou	1990	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	58	58	58
Shores at Waikoloa	1985	-	-	-	-	-	-	-	-	-	-	35	43	42	-	-	-	120	40
Average sales per project		-	-	-	-	-	-	-	-	-	-	35	24	26	9	6	58	69	
Maui Island:																			
Kapalua Bay Villas	1975	23	118	-	-	-	-	-	-	-	-	-	-	-	-	-	-	141	71
The Ridge	1978	-	-	-	134	27	-	-	-	-	-	-	-	-	-	-	-	161	81
Grand Champion Villas	1988	-	-	-	-	-	-	-	-	-	-	-	-	-	82	106	-	188	94
Wailea Ekolu	1976	-	148	-	-	-	-	-	-	-	-	-	-	-	-	-	-	148	148
Average sales project		23	133	-	134	27	-	-	-	-	-	-	-	-	82	106	-	160	
Total sales		23	266	-	134	27	-	-	-	-	-	35	48	51	91	112	58	845	

Source: Multiple Listing Service Hawaii, Inc.

Exhibit V-F

KAHALA CAPITAL CORPORATION

Buyer Characteristics at
Selected Subdivisions

1989 to 1990

	Origin						Purchase motivation			
	Hawaii	West Coast	Other U.S.	Japan	Other foreign	Total	Primary residence	Secondary residence	Invest-ment	Total
Hawaii Island:										
Hale Kehau	55%	10%	14%	17%	3%	100%	70%	20%	10%	100%
Villas at Keauhou	N/A	N/A	N/A	N/A	N/A	100	17	60	22	100
Country Club Villas	17	34	26	14	9	100	N/A	N/A	N/A	N/A
Holua at Mauna Loa	N/A	N/A	N/A	N/A	N/A	100	N/A	N/A	N/A	N/A
Kanaloa at Keauhou	32	40	8	16	4	100	N/A	N/A	N/A	N/A
Shores at Waikoloa	34	21	21	20	4	100	15	15	70	100
Waikoloa Fairways	N/A	N/A	N/A	N/A	N/A	100	N/A	N/A	N/A	N/A
Subaverage	35	26	17	17	5	100	34	32	34	100
Maui Island:										
Kapalua Bay Villas	12	45	25	13	4	100	10	15	69	100
Kapalua Golf Villas	19	9	-	56	16	100	15	10	75	100
The Ridge	-	33	17	50	-	100	20	5	75	100
Grand Champions Villas	15	35	15	30	5	100	10	30	60	100
Wailea Ekolu	32	22	20	27	-	100	10	30	60	100
Subaverage	16	29	15	35	5	100	13	18	69	100
Average	24%	28%	16%	27%	5%	100%	21%	23%	56%	100%

N/A Not available.

Source: Multiple Listing Service Hawaii, Inc. and interviews with brokers and developers.

Exhibit V-G

KAHALA CAPITAL CORPORATION

Original Unit Sales for
Selected Condominium Projects

1975 to 1990

Project	Year devel-oped	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	Total	Annual average sales/ project
Island of Hawaii:																			
Hale Kehau	1986	-	-	-	-	-	-	-	-	-	-	-	5	9	9	6	-	29	7
Villas at Keauhou	1990	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	58	58	58
Shores at Waikoloa	1985	-	-	-	-	-	-	-	-	-	-	35	43	42	-	-	-	120	40
Average sales per project		-	-	-	-	-	-	-	-	-	-	35	24	26	9	6	58	69	
Maui Island:																			
Kapalua Day Villas	1975	23	118	-	-	-	-	-	-	-	-	-	-	-	-	-	-	141	71
The Ridge	1978	-	-	-	134	27	-	-	-	-	-	-	-	-	-	-	-	161	81
Grand Champion Villas	1988	-	-	-	-	-	-	-	-	-	-	-	-	-	82	106	-	188	94
Wailea Ekolu	1976	-	148	-	-	-	-	-	-	-	-	-	-	-	-	-	-	148	148
Average sales project		23	133	-	134	27	-	-	-	-	-	-	-	-	82	106	-	160	
Total sales		23	266	-	134	27	-	-	-	-	-	35	48	51	91	112	58	845	

Source: Multiple Listing Service Hawaii, Inc.

Exhibit V-F

KAHALA CAPITAL CORPORATION

Buyer Characteristics at
Selected Subdivisions

1989 to 1990

	Origin						Purchase motivation			
	Hawaii	West Coast	Other U.S.	Japan	Other foreign	Total	Primary residence	Secondary residence	Invest-ment	Total
Hawaii Island:										
Hale Kehau	55%	10%	14%	17%	3%	100%	70%	20%	10%	100%
Villas at Keauhou	N/A	N/A	N/A	N/A	N/A	100	17	60	22	100
Country Club Villas	17	34	26	14	9	100	N/A	N/A	N/A	N/A
Holua at Mauna Loa	N/A	N/A	N/A	N/A	N/A	100	N/A	N/A	N/A	N/A
Kanaloa at Keauhou	32	40	8	16	4	100	N/A	N/A	N/A	N/A
Shores at Waikoloa	34	21	21	20	4	100	15	15	70	100
Waikoloa Fairways	N/A	N/A	N/A	N/A	N/A	100	N/A	N/A	N/A	N/A
Subaverage	35	26	17	17	5	100	34	32	34	100
Maui Island:										
Kapalua Bay Villas	12	45	25	13	4	100	10	15	69	100
Kapalua Golf Villas	19	9	-	56	16	100	15	10	75	100
The Ridge	-	33	17	50	-	100	20	5	75	100
Grand Champions Villas	15	35	15	30	5	100	10	30	60	100
Wailea Ekolu	32	22	20	27	-	100	10	30	60	100
Subaverage	16	29	15	35	5	100	13	18	69	100
Average	24%	28%	16%	27%	5%	100%	21%	23%	56%	100%

N/A Not available.

Source: Multiple Listing Service Hawaii, Inc. and interviews with brokers and developers.

Exhibit V-G

- Foreign buyers are primarily from Japan. Within the last four years, there have been indications of increased buyer interest from the foreign buyer segment.
    - Hawaii Island - The Japanese market represents 17% of the selected project market on the island of Hawaii. The Shores at Waikoloa achieved the largest Japanese market share with 20% of the market.
    - Maui island - The Japanese market on Maui represents 34% of the total market. Buyer interest is very high in particular at two of the selected projects, representing 50% at The Ridge and 56% at the Kapalua Golf Villas. Japanese buyer interest is considered to be stronger on Maui due to the island's higher visibility in the resort market.

In the future, foreign purchasers, especially the Japanese, are expected to become a greater part of the market due to the following factors:

- Growing awareness of the island of Hawaii as the number of repeat visitors and investments in hotels and other real estate increases.
- Increased development of visitor activities and amenities, such as shopping centers and golf courses.

PROJECT MARKET ASSESSMENT FOR O'OMA II CONDOMINIUM UNITS

The anticipated market for the project is estimated based on the experience of selected comparable condominium projects as adjusted for the O'oma II project location, project concept and anticipated market conditions. Resort area condominiums are used for comparison, because of the expected appeal of O'oma II condominiums to both residents and visitors.

Residential Development Characteristics

From 130 to 150 low-density multifamily units are planned at the O'oma II site under the development concept assessed in this study. A total of about 230 units could be built under planned zoning, although a 230-unit project could have different physical characteristics and buyer appeal. Development characteristics include the following:

- The units are planned to be in a clustered low-rise development.
- The development is planned to embody a first-class level of finish and amenities.
- Unit sizes could range from 1,200 to 1,500 square feet.
- All units are planned to have golf course frontage or golf course views and access to common recreational amenities such as swimming and tennis.
- Units are planned to be enclosed with little or no lanai space to abate noise due to the close proximity of aircraft flight paths to and from the Keahole Airport.

- Condominium units could be attractive to full-time and part-time residents due to the location of the development near Kailua-Kona and its private setting.

Anticipated Buyer Market Segments

Buyers could be expected to be primarily from:

- U.S. mainland, expected to represent from about 50% to 55% of the total units, based on historical condominium sales at selected comparable projects.
    - Couples, mature singles and retirees would be seeking a vacation home and a future residence with sunny climate, proximity to beaches, and the special amenities that will exist within the community such as the golf course and restaurants.
- Hawaii buyers, expected to represent from 30% to 35% of sales due to the project's expected attraction to owner/occupants.
    - Depending upon the amount of foreign investment and the prices of the units, the Hawaii buyers could represent a large proportion of investor market.
- Japanese buyers who could represent about 15% to 20% of the total market.
    - Buyers could be expected to purchase units for use as a vacation home with an emphasis on golf course utilization.

Pricing

Based on comparable sales, average sales prices per unit at the O'oma II project could range from $250 to $280 per square foot or $340,000 to $375,000 per unit with sizes ranging from 1,200 to 1,500 square feet. This pricing structure is supported by the following factors:

- The average sales prices per square foot for the selected comparable condominium units on the island of Hawaii range between $223 and $371.
- Recently developed golf-front units sold for between $280 and $371 per square foot. Residential condominiums with golf course frontage tend to sell at a 20% to 25% premium due to the more favorable appeal of orientation to the golf course.
- The project's first-class orientation could contribute to achieved prices being at the lower to middle spectrum of the golf-front resort condominium market.

Projected Sales Absorption

The projected level of absorption for the subject units could be between 40 and 50 units per year. Market support is anticipated from the project's central location in the region, availability of golf, first-class orientation and pricing considerably below South Kohala resort condominiums.

VI - GOLF COURSE MARKET ASSESSMENT

This chapter assesses potential market support for the proposed golf course at the O'oma II ocean science and recreation community. Existing and planned golf courses in the market area and on the island of Hawaii are reviewed in terms of size, facilities, and green and cart fees. Memberships, initiation fees, and play levels are also discussed. Finally, market performance of the O'oma II golf course is projected.

O'OMA II GOLF FACILITY DESCRIPTION

This section describes planned golf facilities at the O'oma II ocean science and recreation community, including a golf course, clubhouse, and lodging inn.

Golf Course

An 18-hole golf course is planned as a recreational and open space amenity for the O'oma II community. Golf facilities would also include a driving range and sizeable clubhouse with restaurant, pro shop and health spa.

The O'oma II course is intended to accommodate on-property golf demand including:

- Full-time and part-time residents of single-family homes and condominium units.
- Visitors staying in the hotel, residences and condominiums.

To the extent that golf rounds available at O'oma II are projected to be greater than on-property and regional demand, private golf club memberships could be sold. Japanese citizens and corporations would be the primary target markets for club memberships.

Inn

An inn consisting of about 50 lodging units is planned in conjunction with other golf facilities. The preliminary development concept for the inn would emphasize functional and architectural qualities of a Japanese country inn, or ryokan.

Inn accommodations are anticipated to be provided in association with golf club membership, although the inn could also serve group or incentive travelers.

Availability of specialty accommodations could further membership sales or group marketing for the hotel.

ISLAND OF HAWAII EXISTING AND PLANNED GOLF COURSES REVIEW

This section reviews existing and planned golf courses on the island of Hawaii.

Characteristics of resort golf courses are also discussed in this section. The O'oma II course is intended to serve resident, on-property guest and member target markets. Thus, the planned facility would have some comparability to both resort and private club courses.

Island of Hawaii Existing Golf Courses

There are 12 golf courses currently in operation on the island of Hawaii. Existing courses are summarized in Exhibit VI-A.

- Seven of the courses, representing 135 holes, are located in resort areas.
- The remaining five courses are located away from resort areas and cater primarily to island residents and club members.
- Resort courses provide 135 holes to accommodate golf play in the Big Island. Nonresort courses provide 72 holes.

Island of Hawaii Planned Golf Courses

Expansion in the number and capacity of island golf courses is anticipated with the growth of west Hawaii resorts. Planned and proposed golf courses on the Big Island are shown in Exhibit VI-B.

- While Waikoloa Beach Resort has just opened a second course, the other two existing South Kohala area resorts have announced plans for second 18-hole courses to be built in the next few years.
- The Kona Country Club at Keauhou Resort plans to add nine holes to bring its capacity to 36 holes.
- Eight other courses are proposed in conjunction with planned resort development.
- The other proposed courses are mostly in the context of a master-planned resident community or private country club. Development plans for these courses are now somewhat indefinite, but are unlikely to offer play at the low daily fee rates associated with municipal golf courses.

RESORT GOLF COURSES

This section discusses characteristics, green and cart fees of resort golf courses.

Characteristics of Resort Golf Courses

Resort golf courses are primarily utilized by resort guests and residents, and secondly by the general public. Resort golf courses are typically owned and managed by a subsidiary of the master resort landowner/developer. Major management and operational concerns include maintenance of the course and related facilities, and managing the rate of play. Tee times are generally set eight to nine minutes apart compared to seven or fewer minutes at nonresort golf courses.

Exhibit VI-A

KAHALA CAPITAL CORPORATION

Golf Courses on the Island of Hawaii

1990

Course	Location	Number of holes
Resort courses:		
Waikoloa Beach Golf Club	Waikoloa Beach	18
Waikoloa Kings Course	Waikoloa Beach	18
Waikoloa Village Golf Club	Waikoloa Village	18
Kona Country Club	Keauhou	27
Mauna Kea Beach Hotel Golf Course	Mauna Kea	18
Francis I'i Brown	Mauna Lani	18
Sea Mountain Golf Course	Punalu'u	18
Subtotal		135
Off-resort courses:		
Naniloa Country Club	Hilo	9
Hilo Municipal Golf Course	Hilo	18
Volcano Golf and Country Club	Volcano	18
Discovery Harbour Golf Course	Naalehu	18
Hamakua Country Club	Honokaa	9
Subtotal		72
Total golf holes in operation		207

Exhibit VI-B

KAHALA CAPITAL CORPORATION

Planned and Proposed Golf Courses on the Island of Hawaii

1990

Course	Location	Number of holes
Planned:		
Mauna Kea Resort - second course (1991-1992)	Mauna Kea	18
Mauna Lani - second course (1991-1992)	Mauna Lani	18
Waikoloa Highlands course	Waikoloa Village	18
Kaloko course	Kaloko	18
Oneloa course	Puna	36
Kaupulehu resort course	Kaupulehu	36
Subtotal		144
Proposed:		
Additional resort courses	Waikoloa Beach	36
Regent Beach resort course	Regent Beach	36
Huehue Ranch course	Mauka Kaloko	18
Planned resort course	Kohanaiki	18
Kona Country Club expansion	Keauhou	9
Royal Vista Golf and Country Club	North Kona	27
Kohala Ranch	North Kohala	18
Signal Puako	South Kohala	36
Kona Municipal	Kealakehe	18
Waihee Country Club	Hamakua	18
Subtotal		234
Total		378

Source: County of Hawaii Planning Department.

Resort Golf Course Green and Cart Fees

Visitors are the predominant users of resort courses. Those who stay at the resort where the course is located generally receive a preferential rate, as shown in Exhibit VI-C:

- Total green and cart fees at resort courses average $68 per 18-hole round for resort guests, $98 for nonresort players and $58 for Hawaii residents. Resident "kamaaina" rates are extended to both Hawaii resident-players from other islands and Big Island residents.
- On the island of Hawaii, total fees average $74 for Hawaii residents and $58 for resort guest players. Nonresort players pay an average of $98.

INTERNATIONAL PRIVATE GOLF CLUBS

Private memberships are planned to be offered in the O'oma II golf club. International members are expected to be predominantly Japanese nationals. This section discusses international private golf clubs in Hawaii in terms of:

- Membership fees and types
- Number of memberships sold
- Stages of membership solicitation
- Japanese club member usage patterns

International private country clubs differ from private country clubs based on the residence of member markets. International private country clubs in Hawaii solicit the majority of members in Japan, while other private country clubs in Hawaii solicit most of its members among islands residents.

Membership Fees and Types

Memberships in a number of planned and operating golf courses in the state are now being marketed in Japan. These market solicitations are summarized in Exhibit VI-D. As shown in the exhibit, marketing is carried out through a series of stages in which the focus is broadened from private solicitation of individuals and corporations to public offerings. The cost of memberships generally increases with each successive stage. The majority of golf clubs have two types of memberships; (1) individual and (2) corporate, as also shown in Exhibit VI-D. Corporate memberships are generally twice as expensive as individual memberships and permit use of club facilities by two representatives from a corporation.

For the majority of clubs, most of the membership fee consists of a guarantee, which is a noninterest-bearing loan, refundable after 10 or more years depending on the terms of membership. The remainder is considered an admission fee and is nonrefundable. Most memberships are considered equity memberships in that the guarantee portion can be publicly traded and is expected to appreciate in value over time. Memberships are usually transferable with the approval of the club committee.

Exhibit VI-C

KAHALA CAPITAL CORPORATION

Total Green and Cart Fees at Selected Island of Hawaii Resort Golf Courses

1990

	Resort guests	Nonresort guests	Hawaii residents
Mauna Kea Beach Golf Course	$ 48	98	90
Mauna Lani:			
Peak season (December - March)	65	130	100
Low season (April - November)	65	100	70
Waikoloa Beach Resort and Golf Club:			
Peak season (January - March)	60	95	45
Low season (April - December)	60	95	45
Kona Country Club:			
Peak season (January - March)	57	100	75
Low season (April - December)	50	70	70
Average	$ 58	98	74

KAHALA CAPITAL CORPORATION

Type of Memberships and Fees at
Major Hawaii Private Golf Clubs Soliciting in Japan

1990

Developer	Name and location	Stage of solicitation	Membership type	Membership fee (yen)	Number solicited	Comments
Yanase/Moribia	Honolulu Country Club, Oahu	4th stage	Corporate	25 million	50	Fourth stage began in February 1990.
Sports Shinko	Ocean Resort Club(1)	Private solicitation	Individual	5 million	1,000	In the pilot stage, special memberships were solicited among Sports Shinko clients and 1,000 individuals joined.
		1st stage	Individual Corporate	10 million 20 million	1,000	First stage members were solicited October 1989.
		2nd stage (plan)	Individual Corporate	15 million 30 million	N/A	The membership is transferable after being held for three years with the approval of Sports Shinko.
Yasuo Yasuda	Royal Hawaiian Country Club, Oahu	Private solicitation	Individual Corporate	25 million 25 million	2,500	
Ewa Beach International	Ewa Beach International Golf Club, Oahu	Solicitation	Individual Corporate	5 million 10 million	300	Privately solicited members were being solicited between April and December 1989 and more than 300 individuals joined. The membership is transferable with the approval of the company.
		1st stage	Individual Corporate	8 million 6 million	200 60	The club will not publicly solicit members before the autumn of 1990. Total number of members limited to 2,000.
		2nd stage	Individual Corporate	10 million 20 million	N/A N/A	
Shinwa Golf	Wailea Golf Club (Gold Course), Maui	Private solicitation	Individual Corporate	10 million 10 million	1,000 (total)	Members have been solicited from July 1989. Membership is transferable beginning in late 1993. Shinwa plans to expand the number of members to maximum of 5,000.

Exhibit VI-D

2

KAHALA CAPITAL CORPORATION

Type of Memberships and Fees at
Major Hawaii Private Golf Clubs Soliciting in Japan, Continued

Developer	Name and location	Stage of solicitation	Membership type	Membership fee (yen)	Number solicited	Comments
Hawaii International Sporting Club	Volcano Golf and Country Club, Hawaii	Private solicitation	Individual Corporate	2.3 million 3 million	N/A N/A	Preliminary memberships were solicited in Japan from 1984 through 1987. The Company bought back all the outstanding memberships in 1989 and plans a new offering for 900 members including 460 local members.
		70 years' anniversary	Individual Corporate	5 million 10 million	200 (total)	
Sokan, Inc.	Waihee Oceanfront Country Club, Maui	1st stage	Individual Corporate	5 million 10 million	2,000 (total)	Memberships can be transferred. Refundable. Corporate memberships are for up to four persons.
		2nd stage	Individual Corporate	7 million N/A	500 (total)	Membership fee is returned after ten years.
		3rd stage	Individual Corporate	10 million N/A	500 (total)	
Takao Building Development, Ltd.	Kona Country Club and Waimea Country Club, Hawaii	1st stage	Individual Corporate	10 million 20 million	1,800 (total)	Membership is transferable after three years.

N/A Not available.

(1) Consists of 3 golf courses, one each on Oahu, Maui and Kauai.

Source: Based on interviews with representatives of the respective projects and publicly available information.

Exhibit VI-D, Cont.

As also shown in Exhibit VI-D, individual membership fees currently range in price from about 2 million to 15 million yen, while corporate memberships range from 3 to 30 million yen. The wide range in prices is due to:

- Perceived prestige of course and location
- Marketing strength of sponsor
- Trends in the Japan securities market

Because of the active resale market for memberships and their offering as investments, value of international memberships could change rapidly.

Japanese Club Member Usage Patterns

The seasonality of use of golf facilities by potential Japanese members is one of the major concerns for international private golf clubs in Hawaii, since a course as at O'oma II would need to accommodate on-property, regional and international member play.

The Honolulu Country Club is currently the only club in the state with a significant Japanese membership base, 677 members. Golf course utilization patterns of these nonresident members, as reported by management, are shown in Exhibit VI-E.

- Japanese member play is concentrated into four periods of the year:
  - New Year's season (December 25 to January 10) - Reportedly, virtually all Japanese golf members visit the club during this time.
  - February - About 30% of the Japanese members visit the club during a winter vacation.
  - Golden week (late April/early May) - About 60% of Japanese members visit the club during this traditional spring holiday period.
  - August - Approximately 75% of Japanese members visit the club while taking summer vacation.
- Based on their typical length of stay in Hawaii and utilization of the Honolulu Country Club, visiting members account for about 6,300 rounds of play per year and average about 75 rounds per day distributed very unevenly throughout the year.

Accordingly, international private golf club members are estimated to play approximately 10.5 rounds per member annually. However, play is most likely to be highly seasonal, occurring during four periods of the year consisting of a total of 85 days.

PROJECTED COMMUNITY GUEST AND RESIDENT POPULATIONS

This section projects the average daily population of guests and residents at the O'oma II ocean science and recreation community as a basis for projecting golf course utilization. Community guests include visitors staying at the golf inn, hotel, condominiums and single-family units at O'oma II. Community residents include full-time and part-time residents of condominiums and single-family units.

Exhibit VI-E

KAHALA CAPITAL CORPORATION

International Member Usage of Facilities at Honolulu Country Club by Season

	(A)	(B)	(C)	(D)	(E)	(F)	(G)
Peak season periods	Days in period	International member players	Usage rate of members	Guest players	Average rounds in period	Total rounds	Rounds per day
New Year's season - (December 25 to January 10)	17	600	100%	600	2	2,400	141
February	28	180	30	180	2	720	42
Golden week - (April 29 to May 7)	9	300	50	300	2	1,200	133
Summer vacation - (August)	31	500	83	500	2	2,000	65
Total	85				2	6,320	74

(1) Based on total of 600 international members.

Source: Based on discussions with management.

Projected Average Daily
Guest Population

The total daily resort guest population is comprised of the following types of guests:

- Hotel guests
- Inn guests
- Condominium guests
- Single-family unit guests

Condominium and single-family unit guest population projections are based on the construction and build-out of units as discussed previously in Chapters IV and V. Estimated construction and build-out of single-family units is projected to begin in 1996, as shown in Exhibit VI-F.

- Home completions are projected to begin as early as 1996 and about 60 homes could be completed by 2010.

- Estimates are based on 12% of sold lots being improved per year.

The single-family unit guest population is projected to reach about 7 persons per day by 2010, based on a party-size of 2.5 occupants, as shown in Exhibit VI-G. A 50% occupancy rate for single-family homes used by visitors is projected in 1996 and each of the five-year intervals from 2000 to 2010.

Hotel and condominium guests are estimated at 679 and 69 guests per day, respectively, in 1996 and 888 and 150 per day in 2010, as discussed in Chapter V and subsequently in Chapter VIII. Inn guests are estimated to number 65 in 1996 and 85 in 2010. Total daily community guests are projected at about 800 guests per day in 1996 and are projected to stabilize at about 1,100 guests daily by 2005.

Projected Average Daily
Resident Population

About 50% of the condominiums developed are estimated to be occupied by either full-time or part-time residents, as shown in Exhibit VI-H. Approximately 60% of the total number of single-family units are expected to be occupied by full-time residents and 30% by part-time residents.

The total average daily condominium and single-family unit resident population at the O'oma II community is projected at about 90 persons in 1996, increasing to about 180 in 2010.

Summary of Resident and
Guest Average Daily Population

The total average daily population of residents and guests at the O'oma II community is shown in Exhibit VI-I. The daily census projections indicate that about 900 residents and guests can be expected to populate the community in 1996. By 2005, the on-site population can be expected to average about 1,300 residents and guests per day.

Exhibit VI-F

KAHALA CAPITAL CORPORATION

Lot Sales Absorption and Home Construction
O'oma II Community

1996 to 2010

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Lot sales:															
Lots available	70	40	10	-	-	-	-	-	-	-	-	-	-	-	
Lots sold(1)	30	30	10	-	-	-	-	-	-	-	-	-	-	-	
Cumulative sales	30	60	70	70	70	70	70	70	70	70	70	70	70	70	70
Remaining inventory	40	10	-	-	-	-	-	-	-	-	-	-	-	-	
Home construction:															
Cumulative lot sales	30	60	70	70	70	70	70	70	70	70	70	70	70	70	70
Projected homes completed(2)	-	4	11	18	24	30	35	39	43	46	49	52	54	56	58
Remaining sold lots	30	56	59	52	46	40	35	31	27	24	21	18	16	14	12
Homes constructed in year	4	7	7	6	6	5	4	4	3	3	3	2	2	2	1

(1) Lot sales absorption as shown in Chapter IV.
(2) Based on 12% of sold lots being improved per year.

Exhibit VI-G

KAHALA CAPITAL CORPORATION

Projected Average Daily Guest Population
O'oma II Community

1996 to 2010

	1996	2000	2005	2010
Hotel:				
Number of units	550	550	550	550
Occupancy rate(1)	65%	75%	85%	85%
Party size(2)	1.9	1.9	1.9	1.9
Hotel guests	679	784	888	888
Inn:				
Number of units	50	50	50	50
Occupancy rate(3)	65%	75%	85%	85%
Party size(3)	2.0	2.0	2.0	2.0
Inn guests	65	75	85	85
Condominiums:				
Number of units	150	150	150	150
Units in visitor use	50%	50%	50%	50%
Occupancy rate	37%	56%	81%	80%
Party size(2)	2.5	2.5	2.5	2.5
Condominium guests	69	105	152	150
Single-family homes:				
Number of units	-	24	46	58
Units in visitor use	10%	10%	10%	10%
Occupancy rate	50%	50%	50%	50%
Party size(2)	2.5	2.5	2.5	2.5
Single-Family guests	-	3	6	7
Total daily community guests	814	967	1,131	1,131

(1) As shown in Chapter VIII.
(2) As shown in Exhibit II-D.
(3) Estimated by client.

Exhibit VI-H

KAHALA CAPITAL CORPORATION

Projected Average Daily Resident Population
O'oma II Community

1996 to 2010

	1996	2000	2005	2010
Condominium residents:				
Full-time:				
Units (25% of total)	37	37	37	37
Occupancy rate	95%	95%	95%	95%
Resident households	35	35	35	35
Persons per household	2.2	2.2	2.2	2.2
Residents	77	77	77	77
Part-time:				
Units (25% of total)	37	37	37	37
Occupancy rate	20%	20%	20%	20%
Resident households	7	7	7	7
Persons per household	2.0	2.0	2.0	2.0
Residents	15	15	15	15
Single-family unit residents:				
Full-time:				
Units (60% of total)	-	14	28	35
Occupancy rate	95%	95%	95%	95%
Resident households	-	14	26	33
Persons per household	2.4	2.4	2.4	2.4
Residents	-	33	63	79
Part-time:				
Units (30% of total)	-	7	14	17
Occupancy rate	20%	20%	20%	20%
Resident households	-	1	3	3
Persons per household	2.0	2.0	2.0	2.0
Residents	-	3	6	7
Total resident households	42	57	71	79
Total residents	92	128	160	178

Exhibit VI-I

KAHALA CAPITAL CORPORATION

Summary of Resident and
Guest Average Daily Population
O'oma II Community

1996 to 2010

	1996	2000	2005	2010
Guests(1)	814	967	1,131	1,131
Residents(2)	92	128	160	178
Total O'oma II community daily population	906	1,095	1,291	1,309

(1) As shown in Exhibit VI-G.
(2) As shown in Exhibit VI-H.

PROJECTED ON-PROPERTY GOLF DEMAND

This section projects the average annual demand for golf rounds at the planned O'oma II community golf course based on the estimated resident and guest populations in the community.

Golf Rounds Needed to Accommodate Community Guests and Residents

Golf rounds generated by hotel and inn guests at the O'oma II community are projected at about 9 rounds per 100 hotel guests. Golf rounds played in 1989 averaged 8.4 rounds per 100 hotel guests at selected resorts in Hawaii, as shown in Exhibit VI-J. Golf rounds generated by community residents are estimated at 15 annual rounds per 100 residential condominium and single-family units based on rounds of play at selected resort residential communities.

Projected daily demand for golf at O'oma II is estimated to include 50 rounds for public play, and would total about 130 rounds in 1996 stabilizing at about 160 rounds by 2005, as shown in Exhibit VI-K.

Golf Rounds Available to Accommodate Golf Club Members

The desired level of play at the O'oma II course is recommended to be 200 rounds per day supported by the following:

- Courses with a large visitor clientele generally operate at 8 to 9 minute intervals per four-some.
- The estimated maximum rounds in a 7.25 hour operating day at:
  - 8 minute intervals per foursome is 218 rounds.
  - 10 minute intervals per foursome is 174 rounds.
- The average daily rounds of golf played at selected golf courses on Oahu range from about 137 rounds to 247 rounds, as shown in Exhibit VI-L.

A limited number of rounds could be available for private golf club members while still accommodating community-generated play. The rounds available for golf club membership after accommodating O'oma II on-property and other public play is projected to stabilize at 40 rounds per day or about 15,000 annual rounds by 2005, as shown in Exhibit VI-M.

- Based on 200 rounds per day, the annual capacity at the O'oma II golf course is projected to be 73,000 rounds.
- The bulk of available resort play could be expected to be taken up by community guests. About 7 to 8 rounds per day are expected to be played by community residents.
- A total of 50 rounds per day is expected to be reserved for daily fee play by island residents and others from outside of the O'oma II community.

Exhibit VI-J

KAHALA CAPITAL CORPORATION

Golf Rounds Played Per 100 Hotel Guests at Selected Resort Golf Courses in Hawaii

1989

	Estimated daily hotel population(1)	Rounds per 100 guests
Oahu:		
Makaha	261	13.1
Turtle Bay	748	5.6
Maui:		
Kapalua	317	14.0
Wailea	1,401	4.8
Hawaii - Waikoloa Beach	696	4.5
Average		8.4

(1) Calculated based on total hotel units, average occupancy rates and average number of guests per unit.

Source: Estimated based on discussions with representatives of the respective courses.

Exhibit VI-K

KAHALA CAPITAL CORPORATION

Projected Average Daily Demand for Golf Course Rounds and Public Play

1996 to 2010

	1996	2000	2005	2010
On-property demand:				
Guests:				
Average daily population(1)	814	967	1,131	1,131
Rounds per 100(2)	9	9	9	9
Average daily rounds	78	87	102	102
Condominium residents:				
Average daily population(1)	92	92	92	92
Rounds per 100(3)	6	6	6	6
Average daily rounds	6	6	6	6
Single-family residents:				
Average daily population(1)	-	36	69	86
Rounds per 100(3)	-	2	2	2
Average daily rounds	-	1	1	2
On-property resident play	6	7	7	8
Daily on-property golf demand (rounded)	80	90	110	110
Public play - allowance for public play	50	50	50	50
Total on-property and public play	130	140	160	160

(1) As shown in Exhibit VI-I.

(2) Estimate based on rounds of play at comparable communities, as shown in Exhibit VI-J.

(3) Estimated at 15 annual rounds per 100 condominium and single-family units based on rounds of play at selected resort communities.

Exhibit VI-L

KAHALA CAPITAL CORPORATION

Average Rounds of Golf at
Selected Oahu Golf Courses

1990

	Average annual	Average daily
Private country cluhbs:		
Honolulu Country Club	78,000	213
Waialae Country Club	73,000	200
Oahu Country Club	50,000	137
Mid-Pacific Country Club	66,000	180
Average	66,750	182
Resort courses:		
Turtle Bay Country Club	64,575	177
Sheraton Makaha Resort and Country Club	50,000	137
Average	57,300	157
Other daily-fee courses:		
Hawaii Kai Championship Golf Course	90,000	247
Pearl Country Club	79,000	216
Makaha Valley	75,000	205
Average	81,300	223

Source: Based on interviews with representatives of the respective projects.

Exhibit VI-M

KAHALA CAPITAL CORPORATION

Projected Average Daily and Annual Golf Rounds
O'oma II Community

1996 to 2010

	1996		2000		2005		2010	
	Daily	Annual	Daily	Annual	Daily	Annual	Daily	Annual
Available rounds of golf	200	73,000	200	73,000	200	73,000	200	73,000
Projected guest demand(1)	73	26,600	87	31,800	102	37,200	102	37,200
Projected resident demand(1)	6	2,200	7	2,600	7	2,600	8	2,900
Allowance for public play	50	18,200	50	18,200	50	18,200	50	18,200
Remaining rounds available for members (rounded)	71	26,000	56	20,400	41	15,000	40	14,700

(1) As shown in Exhibit VI-K.

ESTIMATED MEMBERSHIP STRUCTURE AT THE O'OMA II GOLF COURSE

This section presents the number of golf memberships that can be offered in the O'oma II golf club. A recommended pricing structure is also discussed.

Projected Number of Memberships

Approximately 300 private memberships could be offered in the O'oma II golf club supported by the following market conditions:

- The number of golf rounds available for members after accommodating all other on-property and regional play could represent an average of about 40 rounds per day distributed unevenly throughout the year.
- The 677 international members at the Honolulu International Country Club generate approximately 74 rounds per day.
- International members will most likely not play every month allowing solicitation of more memberships than available member daily rounds.
- Most of the international member play will tend to be seasonal and concentrated during four periods throughout the year.

During the peak visitation periods for Japanese members, scarcity in tee times could be alleviated through:

- Reservations policies favoring members.
- Simultaneous tee-offs at the 1st and 10th golf holes.
- Reduction in the intervals between tee-offs, such as from 9 minute intervals to 8 minute intervals, permitting greater overall play.

Membership Pricing

Both international and domestic memberships can reasonably be offered at 5 million yen per membership or about $36,000 assuming an exchange rate of 140 yen to $1 U. S. Corporate memberships can reasonably be offered at 10 million yen per membership or about $72,000. This pricing structure is supported by the following market factors:

- Memberships in island of Hawaii country clubs range from 2.3 million yen at the Volcano Golf and Country Club to 10 million yen at the Kona and Waimea Country Clubs, as shown previously in Exhibit VI-D.
- The O'oma II community facilities offer far more amenities and attractions than other island of Hawaii country clubs. However, the location of the O'oma II community in close proximity to the airport and the possibility of a nuisance factor caused by aircraft noise would position the playing conditions below the Kona and Waimea Country Clubs.
- Other planned Oahu golf clubs, including Ewa Beach International Golf Club and Ocean Resort Club, are soliciting memberships at 5 to 10 million yen. Oahu is a more popular resort destination for Japanese than the island of Hawaii.

Projected Green and Cart Fees

Green and cart fees for the O'oma II golf course could be projected at an average $55 per round for community guests, residents and members. Fees for non-community players could be reasonably projected at $80 per round during the peak season and $60 per round during the low season. Fees for kamaaina players could be projected at $50 per round. The following market conditions support this fee structure:

- Green and cart fees for resort courses on the island of Hawaii averaged $58 per round for resort guests and residents, as previously shown in Exhibit VI-C.
- Fees averaged $98 for non-resort players and $74 per round for non-resort Hawaii residents.
- Although many of the selected resort golf courses on the island of Hawaii charge higher green and cart fees for resort players, these are designer - golf courses in well-established luxury resorts.

VII - RETAIL MARKET ASSESSMENT

This chapter projects market support for retail development at the O'oma II ocean science and recreation community. Market segments are identified for on-property guests and residents and for general west Hawaii regional visitors and ocean science center and water recreation park patrons. Future support for commercial space is estimated based on the growth of these markets at the community, for facilities located in both the hotel and in a planned free-standing shopping center.

RETAIL DEVELOPMENT OVERVIEW

Support for retail development at O'oma II would be generated from on-site population as well as by those attracted to the community by the ocean science center and water recreation park. Because of the large number of visitors included in the projected daily on-site population, resort shopping centers are considered comparable to planned retail facilities at O'oma II.

The strength of Hawaii's visitor economy and the growth of self-contained visitor destination areas have contributed to the emergence of specialized retail development catering to visitors, in the form of the visitor shopping center. This section reviews selected visitor shopping centers in terms of their physical characteristics, relationship to their resort projects and tenant mix.

Shopping centers were selected for review based on comparability to the planned O'oma II retail center in:

- Relative size of on-property market
- Central location within a larger resort area
- Reliance on visitors and resort residents as primary market segments

Two of the selected projects, Wailea Shopping Village and The Shops at Kapalua, are situated on the island of Maui. Two Kauai centers, Kiahuna Shopping Village and Princeville Shopping Center are also reviewed, along with the Keauhou Shopping Village on the island of Hawaii.

Relationship to Resort Development

Comparable resort centers in Hawaii range in size from about 22,000 gross leasable square feet to about 76,000 square feet. The lower figure is for The Shops, which serves a limited and exclusive market at Kapalua Resort; the higher figure is for the Keauhou Shopping Village which is the primary retail center for both a resort and a residential community.

Exhibit VII-A summarizes selected Hawaii visitor retail centers in relation to the regional visitor accommodations inventory that support them. At the surveyed resorts, commercial space represents between about 16 and 59 square feet per visitor unit.

Exhibit VII-A

KAHALA CAPITAL CORPORATION

Shopping Center Retail Space at Selected Hawaii Resort Areas

1990

Resort shopping area	Resort area visitor units	Commercial space (square feet)	Commercial space per visitor unit	Comments
Wailea Shopping Village (Wailea, Maui)	1,261 hotel 711 condominium 1,972 total	31,000	15.7	Presently underserved; Kihei area provides much of the retail needs for the resort. Expansion plans are prepared for additional 40,000 to 60,000 square feet by 1994.
The Shops (Kapalua, Maui)	194 Hotel 528 condominium 722 total	22,000	30.5	Underutilized; small shopping complex with little roadside visibility.
Keauhou Shopping Village (Keauhou, Hawaii)	1,286 hotel 861 condominium 2,147 total	75,600	35.2	Keauhou is also serviced by other retail establishments in Kona expansion planned to about 250,000 square feet.
Kiahuna Shopping Village (Poipu, Kauai)	1,023 hotel 1,098 condominium 2,121 total	35,000	16.5	Serves entire Poipu area.
Princeville Shopping Center (Princeville, Kauai)	300 hotel 826 condominium 1,126 total	66,000	58.6	Highly visible along main highway. Serves north shore resident population as well as visitors. Phase II construction of additional 100,000 square feet to begin in 1991.

Source: Discussions with shopping center management representatives.

Many of the differences in retail space per visitor unit among the neighbor island centers can be explained in terms of competition with non-resort commercial sites, the degree of off-property commercial patronage, and long-term expansion plans. Wailea Shopping Village shares resort visitor retail spending with strip centers in nearby Kihei. The growth of new hotels at Wailea is expected to support expansion of the Wailea commercial center to more than double its present size by 1994.

Physical Characteristics

The selected shopping centers were reviewed with respect to physical characteristics such as site area, gross leasable area, floor area ratios, parking, architectural themes and building types. A summary of physical characteristics is shown in Exhibit VII-B. Principal findings are:

- Site areas vary from 1.6 acres for The Shops at Kapalua to 10.5 acres for the Wailea Shopping Village.
- Gross leasable areas range from The Shops' 22,000 square feet to about 76,000 square feet at Keauhou Shopping Village.
- Floor area ratio is defined as the relationship of gross leasable area to total site area. Floor area ratios at typical neighborhood shopping centers range from .2 to .25, or buildings representing 20% to 25% of site area. All but one of the five centers reviewed have floor area ratios in the same general range, between .10 and .31. The site of the Wailea Shopping Village, which has a .069 floor area ratio, includes the necessary acreage to more than double its current leasable area.
- Architectural themes generally relate to the themes of the resorts where the selected shopping centers have been developed. Wailea Shopping Village has a Hawaiian resort style, with wood construction and ample open air and view orientations. Keauhou Shopping Village resembles a high-quality suburban neighborhood center, while the Princeville center maintains a rustic theme in keeping with Kauai's north shore.
- Building construction is typically single-story or low-rise development in separate buildings. Second floor tenants are often office, rather than retail businesses; however, second floor locations are sought after by restaurants desiring superior view orientations.

Tenant and Market Mix

Tenants at the selected resort shopping centers tend to be oriented toward visitor purchases, although Keauhou Shopping Center also caters to resort and neighboring community residents, with its large supermarket anchor. Apparel, gift, craft or jewelry store and restaurant uses generally represent 85% to 95% of total retail space. Drug and sundries stores are present in each of the centers, but represent only a small portion of total retail space.

Exhibit VII-B

KAHALA CAPITAL CORPORATION

Description of Surveyed Hawaii Resort Shopping Centers

1990

	Year completed	Site area (acres)	Gross leasable area (square feet) Retail	Office	Total	Floor area ratio(1)	Number of shops Retail	Office	Total	Parking space	Parking ratio(2)	Building description
Wailea Shopping Village	1977	10.5	26,500	4,500	31,000	.07	24	8	32	183	5.9	One story plus mezzanine, wood frame with stucco siding. Luxury resort style.
The Shops at Kapalua	1979	1.6	22,152	-	22,152	.31	20	-	20	145	6.6	One two-story concrete building with parking underneath.
Kiahuna Shopping Center	1985	8.0	35,000	-	35,000	.10	36	-	36	N/A	N/A	Five one-story concrete buildings, with kiosks.
Princeville Shopping Center	1978	5.5	52,000	14,000	66,000	.28	19	15	34	204	3.0	Two-story wood frame buildings in plantation style.
Keauhou Shopping Village	1985	7.5	61,200	14,400	75,600	.23	22	15	37	387	5.1	Six one-story buildings and one two-story office building. Freestanding supermarket.

N/A Not available.

(1) Gross leasable area as a percent of total site area.
(2) Parking spaces per 1,000 square feet of gross leasable area.

Source: Discussions with shopping center management and International Council of Shopping Centers, Hawaii Shopping Center Directory, 1989.

Office tenants are present in three of the five surveyed shopping centers and represent from 14% to 21% of total leasable space. Office tenants are geared to serve both the visitor and residential market.

WEST HAWAII COMMERCIAL CENTER REVIEW

Visitors represent an important market for retail facilities outside of resorts, as well as for resort shopping centers. This section describes existing and planned commercial centers in the west Hawaii region.

Existing Retail Centers

Most of the region's existing retail space is located in Kailua-Kona village and/or in surrounding areas of North Kona, as shown in Exhibit VII-C. This space consists of a variety of neighborhood, community and specialty centers that cater to residents and visitors. Kailua-Kona village also includes the majority of visitor-oriented retail areas, with about 295,000 square feet. The South Kohala resort areas only have about 33,000 square feet, which would primarily serve resort guests.

The larger and most resident-oriented centers in North Kona include the 87,500 square foot Lanihau Center and the 83,700 square foot Kona Coast Shopping Center. Both centers serve visitors as well as residents. Tour buses frequently stop at Lanihau and visitors purchase items like macadamia nuts, golf equipment and accessories.

The largest resident-oriented centers in South Kohala are the fully-occupied Parker Ranch Shopping Center and the new Waimea Center in Waimea. The other Waimea centers are significantly smaller at less than 20,000 square feet and are more visitor-oriented, offering several dining facilities. The Hale Kea Ranch in Waimea is visitor-oriented, consisting of a restaurant, open areas for meetings, and a variety of small shops.

Planned Retail Centers

About 850,000 square feet of retail development is planned in North Kona and South Kohala, as shown in Exhibit VII-D. The planned 260,000 square foot addition to Lanihau Center will establish it as the first regional shop- ping center in west Hawaii. Another major center consisting of 245,000 square feet is planned for the Keauhou area. Most of the other planned centers will be located in or near Kailua-Kona village and the Queen Liliuokalani industrial area. Exhibit VII-D indicates shopping centers which are being planned on individual sites. In addition, commercial centers are planned for inclusion at several planned resort or residential communities, including:

- Keauhou resort
- Kohaniki resort
- Regent Beach resort
- Mauna Lani resort
- Kealakehe planned community

Exhibit VII-C

KAHALA CAPITAL CORPORATION

Existing Commercial Center Development in North Kona and South Kohala Market Area by Commercial Node

1990

Commercial node/project name	Year of completion	Gross leasable square feet
Queen Kaahumanu Highway and Palani Road:		
Kona Coast Shopping center	1975	83,700
Lanihau Center	1987	87,500
Subtotal		171,200
Kailua-Kona Village:		
Kim Chong Building(1)	1949	2,800
Kailua Bay Inn Shopping Plaza(1)	1957	15,500
Kona Banyan Court(1)	1962	4,500
Seaside Mall(1)	1971	10,200
Akona Kai Mall(1)	1971	8,900
Foo Building(1)	1972	2,400
North Kona Shopping Center	1973	38,700
Plaza Shopping Arcade(1)	1973	8,800
Kona Marketplace(1)	1974	50,000
Hotel King Kamehameha(1)	1975	32,000
Emma's Marketplace	1975	5,300
Kona Inn Shopping Village(1)	1978	60,000
Kamehameha Square	1985	14,500
Kona Center	1988	18,000
Waterfront Row(1)	1989	23,300
Subtotal		294,900
Other Alii Drive:		
Plantation Building	N/A	1,700
Kona Magic Sands(2)	1966	2,600
Casa De Emdeko	1970	8,600
Kona Hilton Hotel	1970	7,500
Kona Bali Kai(3)	1977	600
Subtotal		21,000
Keauhou Resort(4) - Keauhou Shopping Village	1985	76,000
Other:		
Kaahumanu Plaza(5)	1971	21,000
Sunset Shopping Plaza(6)	1987	10,000
Subtotal		31,000

(Continued)

Exhibit VII-C, Cont.

KAHALA CAPITAL CORPORATION

Existing Commercial Center Development in
North Kona and South Kohala
Market Area by Commercial Node, Continued

Commercial node/project name	Year of completion	Gross leasable square feet
South Kohala:		
Mauna Kea Resort retail	1965	6,600
Mauna Lani Resort retail	1983	6,300
Waikoloa Beach Resort retail	1988	20,000
Subtotal		32,900
Waikoloa Village - Waikoloa Highlands Center(7)	1990	70,000
Waimea:		
Parker Ranch Shopping Center	1968	57,000
Kamuela Country Plaza	1983	3,500
Puukapu Commercial Center	1985	19,000
Mauna Kea Center	1986	7,000
Parker Square	1987	13,000
Opelo Plaza	1988	14,100
Holomua Center	1988	14,400
Waimea Town Plaza	1988	12,200
Hale Kea Ranch (shops and restaurant)	1989	13,000
Waimea Center	1989	75,000
Kamuela Business Center - Phase I	1989	20,000
Subtotal		248,200
Total		945,200

(1) On or near visitor-oriented Alii Drive frontage.
(2) Commercial space consists of one restaurant.
(3) Commercial space consists of one convenience store.
(4) Excluding retail areas in hotels.
(5) Located in Kona light industrial area.
(6) Located on Kuakini Highway near Kona Sea View subdivision.
(7) Leasing.

Sources: International Council of Shopping Centers, Hawaii Shopping Center Directory 1989, and discussions with leasing and management companies.

Exhibit VII-D

KAHALA CAPITAL CORPORATION

Planned Retail Development in South Kohala and North Kona

1990

Project	Location	Projected opening	Gross leasable square feet	Projected rental rates(1)	Developer	Comments
Coconut Grove Marketplace	Alii Drive	1990	6,600	2.50 - 3.75	Mel Shapiro	First floor retail and convenience store. Second floor open air, ocean view restaurant. Completed, but no operator.
Alii Sunset Plaza	Alii Drive	1990	N/A	N/A	N/A	New Hilton, no plans available yet.
Old Kailua Town	Alii Drive	N/A	50,000	N/A	Bryant L. Morris	Planned retail, restaurant, office. Located near Hilton, adjacent placed to Alii Sunset Plaza. No further plans available at this time.
Kopiko Plaza	Kailua Town	1990	34,155	2.50 - 3.00	Elliot Megdal & Associates	N/A.
Kailua Bay Village	Kailua Town	1991	53,000	N/A	Bryant L. Morris	Restaurants, clothing stores, specialty shops.
Gold Coast Plaza	Kailua Town	N/A	N/A	N/A	N/A	Seeking County zoning.
Kona Coast Shopping Center (expansion)	Kailua Town	N/A	110,000	2.50 - 3.50	Bedford Properties	Supermarket, restaurant, retail.
Lanihau Center Phase II (2)	Kailua Town	1992	260,000	3.00 - 3.50	Joint venture: Holomua Corporation, Graham, Russell, & Murata	Negotiating with Liberty House, Woolworth's and Sears.
Goldcoast Warehouse 3 and 4	Industrial(3)	N/A	N/A	.85 - 1.00	Shidler Group	Renovation, showroom space.
Kaahumanu Plaza 2	Industrial(3)	N/A	32,000	N/A	Jim Casper & Associates	Available. 90% leased.
Palm Terrace Phase II	Industrial(3)	N/A	N/A	N/A	N/A	Industrial/retail.
Luhia Center Phase II	Industrial(3)	N/A	N/A	N/A	N/A	Industrial/retail.
Kings' Shops at Waikoloa	Waikoloa Beach Resort	Late 1991	57,900	N/A	Waikoloa Development Company	N/A
Governor Kuakini Shopping Center	Keauhou	1992 to 1998	245,000	N/A	Dillingham Partners	Three phases: 1992, 1995, 1998.
Total			848,655			

N/A Not available.

(1) 1989 dollars.
(2) Construction to be initiated when an anchor tenant has been obtained.

Source: Based on interviews with shopping center managers, commercial brokers and published information.

The large number of planned retail projects reflects existing and anticipated resident and visitor population growth.

RETAIL MARKET ASSESSMENT

This section assesses market support for retail and other commercial uses at the O'oma II community. Potential on-site retail spending is estimated based on primary and secondary target markets. Amount of projected spending to be captured at the site is calculated, with allocation of commercial space for hotel shops and the ocean science center and water recreation park. Supportable commercial space at the shopping center is assessed, along with the amount of land needed to develop the facility under the recommended development concept.

Shopping Center Development Concept

The shopping center planned for the O'oma II community could be sited between the hotel and the ocean science center and water recreation park, near the larger water features designed for the property's makai area. . Characteristics of the center would include:

- Function as a gathering place for on-property visitors, residents and the large numbers of regional visitors anticipated to travel to the resort's marine theme attraction.
- Low-rise building character with relatively low development intensity due to the waterside location.
- Orientation to man-made water features on the property, including frontage on the lagoon.

Target Markets

Target markets for the O'oma II center include on-property guests and residents, who constitute the primary market, and secondary market elements consisting of visitors accommodated within the region. Target markets include the following:

- Visitors staying in the O'oma II hotel, inn, condominium units and single- family residences.
- On-property residents, both full- and part-time, living in condominium units and single-family residences.
- Patrons of the ocean science center and water recreation park.
- The general population of visitors to the west Hawaii region.

On-Property Visitor Retail Spending

Retail spending for projected guests at O'oma II accommodations is estimated in Exhibit VII-E. As shown in the exhibit:

KAHALA CAPITAL CORPORATION

Projected Annual Visitor Retail Spending
O'oma II Community

1996 to 2010

(in millions of 1990 dollars)

	1996	2000	2005	2010
Hotel and inn visitors:				
Average daily population(1)	744	859	973	973
Percentage westbound visitors(2)	90%	85%	85%	85%
Total westbound visitors	670	730	830	830
Average daily spending(3)	$ 66	66	66	66
Total daily westbound hotel and inn visitor spending	$ 44,220	48,180	54,780	54,780
Percentage eastbound visitors	10%	15%	15%	15%
Total eastbound visitors	70	130	140	140
Average daily spending(4)	$ 236	236	236	236
Total daily westbound hotel and inn visitor spending	$ 16,520	30,680	33,040	33,040
Total daily hotel and inn visitor spending	$ 60,740	78,860	87,820	87,820
Condominium and single-family visitors - average daily population(1)	69	108	158	157
Average daily spending(5)	$ 66	74	76	76
Total daily condominium and single-family guest spending	$ 4,610	8,000	11,920	11,890
Total daily visitor spending	$ 65,350	86,860	99,740	99,710
Annual visitor spending(4)	$ 23.9	31.7	36.4	36.4

(1) From Exhibit VI-G.

(2) From Chapter VIII.

(3) From Hawaii Visitors Bureau, Visitor Expenditure Survey, 1989; adjusted to 1990 dollars with 6% inflation factor.

(4) From Exhibit II-H, based on historical difference between westbound and eastbound visitor spending on retail center items, adjusted to 1990 dollars.

(5) Based on average of westbound and eastbound daily visitor retail spending, adjusted for share of visitor population.

- Visitor population is estimated from the market assessment for the single-family residential lots, resort condominiums and hotel as shown in Chapters V, VI, and VIII, respectively.

- Visitor retail spending is estimated using Hawaii Visitors Bureau figures for retail-related expenditures, as follows:

  - Spending for gifts, dining and other related items is estimated for 1989, and adjusted to 1990 dollars with a 6% inflation factor.

  - In 1990 dollars, retail spending is estimated at $66 per day for each westbound visitor and $236 per day for each eastbound visitor.

  - Based on projected trends in visitor arrivals to the island of Hawaii shown in Exhibit IV-F, the proportion of westbound visitors staying at the O'oma II visitor accommodations is established as follows:

    -- 90% westbound in 1996, the first year of hotel operation.
    -- 85% westbound in 2000 and in succeeding years.

  - While visitor spending is estimated separately for westbound and eastbound hotel guests, a composite figure is shown for guests staying in condominium and single-family unit accommodations. For this reason:

    -- As the proportion of eastbound guests increases, the average daily retail spending figure increases from $66 per visitor in 1996 to $76 in 2005 and succeeding years.

  - Retail spending by O'oma II on-property guests is projected at the following levels:

    -- Almost $24 million in 1996
    -- More than $31 million in 2000
    -- More than $36 million in 2010

On-Property Resident Retail Spending

Exhibit VII-F estimates retail expenditures of full-time and part-time residents of the O'oma II community. The exhibit indicates that more than 80% of resident retail spending could be attributed to full-time residents. Resident retail spending is estimated as follows:

- Spending could amount to about $1.2 million in 1996.

- With growth in single-family residence household population, resident spending could increase to $1.7 million in 2000 and $2.5 million by 2010.

Exhibit VII-F

KAHALA CAPITAL CORPORATION

Projected Annual Resident Retail Spending
O'oma II Community

1996 to 2010

(in millions of 1990 dollars)

	1996	2000	2005	2010
Full-time condominium residents:				
Households in residence(1)	31	31	31	31
Average annual income	$ 100,000	100,000	100,000	100,000
Share spent on retail	30%	30%	30%	30%
Annual retail spending	$ 0.9	0.9	0.9	0.9
Part-time condominium residents:				
Households in residence(1)	7	7	7	7
Average annual income	$ 120,000	120,000	120,000	120,000
Share spent on retail	30%	30%	30%	30%
Annual retail spending	$ 0.2	0.2	0.2	0.2
Full-time single-family residents:				
Households in residence(1)	-	14	26	33
Average annual income	$ 120,000	120,000	120,000	120,000
Share spent on retail	30%	30%	30%	30%
Annual retail spending	$ -	0.5	0.9	1.2
Part-time single-family residents:				
Households in residence(1)	-	1	3	3
Average annual income	$ 150,000	150,000	150,000	150,000
Share spent on retail	30%	30%	30%	30%
Annual retail spending	$ -	0.1	0.1	0.2
Total annual community resident retail spending	$ 1.2	1.7	2.2	2.5

(1) From Exhibit VI-H.

Off-Property Visitor Spending

Visitors housed elsewhere on the island could be an important source of secondary market support for O'oma II retail facilities. Target groups include:

- The general visitor population, who could be attracted by golf, hotel, professional meetings center and other facilities at the site, or could constitute drive-in business due to the property's central location with respect to the airport and Kailua-Kona village.

- Attendees at the ocean science center and water recreation park, who could patronize on-property shops and restaurants as part of their visit.

Projected off-property visitor retail spending at the O'oma II resort is summarized in Exhibit VII-G. Estimates are derived as follows:

- General off-property visitor spending is estimated on the basis of:
  - Total visitor arrivals are shown as projected previously in Exhibit II-B.
  - An average of 5% of island visitors are assumed to go to O'oma II retail facilities.
  - Visitor retail-related expenditures are based on Hawaii Visitors Bureau estimates, adjusted as shown previously in Exhibit VII-E.
  - Resort retail facilities are estimated to capture about 10% of average daily retail-related expenditures.
  - Off-property visitor spending at O'oma II is projected to reach the following levels:
    - -- $0.5 million in 1996
    - -- $0.7 million in 2000
    - -- $1.2 million in 2010

- Spending by marine attraction visitors at O'oma II retail outlets is estimated as follows:
  - Projected attendance at the ocean science center and water recreation park is estimated as shown previously in Exhibit III-E.
  - About 50% of marine attraction visitors are projected to shop, entertain or eat, or use services of O'oma retail facili- ties.
  - Visitor retail-related expenditures are based on Hawaii Visitors Bureau estimates, adjusted as shown previously in Exhibit VII-E.
  - O'oma II retail facilities are estimated to capture about 15% of average daily retail-related expenditures.

Exhibit VII-G

KAHALA CAPITAL CORPORATION

Projected Annual Retail Expenditures at
O'oma II Commercial Facilities from Off-Property Visitors

1996 to 2010

(in millions of 1990 dollars)

	1996	2000	2005	2010
Island visitors:				
Visitors to island(1)	1.5	2.0	2.6	3.2
Percentage visiting O'oma II	5%	5%	5%	5%
Annual visitor days	75,850	97,800	127,750	159,750
Daily retail expenditures	$ 66	74	76	76
Estimated retail capture rate	10%	10%	10%	10%
Subtotal	$ 0.5	0.7	1.0	1.2
Ocean science center visitors:				
Park visitors(2)	400,000	500,000	578,000	626,000
Percentage visiting center	50%	50%	50%	50%
Daily retail expenditures	$ 66	74	76	76
Estimated retail capture rate	15%	15%	15%	15%
Subtotal	$ 2.0	2.8	3.3	3.5
Total annual expenditures from off-property visitors	$ 2.5	3.5	4.2	4.8

(1) 2000 to 2010 estimates from Exhibit II-B; 1996 estimate interpolated from Exhibit II-B; in millions, less ocean science center visitors.

(2) From Exhibit III-E.

- Marine attraction visitor spending at O'oma II is projected to reach the following levels:
  - -- $2.0 million in 1996
  - -- $2.8 million in 2000
  - -- $3.5 million in 2010

- Combined retail spending at O'oma II by off-property visitor market segments is projected as follows:
  - $2.5 million in 1996
  - $3.5 million in 2000
  - $4.8 million in 2010

Total Spending at Property Retail Facilities

Aggregate retail expenditures at O'oma II community shopping facilities is projected by applying rates estimated to represent on-property spending to the retail expenditures of each of the market segments, as was done previously for off-property visitors. The resulting total is used to assess potential market support.

Projected retail expenditures at the site are estimated in Exhibit VII-H. As shown in the exhibit:

- A different on-property capture rate is used for each market segment, reflecting differences in shopping habits, mobility and retail needs among the segments. On-property capture rates are as follows:
  - On-property visitors -- 30% of retail spending on-property
  - Part-time residents -- 25%
  - Full-time residents -- 20%
  - Marine theme attraction visitors -- 15%
  - General off-property visitors -- 10%

- Total projected annual retail sales at the site are estimated at:
  - $10 million in 1996
  - $13.4 million in 2000
  - $16.2 million in 2010

Retail Spending Distribution by Market Segment

Distribution of retail spending by market segment is shown in Exhibit VII-I. On-property visitors are expected to constitute the major source of market support, as shown in the exhibit:

- On-property visitors could constitute more than 70% of retail sales in 1996. The on-property visitor share would decline to about 67% by 2010, due to increasing regional visitor counts and growing attendance at the marine theme attraction.

Exhibit VII-H

KAHALA CAPITAL CORPORATION

Projected Retail Expenditures at O'oma II Community

1996 to 2010

(in millions of 1990 dollars)

	1996	2000	2005	2010
On-property visitors:				
Annual retail spending(1)	$ 23.9	31.7	36.4	36.4
Capture rate	30%	30%	30%	30%
Projected annual sales	$ 7.2	9.5	10.9	10.9
Full-time residents:				
Annual retail spending(2)	$ 0.9	1.4	1.9	2.1
Capture rate	20%	20%	20%	20%
Projected annual sales	$ 0.2	0.3	0.4	0.4
Part-time residents:				
Annual retail spending(2)	$ 0.2	0.3	0.4	0.4
Capture rate	25%	25%	25%	25%
Projected annual sales	$ 0.1	0.1	0.1	0.1
Subtotal projected on-property visitor and resident annual sales	$ 7.5	9.9	11.4	11.4
Off-property visitors - regional visitors(3)	$ 0.5	0.7	1.0	1.2
Ocean science center and water recreation park visitors(3)	$ 2.0	2.8	3.3	3.5
Subtotal	2.5	3.5	4.2	4.8
Total projected annual sales	$ 10.0	13.4	15.7	16.2

(1) From Exhibit VII-E.
(2) From Exhibit VII-F.
(3) From Exhibit VIII-G.

Exhibit VII-I

KAHALA CAPITAL CORPORATION

Share of Projected Retail Expenditures at O'oma II Community by Market Segment

1996 to 2010

	1996	2000	2005	2010
Percentage of spending by(1):				
On-property visitors	72%	71%	69%	67%
Residents	3	3	3	3
Regional visitors	5	6	6	7
Ocean science center visitors	20	20	22	23
Total	100%	100%	100%	100%

(1) From Exhibit VII-H.

- Ocean science center visitors could represent about 20% of retail spending in 1996, rising to 23% by 2010.
- Off-property visitors could represent about 5% of retail spending in 1996, increasing to more than 7% by 2010.
- On-property residents could represent less than 3% of retail spending in 1996, and is anticipated to increase only slightly in relative share.

Total Supportable Commercial Area

Total retail area required at the O'oma II community is estimated based on projected retail sales and a target annual sales level of $300 per square foot. Allowance is also made for nonretail space, such as office and service areas, normally provided in shopping centers.

Exhibit VII-J estimates the total retail area supported by projected annual sales levels at the resort. As shown in the exhibit:

- About 38,000 gross leasable square feet of commercial area could be supported in 1996.
- Supportable commercial area could increase to:
    - About 51,000 square feet in 2000
    - More than 62,000 square feet by 2010

Shopping Center Market Assessment

Exhibit VII-J, as shown previously, indicated total commercial area with potential market support at the community. Under the preliminary development plan for O'oma II, commercial area could be developed in three locations:

- Shops situated within the hotel
- Retail housed at the ocean science center and water recreation park site
- Free-standing shopping center

Market support for the shopping center is estimated by subtracting space for the hotel shops and marine attraction retail space from total on-property commercial market support. The residual is estimated support for the shopping center. These projections are shown in Exhibit VII-K, and calculated as follows:

- Hotel shop space is allocated at 15 gross leasable square feet per planned hotel room, based on comparable first-class neighbor island hotels.
- Marine attraction retail space is allocated at 2,000 gross leasable square feet in 1996, increasing to a total of 3,000 square feet in 2000 and succeeding years.
- Remaining space is allocated to the retail center, which could encompass:
    - About 28,000 square feet in 1996
    - More than 40,000 square feet in 2000
    - Almost 51,000 square feet by 2010

Exhibit VII-J

KAHALA CAPITAL CORPORATION

Projected Supportable Commercial Area
at O'oma II Community

1996 to 2010

	1996	2000	2005	2010
Projected annual sales(1)	$ 10.0	13.4	15.7	16.2
Annual retail sales per gross leasable square foot	$ 300	300	300	300
Projected supportable total gross leasable retail area	33,300	44,700	52,300	54,000
Ratio of office and other uses to retail area(2)	15%	15%	15%	15%
Supportable office and other use area	5,000	6,700	7,800	8,100
Total supportable commercial area at community	38,300	51,400	60,100	62,100

(1) From Exhibit VII-H; in millions of 1990 dollars.
(2) Office, service and related nonretail space.

Exhibit VII-K

KAHALA CAPITAL CORPORATION

Projected Distribution of Commercial Area
at O'oma II Community

1996 to 2010

	1996	2000	2005	2010
Total supportable commercial area(1)	38,300	51,400	60,100	62,100
Nonretail center commercial area:				
Hotel shops(2)	8,250	8,250	8,250	8,250
Ocean science center(3)	2,000	3,000	3,000	3,000
Subtotal	10,250	11,250	11,250	11,250
Retail center commercial area	28,050	40,150	48,850	50,850
Floor area ratio(4)	0.1	0.1	0.1	0.1
Required site area (acres)	6	9	11	12

(1) From Exhibit VII-J.
(2) Based on 15 square feet per hotel room.
(3) Based on comparable marine theme attractions.
(4) Commercial space as a percentage of total site area.

- Parcel size for the retail center is estimated on the basis of a floor area ratio of 0.1, considering the water-oriented nature of the center and its lagoon-front location. Land required could be:
  - About 6 acres in 1996
  - About 9 acres in 2000
  - About 12 acres in 2010

VIII - HOTEL MARKET ASSESSMENT

This chapter assesses market support for hotel development within the O'oma II community. Segments in the Hawaii visitor market are described, as well as facilities at selected first-class hotels. Projected supply and demand for visitor accommodations are estimated for the island of Hawaii. Market support for the planned hotel is projected, including occupancy rates and achieved room rates.

VISITOR ACCOMMODATIONS REVIEW

This section describes the O'oma II hotel project and resort classifications based on the type of visitor sought and quality of accommodations offered. This section also discusses trends in Hawaii visitor inventory and reviews the current visitor inventory, occupancy levels and average room rates.

O'oma II Hotel Project Description

The O'oma II community is planned to contain a 550-room first-class hotel with swimming pool and recreational amenities on a site of approximately 21 acres. The hotel could also service and use the professional meetings facility planned at the ocean science center. Hotel development is planned away from the shoreline around a 16-acre man-made lagoon.

Resort Classifications

Successful resort destinations are developed to appeal to certain types of visitors. In general, the breadth of market targeting is in proportion to the size of the resort. Large destination areas such as Maui's Kaanapali Beach Resort can accommodate a number of different market segments; smaller resorts usually focus on particular types of visitors.

Hawaii resorts can generally be classified in three categories, based on the type of visitor sought. An additional market segment, the economy or budget class, is usually served by individual hotels within larger destination areas such as Waikiki, Kailua-Kona or Maui's Napili area. These classifications are shown in Exhibit VIII-A and described as follows:

- Luxury resorts offer the most luxurious accommodations, excellent service and elegant ambiance to the most affluent clientele. These resorts usually have a low development density and feature smaller hotels ranging in size from 200 to 400 rooms. FIT travelers constitute the primary target market for luxury resorts, although high-level meetings can be accommodated.

- Upscale resorts offer a high-activity atmosphere providing high quality accommodations to a less affluent segment than the luxury market. Incentive groups, in which travel is paid for by the employer, are an important target group, along with FIT family travelers. Hotels in upscale resorts range in size from 450 to 1,200 rooms.

Exhibit VIII-A

KAHALA CAPITAL CORPORATION

Resort Classifications

Types of resorts	Characteristics	Examples Resort	Examples Island
Luxury	Offer luxurious accommodations, excellent service, and consistently maintain an elegant ambiance. Service the affluent visitor.	Kapalua Hauna Kea Hauna Lani	Maui Hawaii Hawaii
Upscale	Provide quality services and amenities and serve an upper income market that is just below that served by the luxury resorts. Higher development densities are possible due to the broader guest market.	Ko Olina Wailea Kaanapali Waikoloa Beach	Oahu Maui Maui Hawaii
First-class	Provide above-average accommodations at reasonable rates. Maintain a larger share of group travelers to appeal to the broadest range of guest markets.	Kuilima Makaha Keauhou	Oahu Oahu Hawaii

- First-class resorts offer above-average accommodations at reasonable rates to appeal to the broadest range of visitor markets including FIT, family, package, group and meetings segments. Hotels in first-class resorts generally also provide meeting facilities to attract the group visitor market.

Trends in Hawaii Visitor Inventory

Hawaii's hotel inventory is anticipated to grow substantially in the 1990s. Growth of the luxury-class inventory is the major trend occurring, with:

- Development of new luxury-class destination resorts, especially in South Kohala on the island of Hawaii.
- Greater differentiation of luxury hotels, including high-service, high-activity and retreat properties.
- Increased number of international and U. S. luxury hotel operators represented in the Hawaii market.

Hawaii's hotel inventory has historically consisted mainly of first-class and economy properties. New development, which is mainly oriented at higher market segments, would result in a considerable departure from historic market orientation.

State of Hawaii Visitor Inventory

Approximately 68,000 hotel and condominium units were in the state of Hawaii visitor inventory as of February 1989, as shown in Exhibit VIII-A.

- About 54% of the total visitor units or 36,700 units are currently located on Oahu, primarily in Waikiki. Since 1980, visitor inventory has increased more rapidly on the neighbor islands than on Oahu. Reasons for this trend include:
  - The lack of new developable sites in Waikiki.
  - Development of hotel and condominium projects within master-planned resort areas which offer a full complement of visitor services and amenities in contrast to the stand-alone facilities in Waikiki.
- Total visitor units in the state of Hawaii increased by 2.6% per year since 1970. The county of Maui, which includes the islands of Molokai and Lanai, has the most visitor units next to Oahu.

Island Visitor Unit Inventory

The island of Hawaii had 8,161 visitor units in 1989. This represents 12% of the state's total, as shown in Exhibit VIII-B. The number of units decreased from 8,823 in 1988 due to the conversion of visitor condominium units to residential use and the closing of the Kona Lagoon Hotel for renovations.

Island of Hawaii visitor units have increased an average of 3.7% per year since 1980. High-quality master-planned visitor facility development has occurred in several resort areas on the Kona and Kohala coastlines of the island:

Exhibit VIII-B

KAHALA CAPITAL CORPORATION

Visitor Rooms in the State of Hawaii

1970 to 1989

	Oahu	Hawaii	Maui(1)	Kauai	State
1970	18,449	3,166	2,743	2,565	26,923
1975	25,352	5,348	5,830	3,102	39,632
1980	34,334	5,889	9,701	4,322	54,246
1985	38,600	7,511	14,152	5,656	65,919
1988	37,841	8,823	15,168	7,180	69,012
1989(2)	36,739	8,161	16,028	7,251	68,179
Share of state total:					
1970	68.5%	11.8%	10.2%	9.5%	100.0%
1980	63.3	10.9	17.9	8.0	100.0
1989	53.9	12.0	23.5	10.6	100.0
Compound annual percentage increase - 1980 to 1989	0.8%	3.7%	5.7%	5.9%	2.6%

(1) Includes Molokai and Lanai.
(2) As of February 1989.

Sources: Figures for 1970 to 1984 represent number of visitor units as of February of the year indicated, from Hawaii Visitors Bureau, Annual Research Report, 1984. Hawaii Visitors Bureau, Visitor Plant Inventory, February (annual) since 1985.

- Mauna Kea Resort
- Mauna Lani Resort
- Waikoloa Beach and Village Resorts
- Keauhou Resort

Planned Visitor Inventory

Approximately 8,600 hotel rooms are planned to be added to the island of Hawaii visitor inventory by 2010, as shown in Exhibit VIII-C. For analytical purposes, the number of hotel units in projects planned after 1995 is reduced by 25% in recognition of the fact that zoning maximums generally exceed project densities.

Proposed hotel development is summarized as follows:

- About 4,500 hotel rooms are proposed for development on the island through 1995, increasing the existing inventory by nearly 55%. Most of the development is planned in the North Kona and South Kohala districts.

- Three hotels within new resorts and six within existing resorts are planned. The Ritz-Carlton Mauna Lani in South Kohala will add 540 new luxury hotel rooms in 1990. The Kona Lagoon is under renovation and is planned to reopen with 309 rooms in 1991.

Approximately 9,500 condominium units are planned to be developed on the island by 2010, as shown in Exhibit VIII-D. The total number of condominium units planned after 1995 is also estimated to be about 25% lower than under current maximum zoning densities. An estimated 50% of all condominium units are anticipated to be available to visitors.

- Five condominium projects are currently under construction. Six proposed developments are planned within existing resorts, and three would be located within new master-planned resorts.

- All of the projects, except at Punalu'u resort, are located in North Kona or South Kohala.

Historical Occupancy Rates

The average annual occupancy rate for visitor accommodations in the state was estimated at about 80% for the first six months of 1990, as shown in Exhibit VIII-E. Statewide occupancy rates throughout the 1980s can be summarized as follows:

- The island of Oahu has generally realized the highest occupancy rates of all the Hawaiian Islands.

- Occupancy levels of Maui visitor accommodations have been the second highest in the state next to Oahu.

Occupancy rates on the island of Hawaii have generally been below the statewide average. Occupancy levels have improved in the last decade increasing from 51% in 1980 to 65% in 1990, as shown in Exhibit VIII-F. The upward trend in island of Hawaii occupancy levels is due to the following factors:

KAHALA CAPITAL CORPORATION

Planned Hotel Development on the Island of Hawaii

1989 to 2010

	Location	1989 to 1990	1991 to 1995	1996 to 2000	2001 to 2005	2006 to 2010	Total 1989 to 2010
Under construction - Ritz Carlton Mauna Lani	South Kohala	540	-	-	-	-	540
Under renovation - Kona Lagoon	North Kona	-	309	-	-	-	309
With all land approvals within existing resort(1):							
Waikoloa Beach Resort	South Kohala	-	400	400	400	-	1,200
Mauna Lani Resort	South Kohala	-	-	600	-	-	600
Keauhou Resort	North Kona	-	-	500	500	700	1,700
Kona Village addition	North Kona	-	50	-	-	-	50
Hapuna Beach Hotel	South Kona	-	350	-	-	-	350
Punalu'u	Ka'u	-	425	210	400	-	1,035
Subtotal		-	1,225	1,710	1,300	700	4,935
With all land approvals within new resort(1):							
Kaupulehu	North Kona	-	950	-	-	-	950
Regent Beach Resort	North Kona	-	400	-	-	-	400
Kohanaiki	North Kona	-	1,050	450	-	-	1,500
Subtotal		-	2,400	450	-	-	2,850
Planned total(2)		540	3,934	2,160	1,300	700	8,634
Adjusted total(3)		540	3,934	1,620	975	525	-

(1) County General Plan, County zoning and State Land Use Commission approvals in place.

(2) Numbers represent maximum units proposed, where more specific plans have not been announced.

(3) Total number of units planned after 1995 reduced by 25% given probability that these units will not enter market within forecast time frame or as currently allowed under maximum zoning densities.

Exhibit VIII-C

KAHALA CAPITAL CORPORATION

Planned Resort Condominium Development on the Island of Hawaii

1989 to 2010

	Location	1989 to 1990	1991 to 1995	1996 to 2000	2001 to 2005	2006 to 2010	Total 1989 to 2010(2)
Under construction:							
Villas at Keauhou	North Kona	58	-	-	-	-	58
The Bluffs at Hapuna Beach	South Kohala	67	-	-	-	-	67
Shores at Waikoloa II	South Kohala	172	-	-	-	-	172
Holua at Maunaloa Village	North Kona	-	400	-	-	-	400
The Islands at Mauna Lani	South Kona	-	46	-	-	-	46
Subtotal		297	446	-	-	-	743
With all land approvals within existing resort(1):							
Waikoloa Beach Resort	South Kohala	168	540	800	800	165	2,473
South Kohala Resort	South Kohala	-	-	450	-	-	450
Mauna Lani Resort	South Kohala	-	500	500	600	-	1,600
The Bluffs at Hapuna Beach	South Kohala	-	150	-	-	-	150
Keauhou Resort	North Kona	-	250	350	213	-	813
Punalu'u	Ka'u	-	430	450	490	500	1,870
Subtotal		168	1,870	2,550	2,103	665	7,356
With all land approvals within new resort(1):							
Kaupulehu	North Kona	-	200	200	200	-	600
Regent Beach Resort	North Kona	-	200	-	-	-	200
Kohanaiki	North Kona	-	150	350	200	-	700
Subtotal		-	550	550	400	-	1,500
Planned total(2)		465	2,866	3,100	2,503	665	9,599
Adjusted total(3)		465	2,866	2,325	1,877	499	8,032

(1) County General Plan, County zoning and State Land Use Commission approvals in place.

(2) Numbers represent maximum units proposed, where more specific plans have not been announced.

(3) Total number of units planned after 1995 reduced by 25% given probability that these units will not enter market as currently allowed under maximum zoning densities.

Exhibit VIII-D

Exhibit VIII-E

KAHALA CAPITAL CORPORATION

Occupancy Levels of
Hawaii Visitor Accommodations

1980 to 1990

Location	1980	1985	1989	1990(1)
Waikiki:				
On beach	73.9%	82.9%	87.0%	86.7%
Off beach (with restaurant)	73.2	83.8	88.3	89.1
Off beach (without restaurant)	-	-	86.8	89.6
Total Waikiki(2)	-	-	87.1	88.2
Other Oahu	74.6	82.7	78.6	75.6
Total island of Oahu	72.3	81.9	86.7	87.6
Hilo	34.4	57.8	53.9	61.2
Kona	59.0	58.7	65.4	69.7
Kohala Coast(2)	-	-	61.0	61.9
Total island of Hawaii	51.0	58.5	61.5	64.9
West Maui	74.8	83.2	65.4	71.2
Other Maui	67.4	67.3	66.4	65.1
Kaanapali(2)	-	-	77.5	76.8
Total island of Maui	73.0	78.2	71.5	72.2
East Kauai	75.1	64.1	-	-
South Kauai	52.5	73.5	78.5	75.9
North Kauai(2)			50.5	41.9
Central Kauai(2)	-	-	69.2	68.1
Total island of Kauai	69.6	67.1	70.8	67.9
State total	69.3	77.6	79.4	80.4

(1) For the six-month period ending June 1990. Seasonality could affect full-year results.

(2) New geographical areas effective January 1990; historical data available for 1989 only.

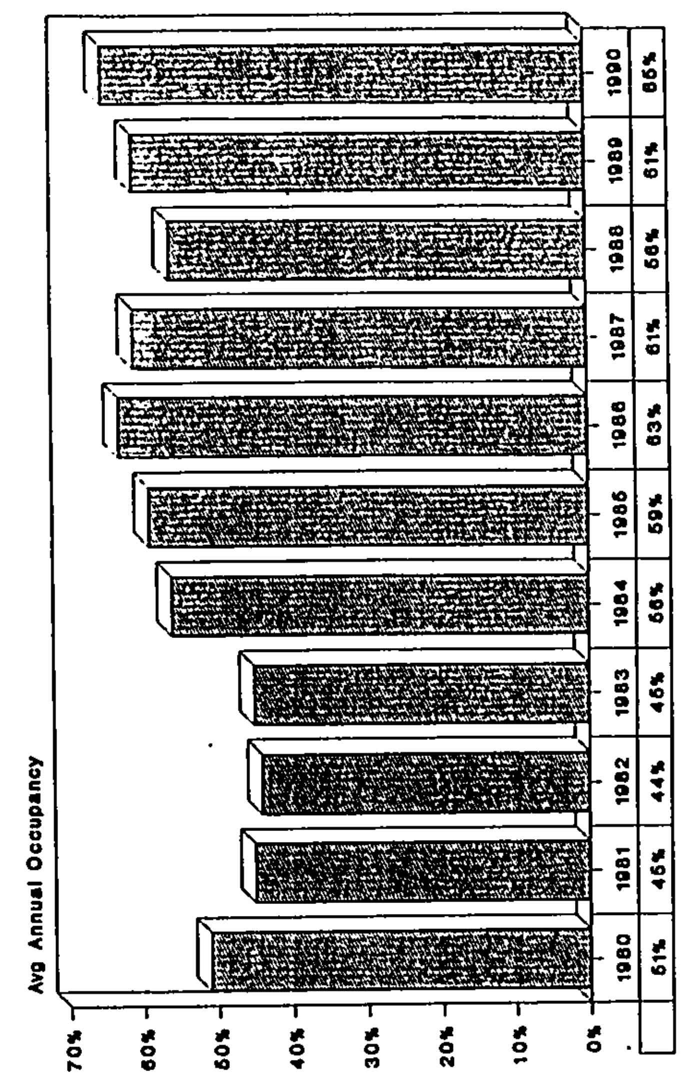
Source: Pannell Kerr Forster, Trends in the Hotel Industry, monthly.

Exhibit VIII-F

KAHALA CAPITAL CORPORATION

Island of Hawaii Visitor Room Occupancy

1980 to 1990



Source: HVB

- Maturation of Waikiki on Oahu as a visitor destination and the resulting increase in popularity of neighbor islands.
- Increasing numbers of repeat visitors to Hawaii looking for new experiences.
- Development of new master-planned resorts offering a variety of facilities and amenities.
- Longer length of stay on the island due to more diverse attractions and activities available.

Average Room Rates

The average statewide room rate increased from $47.37 in 1980 to $105.75 as of June 1990, as shown in Exhibit VIII-G. Room rates vary significantly by island and region. This differential is partly a reflection of the relatively newer visitor plant on the neighbor islands. Maui visitor units achieved the highest island average room rate of $138.04 in the first half of 1990.

The most significant increases in room rates during the last ten years occurred on the island of Hawaii. The average daily room rate of $130 in 1990 is nearly three times higher than the $46 of a decade ago, as shown in Exhibit VIII-H. This upward trend in the average island room rate is due to the completion of several high-quality projects such as the Mauna Lani Bay Hotel and Hyatt Regency Waikoloa in the South Kohala district and more aggressive marketing of the island. Average room rates in the Kohala coast area reached more than $200 in the first half of 1990.

O'OMA II HOTEL MARKET ASSESSMENT

This section assess the market for the planned O'oma II first-class hotel based on projections of island of Hawaii visitor unit demand, potential target guest markets, room rates and occupancy rates.

Historical and Projected Visitor Room Demand

The average visitor room demand as measured by total daily room-nights is projected to exceed 5,800 in 1990 and increase by 6.1% per year through 2010, as shown in Exhibit VIII-I. Average daily visitor room-nights are based on the following factors:

- Percent of visitors utilizing commercial accommodations
- Average length of stay
- Average number of persons per room

Westbound visitor room-nights increased from about 81,000 in 1985 to over 110,000 in 1989, as shown in Exhibit VIII-I. The projections in westbound room-nights are summarized as follows:

- While a greater proportion of westbound visitors are anticipated to stay outside of commercial accommodations, the average length of stay is expected to continue to increase.

Exhibit VIII-G

KAHALA CAPITAL CORPORATION

Average Room Rates of
Hawaii Visitor Accommodations

1980 to 1990

Location	1980	1985	1989	1990(1)
Waikiki:				
On beach	$ 59.01	$ 84.13	$ 122.84	$ 136.26
Off beach (with restaurant)	34.78	44.31	67.54	77.50
Off beach (without restaurant)	27.67	35.41	50.70	56.29
Total Waikiki(2)	N/A	N/A	86.65	96.11
Other Oahu	45.45	59.31	74.20	80.56
Total island of Oahu	42.70	57.70	86.11	95.50
Hilo	33.71	34.88	49.10	56.35
Kona	49.96	71.76	76.58	77.83
Kohala Coast(2)	-	-	190.26	204.37
Total island of Hawaii	46.40	65.35	126.00	129.62
West Maui	63.19	105.84	126.68	123.85
Other Maui	55.30	72.16	109.42	111.59
Kaanapali(2)	-	-	160.38	157.57
Total island of Maui	61.34	96.75	140.77	138.04
East Kauai	52.66	60.48	-	-
South Kauai	66.36	86.22	120.95	131.80
North Kauai(2)	-	-	107.10	81.70
Central Kauai(2)	-	-	77.84	79.15
Total island of Kauai	55.16	69.51	97.69	95.11
State total	47.37	65.66	99.42	105.75

N/A Not available.

(1) For the six-month period ending June 1990. Seasonality could affect full-year results.

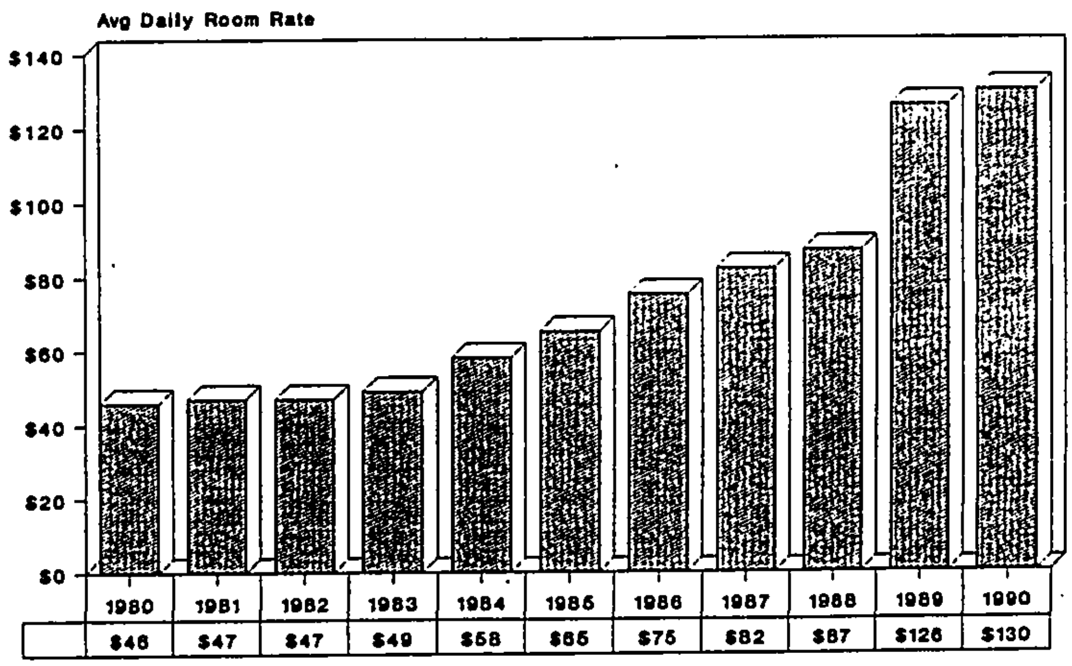
(2) New geographical areas effective January 1990, historical data available for 1989 only.

Source: Pannell Kerr Forster, Trends in the Hotel Industry, monthly.

KAHALA CAPITAL CORPORATION

Island of Hawaii Visitor Room Rates

1980 to 1990



Source: HVB

Exhibit VIII-H

KAHALA CAPITAL CORPORATION

Historical and Projected Visitor Room Demand
for the Island of Hawaii

1985 to 2010

	Westbound					Eastbound						
	Visitors(1)	Percent utilizing commercial accommo-dations	Average length of stay	Average persons per room	Average daily visitor room nights	Visitors(1)	Percent utilizing commercial accommo-dations	Average length of stay	Average persons per room	Average daily visitor room nights	Resi-dents room nights(2)	Total daily room demand
Historical:												
1985	697,380	99%	3.2	1.6	3,780	80,841	99%	1.5	1.8	180	440	4,400
1986	786,930	98	3.6	1.9	3,980	90,850	99	1.4	2.0	170	440	4,590
1987	782,550	93	3.7	1.9	3,860	90,444	98	1.4	2.0	170	450	4,480
1988	782,360	90	4.0	1.8	4,290	102,319	97	1.6	2.1	210	450	4,950
1989	959,890	79	4.2	2.0	4,360	110,678	95	1.5	2.1	210	450	5,020
Projected:												
1990	1,084,000	77	4.5	2.0	5,150	127,000	95	1.5	2.0	250	450	5,850
1995	1,534,000	75	4.7	2.0	7,410	276,000	93	1.8	2.0	630	476	8,516
2000	1,939,000	73	5.0	2.0	9,700	517,000	90	2.2	2.0	1,400	500	11,600
2005	2,405,000	73	5.2	2.0	12,510	728,000	87	2.6	2.0	2,260	550	15,320
2010	2,976,000	70	5.5	2.0	15,700	845,000	85	3.0	2.0	2,950	590	19,240
Compounded annual percentage increase: (1990 to 2010)					5.7%					13.1%	1.4%	6.1%

(1) From Exhibit II-8.
(2) Resident patronage estimated from interviews with hotel and property managers; growth projected at rate of resident population increase.

Exhibit VIII-I

- Average daily westbound visitor room-nights are projected to reach about 5,100 nights in 1990 and increase by 5.7% per year through 2010.

Eastbound visitor room-nights increased from about 180 in 1985 to 210 in 1989. Projection of eastbound visitor room-nights are summarized as follows:

- The majority of eastbound arrivals are from Japan. Most Japanese travelers prefer to stay in hotels; however, their average length of stay is generally shorter than westbound visitors.

- Eastbound visitor room nights are projected to reach 250 room-nights in 1990 and increase by a much higher annual rate of 13.1% than westbound room-nights.

Projected Visitor Unit Occupancy Rates

Visitor unit occupancy rates are projected at 60% in 1995 for all island visitor accommodations and 68% for hotels, as shown in Exhibit VIII-J. Projected occupancy levels for the island of Hawaii are summarized as follows:

- Occupancy rate projections are derived from historical and projected visitor unit supply, shown previously in Exhibits VIII-B through VIII-D, and demand shown previously in Exhibit VIII-I.

- Visitor unit occupancy is projected for both hotel and visitor condominium units.

- Condominium occupancies, in general, are anticipated to be lower than hotel occupancy, particularly in periods where demand increases more slowly than supply.

- Total visitor unit occupancy rates are anticipated to decline from 65% in 1990 to 60% in 1995 due to substantial inventory growth. Overall occupancy could increase to 68% by 2000 and to 80% by 2010.

- Hotel unit occupancy could decline from 70% in 1990 to about 68% in 1995, and subsequently rise to 73% in 2000 and 80% in 2010.

- Condominium unit occupancy could fall from 53% in 1990 to 37% in 1995, and increase thereafter to reach 56% in 2000 and 80% by 2010.

Projected O'oma II Hotel Occupancy Rates

The performance of the planned first-class hotel at O'oma II is expected to exceed the projected hotel occupancy level for the island of Hawaii. This is due to the appeal of visitor attractions such as on-property golf and the ocean science center and water recreation park and to the hotel's first-class market orientation. Accordingly, O'oma II hotel occupancy is projected as follows:

	Occupancy rate
1995	65%
2000	75
2005	85
2010	85

Exhibit VIII-J

KAHALA CAPITAL CORPORATION

Projected Visitor Unit Occupancy Rates for the Island of Hawaii

1985 to 2010

	Daily room demand	Visitor room inventory(1)	Average occupancy rate: Total	Hotel	Condominium(2)
Historical:					
1985	4,400	7,511	59%	76%	25%
1986	4,590	7,280	63	74	31
1987	4,480	7,328	61	70	40
1988	4,950	8,823	56	77	44
1989	5,020	8,161	62	65	36
Projected:					
1990	5,840	8,934	65	70	53
1995	8,516	14,278	60	68	37
2000	11,600	17,060	68	73	56
2005	15,320	18,974	81	81	81
2010	19,240	23,922	80	80	80

(1) Historical inventory from Hawaii Visitors Bureau, Visitor Unit Inventory, annual: projected inventory includes planned resort hotels with development approvals, as shown in Exhibit III-C and 50% of planned condominium units as shown in Exhibit III-D; 2010 inventory is estimated based on the compound annual percentage increase from 1985 to 2005.

(2) For units in visitor use.

Target Markets

The planned O'oma II hotel is defined as a first-class hotel. Target guest markets for the hotel are identified as follows:

- Free and independent traveler segment - would consist of value-conscious families looking for a first-time island experience complete with abundant opportunities for shopping, recreation, learning and entertainment as well as repeat visitors looking for new and exciting travel experiences at an affordable price.
- Business travel segment - would consist of individuals staying overnight for business purposes, who could find the hotel's first-class orientation and proximity to Keahole airport attractive.
- Package guest segment - would consist of free-independent travelers with discount room packages from wholesalers. Packages could be marketed as golf, honeymoon and seasonal air, hotel and car packages.
- Group segment - would consist of small groups made up of sales and other professional staff and ocean-related academic and scientific visitors.

Projected Room Rates for the Planned O'oma II Hotel

Standard room rates for the planned O'oma II first-class hotel are projected to range from $120 to $250 per night. Room rates for suites are projected to range from $400 to $500 per night. The average achieved rate is anticipated to be $120 to $140 per room.

The projected rate structure is supported by the following market factors:

- Five first-class resort hotels considered comparable to the planned O'oma II hotel were reviewed:
  - Royal Waikoloan
  - Maui Inter-continental Wailea
  - Maui Marriott
  - Sheraton Kauai
  - Stouffer Waiohai Beach Resort
- Standard room rates for the selected comparable hotels range from $100 to $350 per night, as shown in Exhibit VIII-K. Suite room rates range from $325 to $1,285 per night.
- The O'oma II hotel would be located in a relatively high-rate destination area.

O'OMA II HOTEL FACILITY RECOMMENDATIONS

This section summarizes facility recommendations for the planned hotel in serving the target guest markets. The following sections describe the potential food and beverage facilities, function areas and recreational amenities for the hotel.

Exhibit VIII-K

KAHALA CAPITAL CORPORATION

Published Room Rates of
Selected Comparable First-Class Hotels

1990

Hotel	Standard	Suite
Royal Waikoloan	$ 100 to 300	$ 550
Maui Inter-continental Wailea	185 to 350	350 to 950
Maui Marriott	195 to 280	. None
Sheraton Kauai	110 to 210	325 to 330
Stouffer Waiohai Beach Resort	150 to 250	450 to 1,285
Range	$ 100 to 350	$ 325 to 1,285

Source: Hawaii Visitors Bureau, Accommodation and Car Rental Guide, 1990.

Hotel Food and Beverage Facilities

The O'oma II hotel should plan to offer from 2 to 3 restaurant facilities, lounges and snack bars. The recommended food and beverage facilities mix is supported as follows:

- The selected comparable first-class hotels offer from 3 to 7 restaurant facilities, as shown in Exhibit VIII-L.
- The selected comparable hotels offer from 1 to 3 lounges.
- Food and beverage services could also be available at the nearby shopping center.

Snack bar facilities could be located at poolside and near the swimming area of the man-made lagoon of the resort.

Hotel Function Areas

The resort concept allows the separation of the function areas from the planned hotel. Ballroom facilities could be located within the hotel proper, however, the conferencing areas could be concentrated at the professional meetings center.

Hotel Recreational Amenities

The planned hotel should offer 5 to 6 tennis courts in addition to at least one swimming pool to complement the beach and swimming areas around the man-made lagoon. Most of the selected comparable hotels have at least one swimming pool and tennis courts. Spa facilities could also be included.

Activities involving water sports could be offered in addition to day-care type programs for children and enrichment programs for adults.

Exhibit VIII-L

KAHALA CAPITAL CORPORATION

Characteristics of Selected First-Class Hawaii Hotels

Hotel	Location	Number of rooms	Year opened	Food and beverage facilities	Banquet facilities: Total square feet	Banquet facilities: Total seating capacity	Meeting facilities: Number of areas	Meeting facilities: Total square feet	Meeting facilities: Total seating capacity	Beach access and condition	Other amenities
Royal Waikoloan	Waikoloa, Hawaii	543	1981	7 restaurants	6,656	720	1 indoor 1 outdoor	2,250 10,000	250 600	Large lagoon and white sand beach; excellent swimming and beach activities.	Two 18-hole golf courses, swimming pool, 6 tennis courts, nearby horseback riding, sailing, surfing and snorkeling.
Maui Intercontinental Wailea	Wailea, Maui	550	1976	N/A	6,864(1)	700	8 indoor	4,500	200	Large white sand beach; excellent swimming.	Two 18-hole golf courses, swimming pool and tennis center at resort.
Maui Marriott	Kaanapali Beach, Maui	720	1981	4 restaurants 3 lounges	14,040	1,700	None	None	None	Large white sand beach; excellent beach activities and swimming	Two 18-hole golf courses, 5 tennis courts, 2 swimming pools and sailing.
Sheraton Kauai	Koloa, Kauai	456	1968	3 restaurants 2 snack bars	5,876	800	1 outdoor	2,000	N/A	Large white sand beach; excellent swimming.	18-hole golf course, [illegible] tennis courts and swimming pool.
Stouffer Waiohai Beach Resort	Poipu Beach, Kauai	425	1981	3 restaurants 3 lounges	7,400	900	10 indoor	12,050	1,040	Excellent swimming beach.	18-hole golf course, 6 tennis courts and 3 swimming pools.

N/A Not available.

(1) Over 35,000 square feet of additional meeting and banquet space will become available in January 1991.

Source: Hawaii Visitors Bureau, Meeting Planner, 1990.

APPENDIX R

INFRASTRUCTURE ASSESSMENT

R.M. Towill Corporation

INFRASTRUCTURE STUDY for O'OMA II, Kona, Hawaii

JUNE 1991

PREPARED FOR:

Kahala Capital Corporation
Kona, Hawaii

RMTC

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INFRASTRUCTURE STUDY

FOR

O'OMA II
Kona, Hawaii

PREPARED FOR:

Kahala Capital Corporation
Kona, Hawaii

JUNE 1991

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1. INTRODUCTION

This report updates the infrastructure analysis prepared by M&E Pacific for the O'oma II Environmental Impact Statement dated September 1986. The proposed road network, potable water system, wastewater disposal system, electrical and communication system and storm drainage facilities are presented in this report.

2. ROADWAYS

Two major roadways serve the North Kona area: Queen Kaahumanu Highway (FAP 19) and Mamalahoa Highway (also referred to as the Hawaii Belt Road). Queen Kaahumanu Highway is a two-lane, Class I State Highway, designed for a 70-mile per hour vehicle speed. It is a limited access highway within a 300-foot right-of-way. Dedicated in 1975, the highway is 38 miles long and connects the towns of Kawaihae and Kailua-Kona. It provides a vital transportation link between the growing coastal resort areas of South Kohala, Keahole Airport, and Kailua-Kona.

Mamalahoa Highway was the main road between Kailua-Kona and Kamuela prior to the opening of Queen Kaahumanu Highway in 1975. It still provides a major transportation link between Hilo and Kailua-Kona (via Kamuela or directly when traveled in conjunction with the Saddle Road).

The primary arterial roadway will have a 120-foot right-of-way, collector streets 60 feet, and minor streets and cul-de-sacs 50 feet. All roadways will have two lanes with the exception of the primary arterial roadway, which will have four lanes. Roadway sections will conform to County of Hawaii standards, Standard Details for Public Works Construction, Detail R-33. The design speed for the primary roadway and other roadways will be 25 miles per hour (mph) and 15 mph, respectively. The grades along the proposed roadway will vary from 1/2 percent minimum to 12 percent maximum.

The proposed development will generate vehicular traffic both internally and externally. A traffic impact assessment report was prepared to determine potential impacts on the highway network (see Traffic Impact Assessment Report by Traffic Management Consultant).

3. POTABLE WATER SYSTEM

A. Existing Conditions

There is an existing 12-inch line along Queen Kaahumanu Highway. This system is part of the County's North Kona System which serves the area between Kealakekua to the south and Keahole Airport to the north. Water is supplied by wells and a shaft in the Kahaluu area.

The 16-inch transmission main from Kahaluu reduces to 12-inch beyond Honokohau Small Boat Harbor and terminates at a 0.5 MG reservoir for the airport complex. Presently, the municipal system is inadequate for this project. Therefore, other sources of water must be privately developed.

B. Water Demand

Potable Water

Estimates indicate that the residential units, hotel, inn, ocean center, business technology park, golf course, clubhouse, shops, water recreation park, and other facilities planned for the site are expected to require an average daily demand of 0.74 million gallons per day (mgd). This is based on an average daily demand of 600 gallons per unit per day for the residential units, 4,000 gallons per acre per day for the golf clubhouse shop, water recreation park, and 5,000 gallons per acre per day for the ocean center and Conference/Science Center. The average daily demands were based on the Domestic Consumption Guideline in the Water System Standards of the Department of Water Supply, County of Hawaii, 1985. The maximum daily demand is estimated to be 150 percent of average daily demand or 1.11 mgd. The breakdown of the water demand is as shown in Table 1.

TABLE 1 - ESTIMATED POTABLE WATER DEMAND

DESCRIPTION	GALLONS PER DAY (GPD)
Single Family	42,000
Condominiums	138,000
Inn	30,000
Hotel	330,000
Ocean Center	60,000
Conference/Science Center	15,000
Golf Clubhouse	20,000
Shops	32,000
Water Recreation Park	76,000
TOTAL AVERAGE DEMAND:	0.74 MGD
MAXIMUM DAILY DEMAND:	1.14 MGD

Non-Potable Water

Non-potable water is estimated to be approximately 1 mgd. This includes irrigation water for the golf course (173 acres at 4,500 gal/acre/day or 778,500 gpd) and other open space areas.

C. Water Sources

Potable Water Sources

Fresh water wells with a total installed pumping capacity of up to 1.14 mgd may be needed, along with wells having appropriate standby pumping capacity. These wells would be located in the water resource development zone, indicated by the Keahole-to-Kailua Development Plan of November 1990. Such wells would be developed in cooperation with the County Board of Water Supply. Consideration is also being given to desalination of brackish or salt water sources located on or near the project, in order to facilitate the timely development of at least a portion of source requirements.

Salt Water Sources

The Ocean Center and Water Park will require large quantities of clean salt water. Large capacity source wells will be developed near the facilities. An alternative water source under consideration would be to acquire water from HOST Park.

Irrigation Water Sources

To offset the use of potable water for irrigation, the golf course and other open space areas will be initially furnished by onsite sewage effluent supplemented with brackish water. After the Keahole to Kailua Development Plan is implemented, irrigation will probably be provided by non-potable water from Municipal Sewage Treatment Plant No. 1. Currently, the development plan shows a 16-inch effluent disposal line for public and private irrigation purposes.

Water Source Development and Phasing

The required wells, storage tanks/reservoirs and transmission lines must be completed before occupancy of the project's first homes. The County of Hawaii's Keahole to Kailua Development Plan indicates a new 16-inch water line along Queen Kaahumanu Highway east of the proposed development. The average water demand used to size the 16-inch water line is 0.91 mgd for the O'oma II development. However, the implementation schedule of the County for these improvements is not compatible with the project schedule. Therefore, the design and construction of certain water system improvements will be undertaken as part of the proposed project. All potable water system improvements will be designed and constructed in compliance with applicable State Department of Health and Water Resources Development Commission rules and regulations and permit requirements, and the County Board of Water Supply standards.

4. WASTEWATER TREATMENT AND DISPOSAL

A. Existing Conditions

No municipal wastewater treatment and disposal facility exists in the area. The only existing sewage treatment facility is a 0.04 mgd STP at Keahole Airport to serve the airport complex.

B. <u>Wastewater Flows and Disposal</u>

The average flow from the residential units, inn, hotel, ocean center, etc., and other facilities proposed on the site is estimated to be 0.45 mgd. The peak flow is estimated to be 2.0 mgd. The wastewater flows are based on Design Standards of the Wastewater Management, Volume 1, Dept. of Public Works, City and County of Honolulu, Feb. 1984, and State of Hawaii, Dept. of Health Standards, Nov. 1988. A breakdown of the estimated flow from the development for the various land uses is shown in Table 2 as follows:

TABLE 2 - ESTIMATED WASTEWATER FLOWS

USE	GALLONS PER DAY (GPD)
Single Family	22,400
Condominiums	73,600
Inn	16,000
Hotel	176,000
Ocean Center	48,000
Conference/Science Center -	9,600
Golf Clubhouse	16,000
Shops	25,600
Water Recreation Park	60,800
AVERAGE FLOW (gal/day):	448,000
INFILTRATION (gal/day):	26,200
TOTAL AVERAGE FLOW (gal/day):	474,200
TOTAL PEAK FLOW (gal/day):	2,014,000

There are no existing municipal sewage disposal facilities to be impacted at present. However, the current Keahole to Kailua Development Plan shows sewage from this development discharging to a proposed Municipal Treatment Plant No. 2 will be located approximately 2 miles north of Keahole Airport. This plant is scheduled to completed in the year 2005.

In the interim, a temporary sewage treatment plant will be constructed as part of the proposed project at approximately the center of the south boundary of the development. Six acres will be reserved for this purpose. The temporary facility will be maintained and operated as a private facility. Effluent from the treatment plant will be used to irrigate the golf course until the Municipal

Treatment Plant and the 16-inch effluent disposal line along Queen Kaahumanu Highway is in operation.. Onsite gravity sewers and force mains were sized by the City and County of Honolulu, Department of Public Works Standards. Sewage velocities and pipe sizes were checked to ensure adequate flushing and capacity (see Exhibit 2). All wastewater system improvements will be designed, engineered and constructed in compliance with applicable State Department of Health and County Department of Public Works rules and regulations and permit requirements.

5. STORM DRAINAGE

A. Existing Conditions

The project site is generally flat. The terrain typically reflects the original surface of basaltic lava flows in both the a'a and pahoehoe forms. The ground surface slopes from about elevation 105 feet above sea level at Queen Kaahumanu Highway which forms the eastern boundary to approximately elevation 5 feet above sea level at the ocean which forms the western boundary of the project.

The existing O'oma II watershed contains an area of approximately 482 acres and extends from the western slopes of Hualalai to the coast. There are no perennial streams or well defined water courses in the watershed. Based on a 10-year 1-hour storm, a total of 90 cubic feet per second (cfs) enters the project site from the eastern and southern boundaries and 268 cfs of runoff is generated within the project area. The O'oma II coastline receives 190 cfs of runoff from on-site areas and 4 cfs from off-site areas.

Most of the ground surface is covered with basaltic cobbles and gravel (clinker) with localized exposures of in-situ basalt rock formation. The porous character of the lava results in relatively rapid percolation of rainwater. This condition together with the semi-arid climate of Kona results in the fact that there are no well-defined drainageways on the property. There is also no evidence of streams or flooding. The majority of precipitation falling on the site infiltrates immediately and there is little or no runoff. Since the property is undeveloped, there are presently no drainage structures on site.

B. <u>Development Impacts</u>

The residential and non-residential uses of the subject property will alter the character of the surface runoff from the area. The paved roadways, sidewalks, roofs, parking lots and other impermeable surfaces will contribute to an increase in surface runoff. Percolation of rainwater through the porous lava into the underground water table will therefore be reduced because of the decrease in permeable surface area.

The change in land use effected by O'oma II development, particularly the increase in impervious surfaces, is expected to increase storm runoff within the site from approximately 260 cfs to 450 cfs. The overall drainage scheme would protect developed areas by intercepting storm runoff from open and off-site areas through a network of cut-off swales and ditches, inlets, and drain pipes located within the road right-of-ways. The use of unlined channels, wherever possible, would allow infiltration of runoff into the porous lava rock and thus minimize flows at the discharge points.

Currently the main discharge points are coastal outlets located at the north and south ends of the property. Most of the channelized runoff from this project will be discharged to the south. This would minimize any impacts on the HOST park facility. The majority of the runoff would be allowed to drain naturally by sheetflow into the ocean, by percolation into the soil, and into a series of drywells. The modified drainage plan will be designed to preclude "downstream flooding" of adjacent properties and is not anticipated to have a significant adverse effect on the environment. All drainage improvements will be designed and built to County standards.

Because of the porous nature of volcanic soils throughout the island, disposal of storm water will typically be handled by seepage from swales and drywells. In addition areas will be left in open space for drainage infiltration into the ground. The primary open space will be the golf course area which will provide areas for retention basins for excess runoff.

Design and use of drywells within the project area will be based on the County of Hawaii, Department of Public Works' policies, guideline and design specification as well as the State Department of Health's UIC regulations.

The Department of Public Works' policy is to limit 6 cubic feet per second of storm water discharge per drywell. Drywells will be 5 feet in diameter and 20 feet deep. Based on this guideline, the projects's drywells will be considered as injection wells and will require a UIC permit from the Department of Health. The requisite test reports will be prepared and submitted to the Department of Health. County application for drywell permit will be undertaken at the time of design. The actual siting of the drywells will be determined at the design phase. All applicable State and County standards will be followed.

The O'oma II watershed is relatively well contained. The project would not be affected by future urbanization of upslope areas because of the interceptor ditch located mauka of the highway which diverts the runoff and discharges it away from the site.

6. ELECTRICAL POWER

A. Existing Conditions

Electrical service to the project areas as well as the entire island is provided by Hawaii Electric Light Company (HELCo). An existing 69 KV transmission line along Queen Kaahumanu Highway, on the mauka side of the highway, will serve the project site. Present information from HELCo is that their electrical generating capacity is 163.4 MW, with a peak demand of approximately 139.0 MW. Projected additional future load growth on HELCo's system for the next five years, is expected to increase by 25.0 MW in mid-1991 and another 20.8 MW in 1992 so that there is spare capacity to support the project.

B. <u>Development Impact</u>

The development is expected to have an estimated demand of approximately 10 MVA ultimate demand load with approximately 5 MVA materializing as early as next five years and the remainder being completed perhaps within ten years. This program does not burden HELCo's ability to support their customers in the area or the island as a whole. A new step down substation, to be located near Queen Kaahumanu highway, will be required for the project. It is anticipated that the substation will be located mauka of the highway and that it will require land acquisition as well as PUC approval. Underground feeders for all utilities, including the HELCo, telephone, and CATV facilities will cross the highway. Switching vaults within the site will serve the project facilities. The underground distribution system will be developed by HELCo, utilizing 12.47 KV underground feeder cables.

It is not anticipated that HELCo's present customers will be adversely or directly affected by the anticipated project since there is sufficient system capacity to support the project. In addition, reconductoring of the 69 KV on Queen Kaahumanu Highway is not anticipated. The new substation serving this project will provide all the necessary power required for the project and it will not be necessary to support the project needs from other customer substations in the near vicinity.

C. <u>Mitigating Measures</u>

A portion of the Island of Hawaii's electrical capacity is obtained from the use of traditionally accepted renewable sources such as bagasse burning, geothermal energy, hydroelectrical power, and wind power. However, even though nearly 30 percent of the system's KWHrs are supplied through bagasse plants, these plants now largely are run on oil and therefore have a diminishing role in the use of renewable materials. Wind and hydroelectrical power are considered to be oil replacement rather than capacity generating because from time to time the renewable sources are unavailable. Therefore, there remains a portion of HELCo's generating capacity that is now obtained from renewable sources. The commercial viability of some of these sources, as well as the long-term potential of the Ocean Thermal Energy Conversion (OTEC) process will help to lessen the consumption of petroleum, a non-renewable resource.

7. TELEPHONE

A. Existing Conditions

Hawaiian Telephone Company (HTCo) serves the project area from their Kailua-Kona ECC facilities with trunk cables supported on the HELCo 69 KV poles. There are no significant spares in the trunking cables to support new major developments, in accordance with PUC directives.

B. Development Impacts

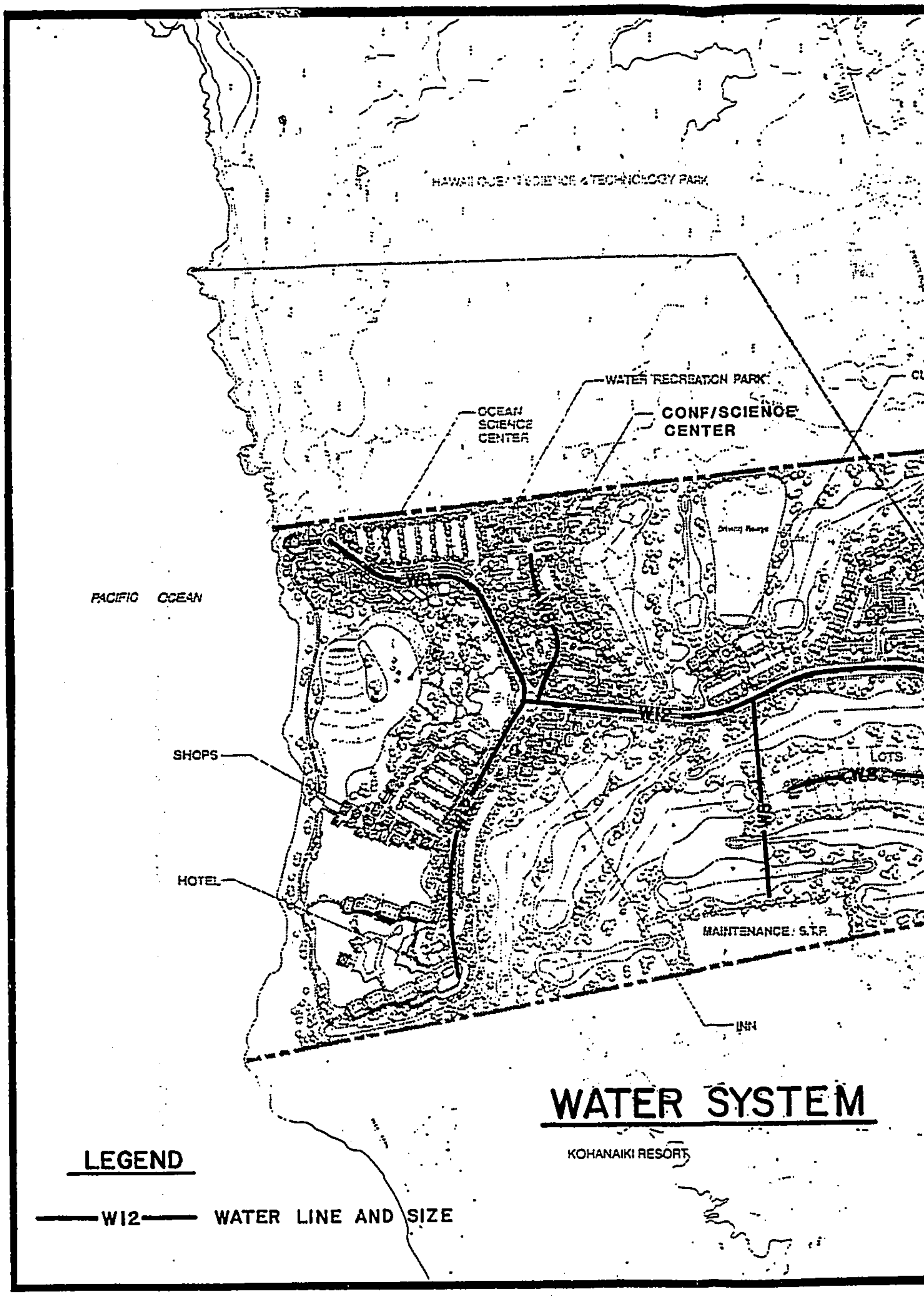
The telephone company's facilities at their ECC station are adequate to support the new telephone requirements for the project. However, it will be necessary to supplement the cable run between the Kailua-Kona ECC and the project site. Underground easement will be required between the 69 KV riser pole, including highway crossing, and facilities makai of the highway.

8. CABLE TELEVISION

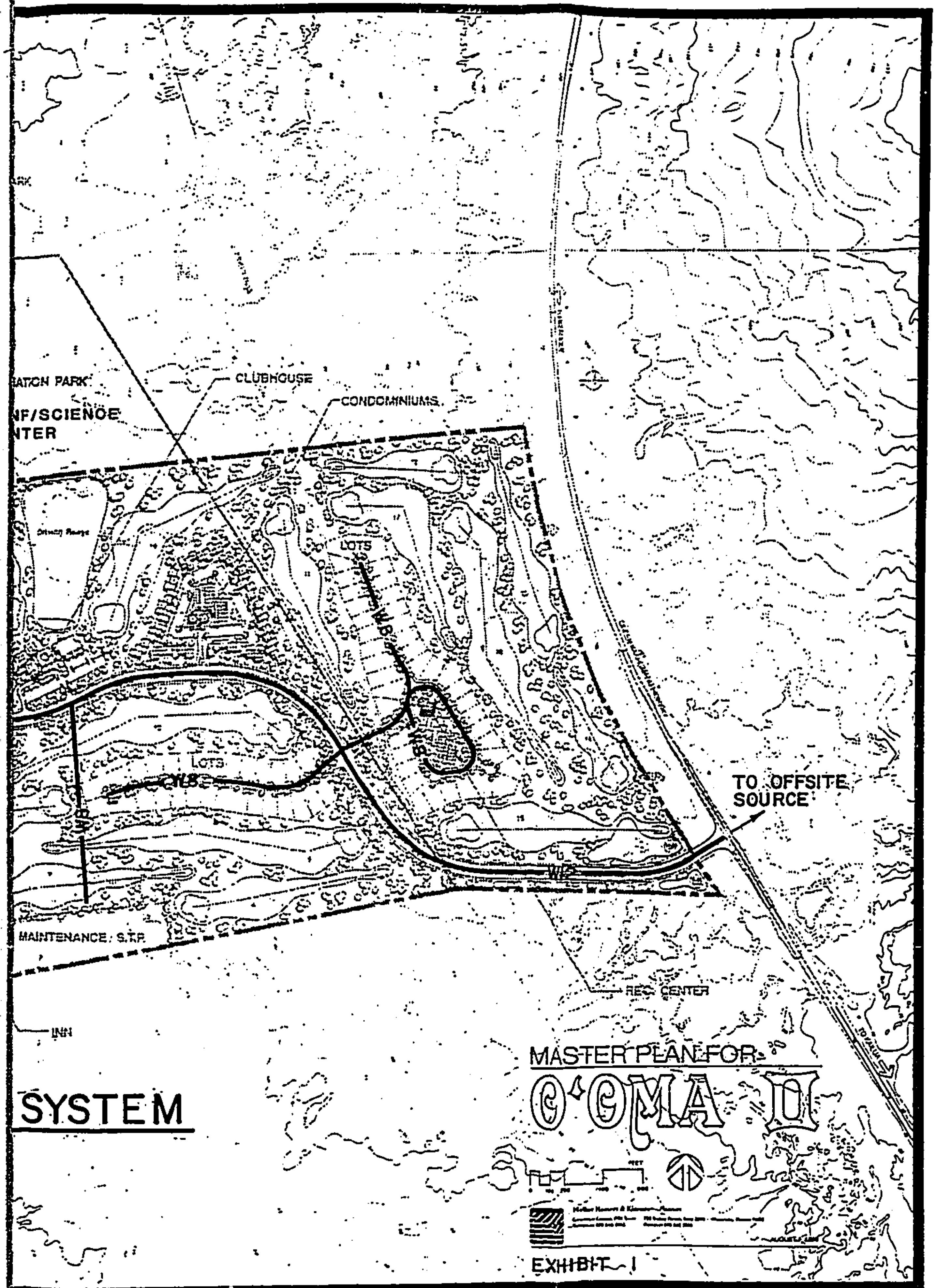
The anticipated population levels in the initial phases of the project are insufficient to justify Sun Cablevision's expansion of their facilities to the project site. Cable service can be made available through developer funding of the capital improvements necessary. Several portions are available and they include microwave relay reception at the site and extension of new trunking cables of fiber optics along Queen Kaahumanu Highway. Underground easement will be required between the 69 KV

APPENDIX A

EXHIBITS



HAWAII OCEAN SCIENCE & TECHNOLOGY PARK
WATER RECREATION PARK
OCEAN SCIENCE CENTER
CONF/SCIENCE CENTER
PACIFIC OCEAN
SHOPS
HOTEL
LOTS
MAINTENANCE / S.T.P.
INN
WATER SYSTEM
KOHANAIKI RESORT
LEGEND
W12 WATER LINE AND SIZE



CLUBHOUSE
CONDOMINIUMS
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NF/SCIENCE
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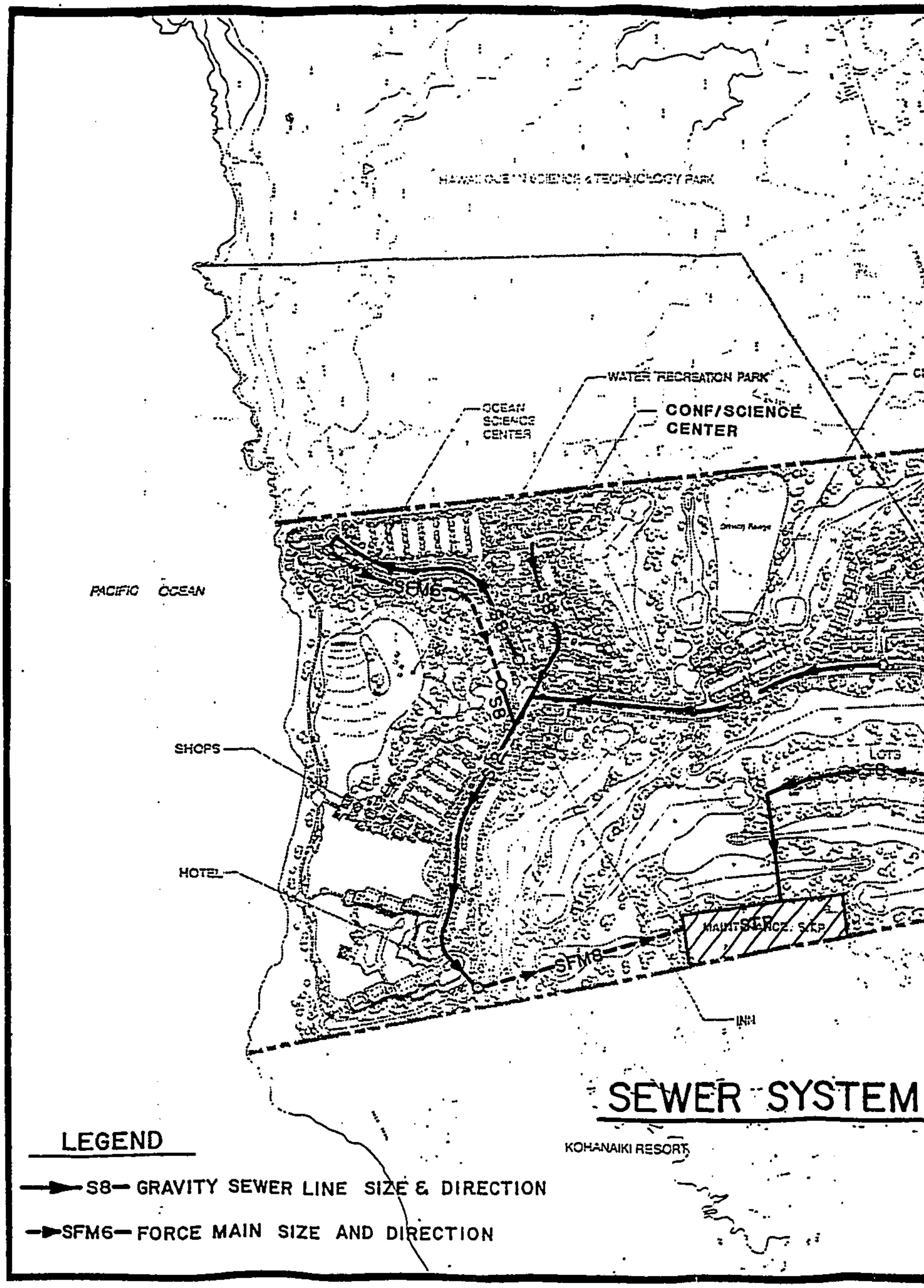
LOTS
LOTS
TO OFFSITE
SOURCE
MAINTENANCE / S.T.P.
REC. CENTER
INN
SYSTEM
MASTER PLAN FOR
O'OMA II
EXHIBIT I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CONF/SCIENCE CENTER
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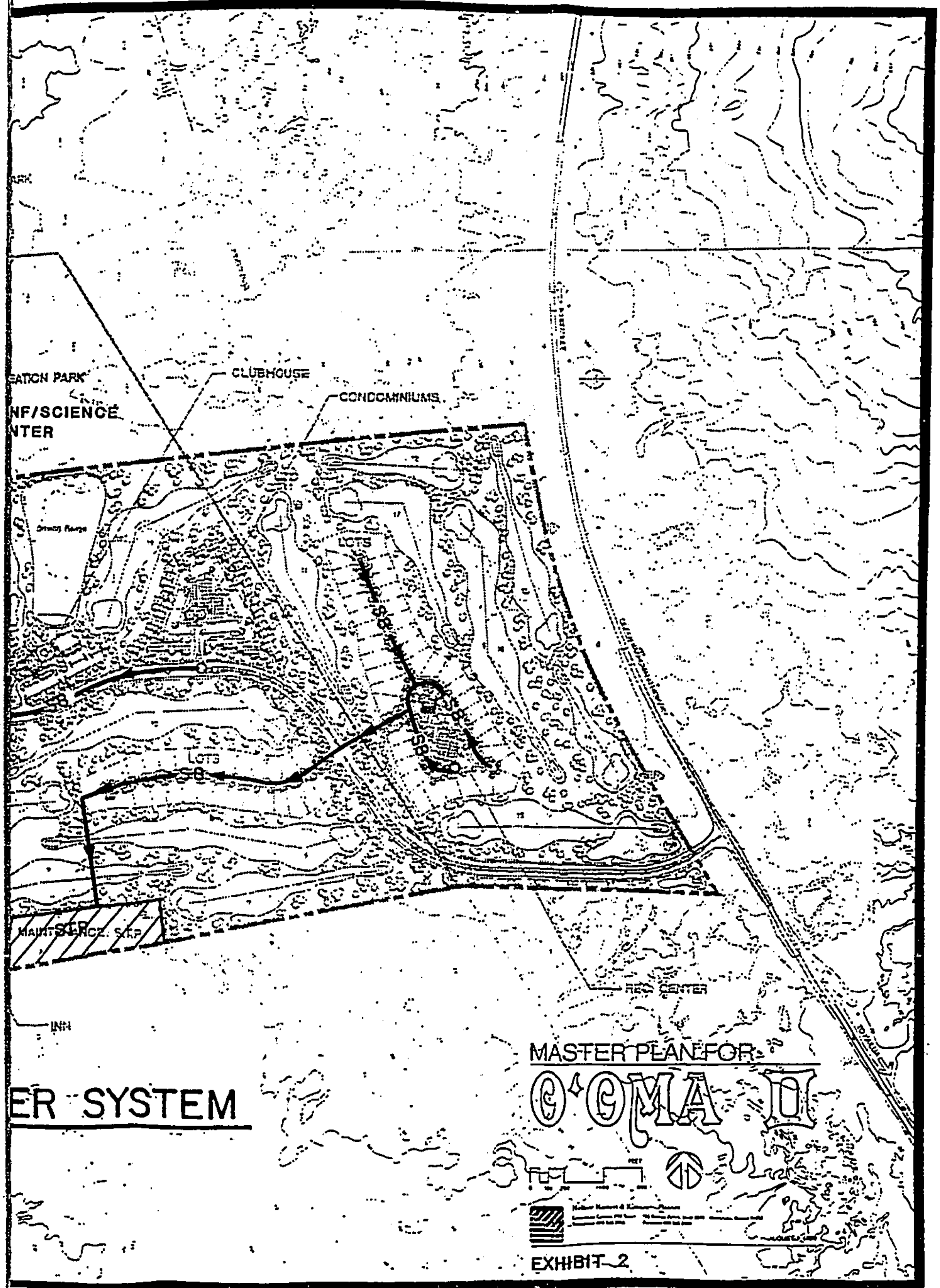
Driving Range
SHOPS
HOTEL
INN
LOTS
SFM6
S8
SEWER SYSTEM
KOHANAIKI RESORT
LEGEND
S8— GRAVITY SEWER LINE SIZE & DIRECTION
SFM6— FORCE MAIN SIZE AND DIRECTION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NF/SCIENCE
NTER
CLUBHOUSE
CONDOMINIUMS
LOTS
SB
LOTS
SB
REC CENTER
INN
ER SYSTEM
MASTER PLAN FOR
O'OMA II
EXHIBIT 2

APPENDIX B

TECHNICAL INFORMATION

WATER SYSTEM

O'OMA II MASTER PLAN SUMMARY
(Based on November 30, 1990 Plan)

USE	AREA	UNIT COUNT	ADDITIONAL INFORMATION
Ocean Science Center	12 acres	---	Contains indoor and outdoor tanks, tide pools, archaeological sites/exhibits, restaurant, small theater ans over 300 parking stalls.
Conference Center/ Science Center Expansion	3 acres	---	Conference center and/or expansion of the Ocean Science Center with 100 additional parking stalls.
Water Recreation Park	19 acres	---	Contains beach, 7-acre swimming lagoon, natural water slides and pools, wave machine, snack bar and restrooms.
Golf Course and Clubhouse	176 acres	18 holes	Regulation par-72 golf course with driving range, practice greens, clubhouse with pro shop, restaurant, pool and cart barn.
Inn	5 acres	50 rooms	Japanese style inn (ryokan) with restaurant, tennis court and all rooms with golf course frontage.
Golf Course House Lots	24 acres	70 lots	10,000 s.f. lots, all with golf course frontage; central recreational facility, pool and tennis courts.
Golf Course Condominiums	10 acres	130-230 units	Number of units depends on size of each condo; i.e. 130 units if condos average 1,750 s.f.; 230 units if they average 1,000 s.f.; in 2- and 3-story buildings all with golf course views and central recreational facility, pool and tennis courts.
Shops	8 acres	35,000 s.f.	Contains resort shops and restaurants over-looking lagoons and golf course with 350 parking stalls.
Hotel	22 acres	550 rooms	Contains food and beverage facilities, pool and other recreational amenities and 200 parking stalls.
Maintenance/Sewage Treatment Plant	6 acres	---	Contains maintenance facilities for resort and golf course and adjoins S.T.P. site at Kohanaiki in event a joint facility can be built.
Spine Road	15 acres	---	Main road contains two 24' wide paved sections, a 20' wide median and a meandering walkway on the north side only, all within 100' wide right-of-way; north-south legs, similar within 80'-wide right-of-way
TOTAL	300 acres	600 Hotel Rooms 200-300 Residential Units	

17 December 1990

O [illegible]OMA II JUNE 24, 1991

WATER ANALYSIS

DESCRIPTION	NO. OF UNITS	DAILY DEMAND/UNIT	AVERAGE FLOW
SINGLE FAM	70	600 GAL/UNIT	42,000 GPD
CONDOMINIUMS	230	600 GAL/UNIT	138,000 GPD
INN	50	600 GAL/UNIT	30,000 GPD
HOTEL	550	600 GAL/UNIT	330,000 GPD

DESCRIPTION	ACRES	FLOW/ACRE	AVERAGE FLOW
OCEAN CENTER	12	5000 GAL/ACRE	60,000 GPD
CONF CEN/SCIEN CEN	3	5000 GAL/ACRE	15,000 GPD
GOLF CB HOUS	5	4000 GAL/ACRE	20,000 GPD
SHOPS	8	4000 GAL/ACRE	32,000 GPD
WAT REC PARK	19	4000 GAL/ACRE	76,000 GPD
GOLF COURSE	173	4500 GAL/ACRE	(778,500) GPD

AVERAGE DAILY DEMAND = 743,000 GPD

MAXIMUM DAILY DEMAND = 1.5 X AVE DAILY DEMAND
1,114,500 GPD

PEAK HOUR = 5 X AVE DAILY DEMAND LESS GC FLOW
2,936,500 GPD

TABLE 15

DOMESTIC CONSUMPTION GUIDELINE

AVERAGE DAILY DEMAND*

ZONE	HAWAII	KAUAI	MAUI	OAHU
RESIDENTIAL:				
Single Family or Duplex	400gals/unit	500gals/unit	600gals/unit or 3000gals/acre	500gals/unit or 2500gals/acre
Multi-Family Low Rise	400gals/unit	350gals/unit	560gals/unit or 5000gals/acre	400gals/unit or 4000gals/acre
Multi-Family High Rise	400gals/unit	350gals/unit	560gals/unit	300gals/unit
COMMERCIAL:	3000gals/acre	3000gals/acre	6000gals/acre	3000gals/acre
Commercial/Industry Mix	--	500gals/acre	140gals/1000 sq. ft.	100gals/1000 sq. ft.
Commercial/Residential Mix	--	3000gals/acre	140gals/1000 sq. ft.	120gals/1000 sq. ft.
RESORT (To include hotel for Maui only):	400gals/unit	350gals/unit	350gals/unit or 17000gals/acre	350gals/unit or 4000gals/acre
LIGHT INDUSTRY:	4000gals/acre	4000gals/acre	6000gals/acre	4000gals/acre
SCHOOLS, PARKS:	4000gals/acre or 60gals/student	2500gals/acre plus 20gals/student	1700gals/acre or 60gals/student	4000gals/acre or 60gals/student
HOSPITAL			1800gals/acre	
AGRICULTURAL			5000gals/acre	

* Where two or more figures are listed for the same zoning, the daily demand resulting in higher consumption use shall govern the design unless specified otherwise.

TABLE 16

FIRE FLOW REQUIREMENT

LAND USE	FLOW(GPM)/DURATION(HRS.)/SPACING(FT.)			
	HAWAII	KAUAI	MAUI	OAHU
Agriculture	500/0.5/600(1)	0	250/2/500	1000/0.5/700
Rural			400/2/500	
Single Family	(2)	(4)	1000/2/350	1000/1/350
Duplex	1500/1/300	(4)	1250/2/350	1000/1/350
PUD Townhouse and Low Rise Apartments	1500/1/300	(4)	(5)	1500/1/250
Schools, Neighborhood Businesses, Small Shopping Centers, Hotels (except Maui), and High Rise Apartment	2000/2/300	2000/2/350	2000/2/250	2000/2/250
Light Industry, Downtown Businesses, and Large Shopping Center	(3)	3000/3/350	2000/2/250	4000/3/250
Heavy Industry, Hotels			2500/2/500	(3)

(1) Applies to one acre lot size or less
(2) Larger than 10,000 sq. ft. lot size = 500/2/600   10,000 sq. ft. lot size or less = 1000/1/600
(3) Subject to special review and control by Manager.
(4) R-2 = 500/1/600   R-4 = 750/2/500   R-6 = 1000/2/500   R-10 = 1250/2/350   R-20 = 1500/2/350
RR-10 = 1500/2/350   RR-20 = 2000/2/350
(5) A-1 = 1500/2/250   A-2 = 2000/2/250

On dead end streets where further extensions are unlikely due to topography or other limitations, the last F.H. shall be located at one half the spacing distance for F.H.'s from the last house/unit.

PART I

TABLE 17

DEMAND FACTORS

	Maximum Daily Demand	Peak Hour	MGD
Hawaii	1.5 x Average Day	5 x Average Day	-
Maui, Oahu	1.5 x Average Day	3 x Average Day	-
Kauai	1.5 x Average Day	3.5 x Average Day	0-0.1
Kauai	1.5 x Average Day	3.0 x Average Day	0.1-0.5

8.6 Pipeline Sizing

a. Maximum daily flow plus fire flow with a residual pressure of 20 psi at critical fire hydrant.

b. Peak hour flow with a minimum residual pressure of 40 psi.

c. In determining the carrying capacity of the mains, the *"C" values to be applied are:

Diameter	"C"
4", 6"	100
8", 12"	110
16", 20"	120
24" and larger	130

* not for metallic noncement-lined pipe.

d. Maximum velocity in main (without fire flow) is 6 feet per second.

e. The following maximum velocity in mains apply to Maui only.

1. 10 feet per second for distribution mains with fire flow.
2. 20 feet per second for transmission mains without water services or fire flow.
3. For Maui 13 feet per second for fire line.

f. Unless specified otherwise, maximum static or pumping pressure, whichever is greater, shall not exceed 125 psi.

PART I

SECTION 10 - WATER MASTER PLAN

10.1 General. A water master plan is defined as a plan describing the development of any property including all of the proposed water system improvements necessary to provide adequate water service to the development. All proposed work shown on the water master plan submitted to the Manager for approval shall be designed according to these Standards.

In matters of engineering judgment, the Manager's decision will be final.

Approval of plans by the Manager does not constitute a water commitment. Water commitment for the project shall be in accordance with the department's Rules and Regulations.

10.2 Plans. The water master plan, insofar as the water system is concerned, shall show the following:

1. Name of project or subdivision, name of engineer, tax map key, location and acreage
2. Type of development and number of units
3. Access to property
4. Elevations and contours of property
5. Building, street, and lot layout
6. Estimated water demand in gallons per day
7. Development and construction schedules
8. Proposed water facilities
9. Supporting calculations showing adequacy of water facilities during interim and ultimate development

10.3 Development by Phases. If development of the project is to be done in phases over a period of time and our Standards are revised, or if there are changes in the type or layout of development proposed, the master plans shall be revised accordingly and resubmitted for review and approval by the Manager.

SEWER SYSTEM

O'OMA II MASTER PLAN SUMMARY
(Based on August 1, 1990 Plan)

USE	AREA	UNIT COUNT	ADDITIONAL INFORMATION
Ocean Science Center	12 acres	---	Contains indoor and outdoor tanks, tide pools, archaeological sites/exhibits, restaurant, small theater and over 300 parking stalls.
Water Recreation Park	18 acres*	---	Contains beach, swimming lagoon, natural water slides and pools, wave machine, snack bar and restrooms
Shops	9 acres*	35,000 s.f. GLA	Contains resort shops and restaurants built over lagoon with 350 parking stalls
Hotel	21 acres*	550 rooms	Contains full conferencing facilities, pool and other recreational amenities and 200 parking stalls
Business Technology Park	13 acres	11 1-acre lots	Buildings to contain business/professional and office and/or corporate training centers
Inn	3 acres	50 rooms	Japanese style in a (ryokan) with restaurant, tennis court and all rooms with golf course frontage
Golf Course and Clubhouse	172 acres	18 holes	Regulation par-72 golf course with driving range and practice greens, clubhouse with pro shop, restaurant, spa facilities, pool and cart barn
Maintenance/Sewage Treatment Plant	6 acres	---	Contains maintenance facilities for resort and golf course and adjoins S.T.P. site at Kohanaiki in event a joint facility can be built
Condominiums	10 acres	130-230 units	Number of units depends on size of each condo; i.e. 130 units if condos average 1,750 s.f.; 230 units if they average 1,000 s.f.; in 2- and 3-story buildings all with golf course views and central recreational facility, pool and tennis courts
House Lots	24 acres	70 lots	10,000 s.f., all golf course frontage with central recreational facility, pool and tennis courts
Spine Road	12 acres	---	Main road contains two 24' wide paved sections, a 20' wide median and a meandering walkway on the north side only, all within 100' wide right-of-way
TOTAL	300 acres	600 Hotel Rooms 200-300 Residential Units	

*Includes a portion of the 16-acre man-made lagoon (Water Recreation Park: 6-1/2 ac., Shops: 1- 1/2 ac., Hotel: 8 ac.)

Helber Hastert & Kimura
Planners

6 September 1990

Gravity Sewer System

O'OMA II MASTER PLAN SUMMARY
(Based on November 30, 1990 Plan)

USE	AREA	UNIT COUNT	ADDITIONAL INFORMATION
Ocean Science Center	12 acres	---	Contains indoor and outdoor tanks, tide pools, archaeological sites/exhibits, restaurant, small theater ans over 300 parking stalls.
Conference Center/ Science Center Expansion	3 acres	---	Conference center and/or expansion of the Ocean Science Center with 100 additional parking stalls.
Water Recreation Park	19 acres	---	Contains beach, 7-acre swimming lagoon, natural water slides and pools, wave machine, snack bar and restrooms.
Golf Course and Clubhouse	176 acres	18 holes	Regulation par-72 golf course with driving range, practice greens, clubhouse with pro shop, restaurant, pool and cart barn.
Inn	5 acres	50 rooms	Japanese style inn (ryokan) with restaurant, tennis court and all rooms with golf course frontage.
Golf Course House Lots	24 acres	70 lots	10,000 s.f. lots, all with golf course frontage; central recreational facility, pool and tennis courts.
Golf Course Condominiums	10 acres	130-230 units	Number of units depends on size of each condo; i.e. 130 units if condos average 1,750 s.f.; 230 units if they average 1,000 s.f.; in 2- and 3-story buildings all with golf course views and central recreational facility, pool and tennis courts.
Shops	8 acres	35,000 s.f.	Contains resort shops and restaurants over-looking lagoons and golf course with 350 parking stalls.
Hotel	22 acres	550 rooms	Contains food and beverage facilities, pool and other recreational amenities and 200 parking stalls.
Maintenance/Sewage Treatment Plant	6 acres	---	Contains maintenance facilities for resort and golf course and adjoins S.T.P. site at Kohanaiki in event a joint facility can be built.
Spine Road	15 acres	---	Main road contains two 24' wide paved sections, a 20' wide median and a meandering walkway on the north side only, all within 100' wide right-of-way; north-south legs, similar within 80'-wide right-of-way
TOTAL	300 acres	600 Hotel Rooms 200-300 Residential Units	

17 December 1990

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D 'OMA II JUNE 25, 1991

S E W E R   A N A L Y S I S

SEWER SYSTEM

******CHECK FLOW 70 HOMES ENTERING 6 ACRE SEWAGE TREATMENT PLANT****

FLOW BASED ON VITRIFIED CLAY PIPE WITH MINIMUM SLOPE BASED ON THE WASTE WATER MANAGEMENT STANDARDS

DESCRIPTION	NO. OF PER/UNIFLOW/CAPITA		AVERAGE WW FLOW
70 SINGLE FAM	4	80 GCPD	22,400 GPD

```
AVE WASTE WATER FLOW =                      22,400 GPD
MAXIMUM WW FLOW =                           80,640 GPD         (FACTOR =3.6)
DRY WEATHER INFILTRATION/INFLOW =            1,400 GPD         (ASSUME 5 GCD)
** DESIGN AVERAGE FLOW =                    23,800 GPD OR              17 GPM
DESIGN MAXIMUM FLOW =                       82,040 GPD
WET WEATHER INFILTRATION/INFLOW =           30,000 GPD         (24 ACRES)
** DESIGN PEAK FLOW =                      112,040 GPD OR              78 GPM

PEAK FLOW=Qp=            78 GPM
AVE FLOW=Qave=           17 GPM

ASSUME: *n=           0.015
      *PIPE DIAMETER = d=   0.67 FEET
      *SLOPE =         0.01 FEET/FOOT
      *K' =           0.463
```

CALCULATING FULL FLOW:

```
  Qfull= (K'/n)*(d)^8/3*(S)^1/2
  Qfull1.060936048 CFS     OR          476 GPM
```

CALCULATING PERCENTAGE PIPE FLOWING FULL

```
  PERCENT FULL =        16 %       COMPARED TO MAXIMUM 90% FULL
```

CALCULATING VELOCITY FLOWING FULL:

```
  V*A=(K'/n)*(d^2)*(d^2/3)*(S^1/2)
     Vfull =        3.01169 FPS  COMPARED TO 2.5 FPS MIN
```

SINCE,

```
      Qave =           17 GPM
      Qfull=          476 GPM

DISCHARGE PROPORTION = Qave/Qfull       0.04   (FIGURE 3-2, REF 3)

      *VELOCITY PROPORTION= Vactual/Vfull=      0.45
```

THEREFORE, THE ACTUAL VELOCITY IS

```
      Vactual =      1.36 FPS    COMPARED TO 2.0 FPS MINIMUM
```

```
                    U 'OMA II            JUNE 23, 1991
              S E W E R    A N A L Y S I S
SEWER SYSTEM
*******CHECK CONDOMINIUMS AND CLUB HOUSE*******

FLOW BASED ON VITRIFIED CLAY PIPE WITH MINIMUM SLOPE BASED ON
THE WASTE WATER MANAGEMENT STANDARDS

DESCRIPTION           NO. OF PER/UNIFLOW/CAPITA          AVERAGE WW FLOW
-----------           -------------------------          ---------------
   230 CONDOMINIUMS        4               80 GCPD          73,600 GPD

                      NO. OF PER/ACRFLOW/CAPITA          AVERAGE WW FLOW
                      -------------------------          ------------
     5 GOLF CD HOUS       40 CPA           80 GCPD          16,000 GPD

AVE WASTE WATER FLOW =                  89,600 GPD
MAXIMUM WW FLOW =                      412,160 GPD       (FACTOR =4.6)
DRY WEATHER INFILTRATION/INFLOW =        5,650 GPD       (ASSUME 5 GCD)
** DESIGN AVERAGE FLOW =                95,250 GPD OR            66 GPM
DESIGN MAXIMUM FLOW =                  417,810 GPD
WET WEATHER INFILTRATION/INFLOW =       18,750 GPD       (15 ACRES)
** DESIGN PEAK FLOW =                  436,560 GPD OR           303 GPM

PEAK FLOW=Qp=            303 GPM
AVE FLOW=Qave=            66 GPM

ASSUME:*n=            0.015
       *PIPE DIAMETER = d=  0.67 FEET
       *SLOPE =         0.01 FEET/FOOT
       *K' =           0.463

CALCULATING FULL FLOW:
----------------------
  Qfull= (K'/n)*(d)^8/3*(S)^1/2
  Qfull1.060956048 CFS      OR           476 GPM

CALCULATING PERCENTAGE PIPE FLOWING FULL
----------------------------------------
  PERCENT FULL =          64 %       COMPARED TO MAXIMUM 90% FULL

CALCULATING  VELOCITY FLOWING FULL:
-----------------------------------
  V*A=(K'/n)*(d^2)*(d^2/3)*(S^1/2)
     Vfull =        3.01169 FPS   COMPARED TO 2.5 FPS MIN

SINCE,
       Qave =            66 GPM
       Qfull=           476 GPM

DISCHARGE PROPORTION = Qave/Qfull       0.14  (FIGURE 3-2, REF 3)

       *VELOCITY PROPORTION= Vactual/Vfull=     0.57

THEREFORE, THE ACTUAL VELOCITY IS

       Vactual =      1.72 FPS   COMPARED TO 2.0 FPS MINIMUM
```

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D 'OMA II JUNE 23, 1991

S E W E R   A N A L Y S I S

SEWER SYSTEM

*******CHECK WATER RECREATION PARK*******

FLOW BASED ON VITRIFIED CLAY PIPE WITH MINIMUM SLOPE BASED ON THE WASTE WATER MANAGEMENT STANDARDS

	NO. OF PER/ACR	FLOW/CAPITA	AVERAGE WW FLOW
17 WAT REC PARK	40 CPA	80 GCPD	60,800 GPD

AVE WASTE WATER FLOW =	60,800 GPD	
MAXIMUM WW FLOW =	304,000 GPD	(FACTOR =5)
DRY WEATHER INFILTRATION/INFLOW =	3,600 GPD	(ASSUME 5 GCD)
** DESIGN AVERAGE FLOW =	64,400 GPD OR	45 GPM
DESIGN MAXIMUM FLOW =	307,600 GPD	
WET WEATHER INFILTRATION/INFLOW =	23,750 GPD	(19 ACRES)
** DESIGN PEAK FLOW =	331,350 GPD OR	230 GPM

PEAK FLOW=Qp= 230 GPM
AVE FLOW=Qave= 45 GPM

ASSUME: *n= 0.015
*PIPE DIAMETER = d= 0.67 FEET
*SLOPE = 0.01 FEET/FOOT
*K' = 0.463

CALCULATING FULL FLOW:

Qfull= (K'/n)*(d)^8/3*(S)^1/2
Qfull1.060936048 CFS OR 476 GPM

CALCULATING PERCENTAGE PIPE FLOWING FULL

PERCENT FULL = 48 % COMPARED TO MAXIMUM 90% FULL

CALCULATING VELOCITY FLOWING FULL:

V*A=(K'/n)*(d^2)*(d^2/3)*(S^1/2)
Vfull = 3.01169 FPS COMPARED TO 2.5 FPS MIN

SINCE,
Qave = 45 GPM
Qfull= 476 GPM

DISCHARGE PROPORTION = Qave/Qfull 0.09 (FIGURE 3-2, REF 3)

*VELOCITY PROPORTION= Vactual/Vfull= 0.55

THEREFORE, THE ACTUAL VELOCITY IS

Vactual = 1.66 FPS COMPARED TO 2.0 FPS MINIMUM

O 'OMA II JUNE 23, 1991

S E W E R   A N A L Y S I S

SEWER SYSTEM

*******CHECK WATER PARK AND OCEAN CENTER*******

FLOW BASED ON VITRIFIED CLAY PIPE WITH MINIMUM SLOPE BASED ON THE WASTE WATER MANAGEMENT STANDARDS

	NO. OF PER/ACR	FLOW/CAPITA	AVERAGE WW FLOW
12 OCEAN CENTER	20 CPA	200 GCPD	48,000 GPD
19 WAT REC PARK	40 CPA	80 GCPD	60,800 GPD

AVE WASTE WATER FLOW =	108,800 GPD		
MAXIMUM WW FLOW =	576,640 GPD	(FACTOR =4.8)	
DRY WEATHER INFILTRATION/INFLOW =	5,000 GPD	(ASSUME 3 GCD)	
** DESIGN AVERAGE FLOW =	113,800 GPD OR		79 GPM
DESIGN MAXIMUM FLOW =	581,640 GPD		
WET WEATHER INFILTRATION/INFLOW =	38,750 GPD	(31 ACRES)	
** DESIGN PEAK FLOW =	620,390 GPD OR		431 GPM

PEAK FLOW=Qp= 431 GPM
AVE FLOW=Qave= 79 GPM

ASSUME: *n= 0.015
*PIPE DIAMETER = d= 0.67 FEET
*SLOPE = 0.012 FEET/FOOT
*K' = 0.463

CALCULATING FULL FLOW:

Qfull= (K'/n)*(d)^8/3*(S)^1/2
Qfull1.162197211 CFS OR 522 GPM

CALCULATING PERCENTAGE PIPE FLOWING FULL

PERCENT FULL = 83 % COMPARED TO MAXIMUM 90% FULL

CALCULATING VELOCITY FLOWING FULL:

V*A=(K'/n)*(d^2)*(d^2/3)*(S^1/2)
Vfull = 3.29914 FPS COMPARED TO 2.5 FPS MIN

SINCE,
Qave = 79 GPM
Qfull= 522 GPM

DISCHARGE PROPORTION = Qave/Qfull 0.15 (FIGURE 3-2, REF 3)

*VELOCITY PROPORTION= Vactual/Vfull= 0.6

THEREFORE, THE ACTUAL VELOCITY IS

Vactual = 1.98 FPS COMPARED TO 2.0 FPS MINIMUM

O 'OMA II JUNE 23, 1991

S E W E R   A N A L Y S I S

SEWER SYSTEM

*****OCEAN CENTER, WATER RECREATION PARK, BUSINESS TECH PARK, CLUB HOUSE AND CONDOMINIUMS

FLOW BASED ON VITRIFIED CLAY PIPE WITH MINIMUM SLOPE BASED ON THE WASTE WATER MANAGEMENT STANDARDS

DESCRIPTION	NO. OF PER/UNI	FLOW/CAPITA	AVERAGE WW FLOW
230 CONDOMINIUMS	4	80 GCPD	73,600 GPD
50 INN	4	80 GCPD	16,000 GPD
	NO. OF PER/ACR	**FLOW/CAPITA**	**AVERAGE WW FLOW**
12 OCEAN CENTER	20 CPA	200 GCPD	48,000 GPD
3 CONF/SCIE CE	40 CPA	80 GCPD	9,600 GPD
5 GOLF CB HOUS	40 CPA	80 GCPD	16,000 GPD
18 WAT REC PARK	40 CPA	80 GCPD	57,600 GPD

AVE WASTE WATER FLOW =	220,800 GPD	
MAXIMUM WW FLOW =	905,280 GPD	(FACTOR =4.1)
DRY WEATHER INFILTRATION/INFLOW =	12,000 GPD	(ASSUME 5 GCD)
** DESIGN AVERAGE FLOW =	232,800 GPD OR	162 GPM
DESIGN MAXIMUM FLOW =	917,280 GPD	
WET WEATHER INFILTRATION/INFLOW =	61,250 GPD	(49 ACRES)
** DESIGN PEAK FLOW =	978,530 GPD OR	680 GPM

PEAK FLOW=Qp= 680 GPM
AVE FLOW=Qave= 162 GPM

ASSUME: *n= 0.015
*PIPE DIAMETER = d= 1 FEET
*SLOPE = 0.01 FEET/FOOT
*K' = 0.463

CALCULATING FULL FLOW:

Qfull= (K'/n)*(d)^8/3*(S)^1/2
Qfull3.086666667 CFS OR 1385 GPM

CALCULATING PERCENTAGE PIPE FLOWING FULL

PERCENT FULL = 49 % COMPARED TO MAXIMUM 90% FULL

CALCULATING VELOCITY FLOWING FULL:

V*A=(K'/n)*(d^2)*(d^2/3)*(S^1/2)
Vfull = 3.93333 FPS COMPARED TO 2.5 FPS MIN

SINCE,
Qave = 162 GPM
Qfull= 1385 GPM

DISCHARGE PROPORTION = Qave/Qfull 0.12 (FIGURE 3-2, REF 3)

*VELOCITY PROPORTION= Vactual/Vfull= 0.58

THEREFORE, THE ACTUAL VELOCITY IS

Vactual = 2.28 FPS COMPARED TO 2.0 FPS MINIMUM

Q 'OMA II   JUNE 23, 1991

S E W E R   A N A L Y S I S

SEWER SYSTEM

****OCEAN CENTER, WATER RECREATION PARK, BUSINESS TECH PARK, CLUB HOUSE, CONDOMINIUMS, AND SHOPS

FLOW BASED ON VITRIFIED CLAY PIPE WITH MINIMUM SLOPE BASED ON THE WASTE WATER MANAGEMENT STANDARDS

DESCRIPTION	NO. OF PER/UNIFLOW/CAPITA		AVERAGE WW FLOW
230 CONDOMINIUMS	4	80 GCPD	73,600 GPD
50 INN	4	80 GCPD	16,000 GPD

	NO. OF PER/ACRFLOW/CAPITA		AVERAGE WW FLOW
12 OCEAN CENTER	20 CPA	200 GCPD	48,000 GPD
3 CONF/SCIE CE	40 CPA	80 GCPD	9,600 GPD
5 GOLF CB HOUS	40 CPA	80 GCPD	16,000 GPD
8 SHOPS	40 CPA	80 GCPD	25,600 GPD
19 WAT REC PARK	40 CPA	80 GCPD	60,800 GPD

AVE WASTE WATER FLOW =	249,600 GPD	
MAXIMUM WW FLOW =	973,440 GPD	(FACTOR =3.9)
DRY WEATHER INFILTRATION/INFLOW =	13,800 GPD	(ASSUME 5 GCD)
** DESIGN AVERAGE FLOW =	263,400 GPD OR	183 GPM
DESION MAXIMUM FLOW =	987,240 GPD	
WET WEATHER INFILTRATION/INFLOW =	77,500 GPD	(62 ACRES)
** DESIGN PEAK FLOW =	1,064,740 GPD OR	739 GPM

PEAK FLOW=Qp=   739 GPM
AVE FLOW=Qave=   183 GPM

ASSUME: *n=   0.015
*PIPE DIAMETER = d=   1 FEET
*SLOPE =   0.01 FEET/FOOT
*K' =   0.463

CALCULATING FULL FLOW:

Qfull= (K'/n)*(d)^8/3*(S)^1/2
Qfull3.086666667 CFS   OR   1385 GPM

CALCULATING PERCENTAGE PIPE FLOWING FULL

PERCENT FULL =   53 %   COMPARED TO MAXIMUM 90% FULL

CALCULATING VELOCITY FLOWING FULL:

V*A=(K'/n)*(d^2)*(d^2/3)*(S^1/2)
Vfull =   3.93333 FPS   COMPARED TO 2.5 FPS MIN

SINCE,
Qave =   183 GPM
Qfull=   1385 GPM

DISCHARGE PROPORTION = Qave/Qfull   0.13   (FIGURE 3-2, REF 3)

*VELOCITY PROPORTION= Vactual/Vfull=   0.58

THEREFORE, THE ACTUAL VELOCITY IS

Vactual = 2.28 FPS COMPARED TO 2.0 FPS MINIMUM

O 'OMA II JUNE 23, 1991

S E W E R A N A L Y S I S

SEWER SYSTEM
*****OCEAN CENTER, WATER RECREATION PARK, BUSINESS TECH PARK,
CLUB HOUSE, CONDOMINIUMS, SHOPS, AND HOTEL

FLOW BASED ON VITRIFIED CLAY PIPE WITH MINIMUM SLOPE BASED ON
THE WASTE WATER MANAGEMENT STANDARDS

DESCRIPTION	NO. OF PER/UNI	FLOW/CAPITA	AVERAGE WW FLOW
230 CONDOMINIUMS	4	80 GCPD	73,600 GPD
50 INN	4	80 GCPD	16,000 GPD
550 HOTEL	4	80 GCPD	176,000 GPD
	NO. OF PER/ACR	**FLOW/CAPITA**	**AVERAGE WW FLOW**
12 OCEAN CENTER	20 CPA	200 GCPD	48,000 GPD
3 CONF/SCIE CE	40 CPA	80 GCPD	9,600 GPD
5 GOLF CB HOUS	40 CPA	80 GCPD	16,000 GPD
8 SHOPS	40 CPA	80 GCPD	25,600 GPD
19 WAT REC PARK	40 CPA	80 GCPD	60,800 GPD

AVE WASTE WATER FLOW =	425,600 GPD		
MAXIMUM WW FLOW =	1,532,160 GPD		(FACTOR =3.6)
DRY WEATHER INFILTRATION/INFLOW =	24,800 GPD		(ASSUME 5 GCD)
** DESIGN AVERAGE FLOW =	450,400 GPD	OR	313 GPM
DESIGN MAXIMUM FLOW =	1,556,960 GPD		
WET WEATHER INFILTRATION/INFLOW =	105,000 GPD		(84 ACRES)
** DESIGN PEAK FLOW =	1,661,960 GPD	OR	1,154 GPM

PEAK FLOW=Qp= 1154 GPM
AVE FLOW=Qave= 313 GPM

ASSUME:*n= 0.015
*PIPE DIAMETER = d= 1 FEET
*SLOPE = 0.01 FEET/FOOT
*K' = 0.463

CALCULATING FULL FLOW:

Qfull= (K'/n)*(d)^8/3*(S)^1/2
Qfull3.086666667 CFS OR 1385 GPM

CALCULATING PERCENTAGE PIPE FLOWING FULL

PERCENT FULL = 83 % COMPARED TO MAXIMUM 90% FULL

CALCULATING VELOCITY FLOWING FULL:

V*A=(K'/n)*(d^2)*(d^2/3)*(S^1/2)
Vfull = 3.93333 FPS COMPARED TO 2.5 FPS MIN

SINCE,
Qave = 313 GPM
Qfull= 1385 GPM

DISCHARGE PROPORTION = Qave/Qfull 0.23 (FIGURE 3-2, REF 3)

*VELOCITY PROPORTION= Vactual/Vfull= 0.7

THEREFORE, THE ACTUAL VELOCITY IS

V_{actual} = 2.75 FPS COMPARED TO 2.0 FPS MINIMUM

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O 'OMA II JUNE 24, 1991

S E W E R   A N A L Y S I S

SEWER SYSTEM

*******CHECK FLOW ENTERING 6 ACRE SEWAGE TREATMENT PLANT*******

FLOW BASED ON VITRIFIED CLAY PIPE WITH MINIMUM SLOPE BASED ON THE WASTE WATER MANAGEMENT STANDARDS

DESCRIPTION	NO. OF PER/UNIT	FLOW/CAPITA	AVERAGE WW FLOW
70 SINGLE FAM	4	80 GCPD	22,400 GPD
230 CONDOMINIUMS	4	80 GCPD	73,600 GPD
50 INN	4	80 GCPD	16,000 GPD
550 HOTEL	4	80 GCPD	176,000 GPD
	NO. OF PER/ACRE	FLOW/CAPITA	AVERAGE WW FLOW
12 OCEAN CENTER	20 CPA	200 GCPD	48,000 GPD
3 CONF/SCI CEN	40 CPA	80 GCPD	9,600 GPD
5 GOLF CB HOUS	40 CPA	80 GCPD	16,000 GPD
8 SHOPS	40 CPA	80 GCPD	25,600 GPD
19 WAT REC PARK	40 CPA	80 GCPD	60,800 GPD

AVE WASTE WATER FLOW =	448,000 GPD	
MAXIMUM WW FLOW =	1,612,800 GPD	(FACTOR =3.6)
DRY WEATHER INFILTRATION/INFLOW =	26,200 GPD	(ASSUME 5 GCD)
** DESIGN AVERAGE FLOW =	474,200 GPD OR	329 GPM
DESIGN MAXIMUM FLOW =	1,639,000 GPD	
WET WEATHER INFILTRATION/INFLOW =	375,000 GPD	(300 ACRES)
** DESIGN PEAK FLOW =	2,014,000 GPD OR	1,399 GPM

PEAK FLOW=Qp= 1399 GPM
AVE FLOW=Qave= 329 GPM

ASSUME: *n= 0.015
*PIPE DIAMETER = d= 1.25 FEET
*SLOPE = 0.017 FEET/FOOT
*K' = 0.463

CALCULATING FULL FLOW:

Qfull= (K'/n)*(d)^8/3*(S)^1/2
Qfull7.296941996 CFS OR 3275 GPM

CALCULATING PERCENTAGE PIPE FLOWING FULL

PERCENT FULL = 43 % COMPARED TO MAXIMUM 90% FULL

CALCULATING VELOCITY FLOWING FULL:

V*A=(K'/n)*(d^2)*(d^2/3)*(S^1/2)
Vfull = 5.95103 FPS COMPARED TO 2.5 FPS MIN

SINCE,
Qave = 329 GPM
Qfull= 3275 GPM

DISCHARGE PROPORTION = Qave/Qfull = 0.1 (FIGURE 3-2, REF 3)

*VELOCITY PROPORTION= Vactual/Vfull= 0.72

THEREFORE, THE ACTUAL VELOCITY IS

V_{actual} = 4.28 FPS COMPARED TO 2.0 FPS MINIMUM

Sewer Force Main Sizing

FORCE MAIN SIZING
FOR
SEWAGE PUMP STATION #1

DATE: 6-24-91
FIRM: R. M. TOWILL CORP.

SPS NAME: SEWAGE PUMP STATION # 1
SPS LOCATION: NORTHWEST CORNER OF SITE

GIVEN:

1.	FLOW PER UNIT =		
2.	NO. OF UNITS =		
3.	AVE DAILY FLOW =	108,800 GPD	
4.	MAXIMUM FLOW (MGD) =	576,640 GPD	
5.	DRY WEATHER I/I (MGD) =	5,000 GPD	
6.	AVE DESIGN FLOW (MGD) =	113,800 GPD	79.03 GPM
7.	MAXIMUM DESIGN FLOW (MGD) =	581,640 GPD	
8.	WET WEATHER I/I (MGD) =	38,750 GPD	
9.	DESIGN PEAK FLOW =	620,390 GPD	430.83 GPM

WETWELL SIZING:

D = PUMP Q (GPM) =	370	
VOL = STORAGE VOL. (ON TO OFF) (GAL) =	TO BE DET.	
Q = AVE Q INTO WETWELL (GPM) =	79.03	
T = CYCLE TIME (MIN) = (15 MIN TO 20 MIN ALLOWABLE)	15	20

VOL = t*q/4 where, t=storage time, and q= maximum pumping rate

VOL (T=15 MIN)	1615.61 GAL	215.99 CF <=============
VOL (T=20 MIN)	2154.15 GAL	287.99 CF

VELOCITY CHECK:

SFM SIZE	AVE FLOW VEL (FPS)	PEAK FLOW VEL (FPS)	PEAK PUMPING RATE (C=140) VEL (FPS)
4 INCH	2.0	11.0	9.5
6 INCH	0.9 <----------	4.9	4.2 <--------
8 INCH	0.5	2.8	2.4
10 INCH	0.4	2.1	1.8
12 INCH	0.2	1.2	1.1

SYSTEM HEAD CURVE:

FORCEMAIN DIA. (IN) = 6
FORCEMAIN LENGTH (FT) = 1800
STATIC HEAD (FT) = 40

GPM	HL/100FT C= 100	FRIC. HL (OLD PIPE)	STATIC HL	TOTAL HL
50	0.0473914	0.85	40	40.85
70	0.0883154	1.59	40	41.59
100	0.1708462	3.08	40	43.08
150	0.3617213	6.51	40	46.51
200	0.6159008	11.09	40	51.09
250	0.930667	16.75	40	56.75
300	1.304006	23.47	40	63.47
350	1.7343277	31.22	40	71.22
400	2.2203235	39.97	40	79.97
450	2.7608857	49.70	40	89.70
500	3.3550561	60.39	40	100.39
550	4.0019924	72.04	40	112.04
600	4.7009442	84.62	40	124.62
700	6.2522546	112.54	40	152.54
800	8.0042705	144.08	40	184.08
900	9.9529981	179.15	40	219.15
1000	12.094983	217.71	40	257.71

GPM	HL/100FT C= 140	FRIC. HL (NEW PIPE)	STATIC HL	TOTAL HL
50	0.025431	0.46	40	40.46
70	0.0473914	0.85	40	40.85
100	0.0916787	1.65	40	41.65
150	0.1941052	3.49	40	43.49
200	0.3305019	5.95	40	45.95
250	0.4994102	8.99	40	48.99
300	0.6997497	12.60	40	52.60
350	0.930667	16.75	40	56.75
400	1.1914598	21.45	40	61.45
450	1.4815338	26.67	40	66.67
500	1.8003748	32.41	40	72.41
550	2.1475307	38.66	40	78.66
600	2.522599	45.41	40	85.41
700	3.3550561	60.39	40	100.39
800	4.2952148	77.31	40	117.31
900	5.3409321	96.14	40	136.14
1000	6.4903544	116.83	40	156.83

FORCE MAIN SIZING
FOR
SEWAGE PUMP STATION #2

DATE: 6-24-91
FIRM: R. M. TOWILL CORP.

SPS NAME: SEWAGE PUMP STATION # 2
SPS LOCATION: SOUTHWEST CORNER OF SITE

GIVEN:

1.	FLOW PER UNIT =		
2.	NO. OF UNITS =		
3.	AVE DAILY FLOW =	425,600 GPD	
4.	MAXIMUM FLOW (MGD) =	1,532,160 GPD	
5.	DRY WEATHER I/I (MGD) =	24,800 GPD	
6.	AVE DESIGN FLOW (MGD) =	450,400 GPD	312.78 GPM
7.	MAXIMUM DESIGN FLOW (MGD) =	1,556,960 GPD	
8.	WET WEATHER I/I (MGD) =	105,000 GPD	
9.	DESIGN PEAK FLOW =	1,661,960 GPD	1154.14 GPM

WETWELL SIZING:

D = PUMP Q (GPM) =	1000	
VOL = STORAGE VOL. (ON TO OFF) (GAL) =	TO BE DET.	
Q = AVE Q INTO WETWELL (GPM) =	312.78	
T = CYCLE TIME (MIN) = (15 MIN TO 20 MIN ALLOWABLE)	15	20

VOL = t*q/4 where, t=storage time, and q= maximum pumping rate

VOL (T=15 MIN)	4328.03 GAL	578.61 CF <============
VOL (T=20 MIN)	5770.70 GAL	771.48 CF

VELOCITY CHECK:

SFM SIZE	AVE FLOW VEL (FPS)	PEAK FLOW VEL (FPS)	PEAK PUMPING RATE (C=140) VEL (FPS)
4 INCH	8.0	29.5	25.5
6 INCH	3.6	13.1	11.4
8 INCH	2.0 <----------	7.4	6.4 <----------
10 INCH	1.5	5.6	4.9
12 INCH	0.9	3.3	2.8
14 INCH	0.7	2.4	2.1
16 INCH	0.5	1.8	1.6
18 INCH	0.4	1.5	1.3

SYSTEM HEAD CURVE:

FORCEMAIN DIA. (IN) = 8
FORCEMAIN LENGTH (FT) = 1400
STATIC HEAD (FT) = 35

GPM	HL/100FT	FRIC. HL (OLD PIPE)	STATIC HL	TOTAL HL
C=	100			
50	0.0116908	0.16	35	35.16
70	0.0217861	0.31	35	35.31
100	0.0421452	0.59	35	35.59
150	0.0892312	1.25	35	36.25
200	0.1519335	2.13	35	37.13
250	0.2295816	3.21	35	38.21
300	0.3216787	4.50	35	39.50
350	0.4278326	5.99	35	40.99
400	0.5477205	7.67	35	42.67
450	0.6810691	9.53	35	44.53
500	0.827642	11.59	35	46.59
550	0.9872315	13.82	35	48.82
600	1.1596524	16.24	35	51.24
700	1.5423374	21.59	35	56.59
800	197.45334	2764.35	35	2799.35
900	245.52553	3437.36	35	3472.36
1000	298.3651	4177.11	35	4212.11

GPM	HL/100FT	FRIC. HL (NEW PIPE)	STATIC HL	TOTAL HL
C=	140			
50	0.0062725	0.09	35	35.09
70	0.011689	0.16	35	35.16
100	0.0226125	0.32	35	35.32
150	0.0478759	0.67	35	35.67
200	0.0815179	1.14	35	36.14
250	0.123179	1.72	35	36.72
300	0.1725925	2.42	35	37.42
350	0.229548	3.21	35	38.21
400	0.2938723	4.11	35	39.11
450	0.3654188	5.12	35	40.12
500	0.4440606	6.22	35	41.22
550	0.5296862	7.42	35	42.42
600	0.6221965	8.71	35	43.71
700	0.8275211	11.59	35	46.59
800	1.0594103	14.83	35	49.83
900	1.3173354	18.44	35	53.44
1000	1.6008392	22.41	35	57.41

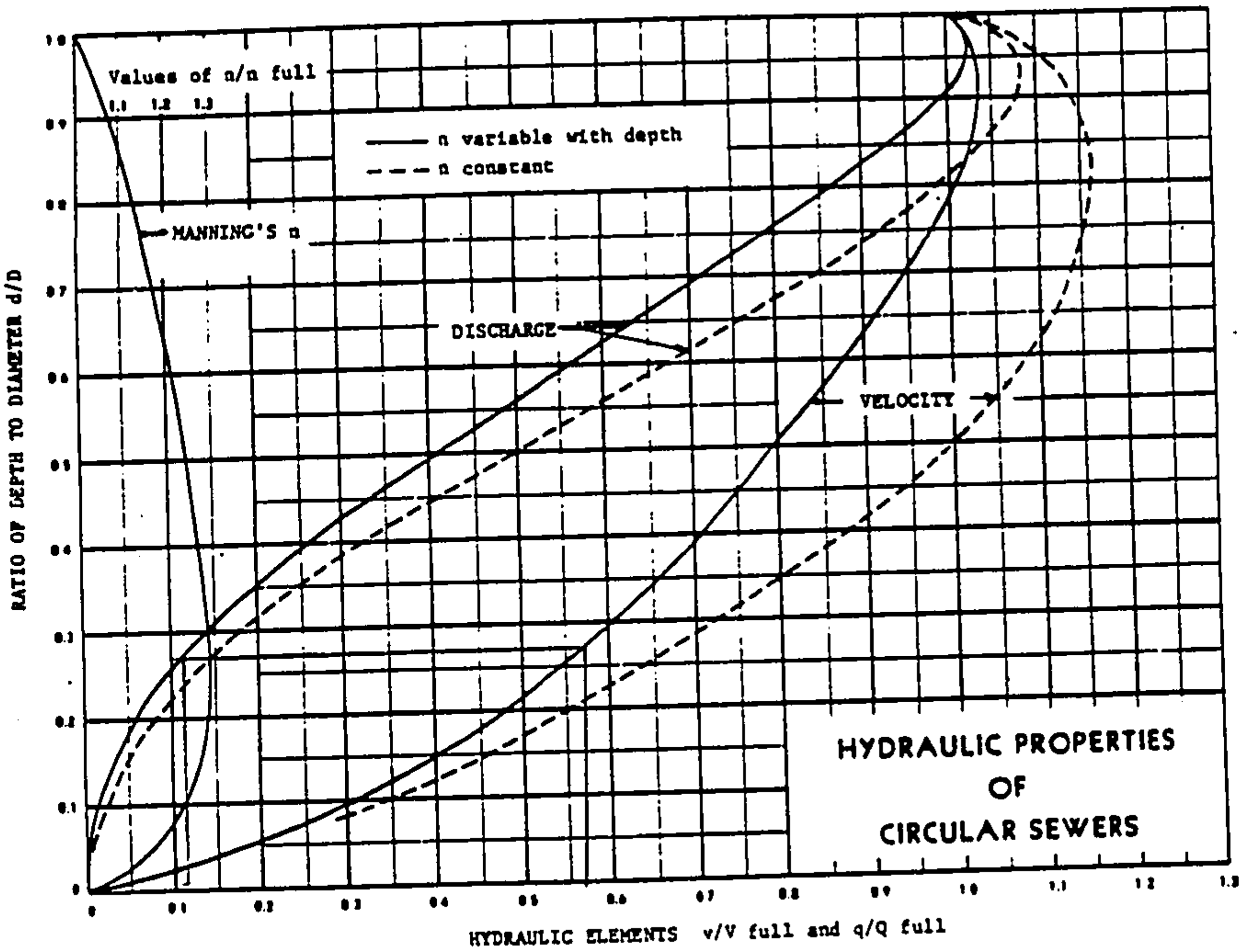
Sewer Design Guides

1) Clay Pipe Engineering Manual, July 1982
2) C&C of Honolulu, Wastewater Mgmt, Feb 1984
3) State Dept. of Health Guidelines, Nov. 1988

90 percent full. Critical depths for various flows and pipe diameters can be obtained from standard hydraulics textbooks.

3-3. Depressed sewers.

a. Velocity and flow analysis. Since a depressed sewer, or inverted siphon, is installed below the hydraulic grade line, the pipe will always be full of wastewater under pressure, even though there may be little or no flow. Thus, the design requires special care to secure velocities that will prevent clogging due to sedimentation of solids. The velocity should be as high as practicable, with a minimum requirement set at 3.0 feet per second. Hydraulic calculations may be based on the Manning formula or Hazen-Williams analysis. A minimum Manning roughness coefficient of 0.015 is recommended due to possible accumulations of grease and other materials on pipe walls. Procedures using Hazen-Williams design for pressure pipe flow are given in TM 5-814-2/AFM 88-11, Chapter 2. The pipe will be as small as the available head permits except that pipe smaller than 6-inch is not permitted. Inasmuch as the sewer must be of sufficient size to discharge the extreme peak flows, better velocities for the normal range of flows can often be obtained by using several small pipes instead of one large pipe. This requires an entrance box equipped with a diversion gate for the periodic alternation of pipes in service and with an overflow weir so arranged that, when the flow exceeds the capacity of one pipe, the excess can over-



Source: Clay Pipe Engineering Manual by National Clay Pipe Institute, July 1982, p. 25.

Figure 3-2. Hydraulic properties of circular sewers.

CHAPTER 20

DESIGN OF SEWERS

21. General

21.1 Type of System: All sewers shall be designed as Sanitary Sewers.

21.2 Ordinance Requirements: The wastewater from industrial or commercial plants should be thoroughly evaluated. Provisions of the existing City Ordinance (Sec. 11-1.6, Revised Ordinances of Honolulu, 1978, as amended) impose certain restrictions on the quantity, strength and character of industrial wastewater which may be discharged into public sewers.

22. Quantity of Wastewater

22.1 Design Period: In general, sewer systems should be designed for the estimated ultimate tributary equivalent population, except for systems that can be readily increased in capacity. Where Federal or other legal requirement dictates the use of other specific design period, the design period required by them may be used, unless modified by the City.

22.2 Design Flows: In determining the required capacities of sanitary sewers, the following factors shall be considered:

22.2.1 Average Daily per Capita Flow: New sewer systems shall be designed on the basis of an average per capita flow of wastewater of 80 gallons per day, unless other current data has been established by the City. Densities of residential occupancy shall be assumed to be 4 persons per home and 2.8 persons per apartment unit.

22.2.2 Other Average Flows: Other wastewater flows shall be based on land use or best available data, whichever is higher. Considerations shall be given for high wastewater generation for particular types of industries. The following equivalent populations or average flow data shall be used for the various land uses:

a.	Central Business	300 cpa.*
b.	Community Business	140 cpa.

c.	Neighborhood Business	40 cpa.
d.	Resort	400 cpa.
e.	Apartment (high density)	390 cpa.
f.	Apartment (medium density)	250 cpa.
g.	Apartment (low density)	85 cpa.
h.	General Industry	100 cpa.
i.	Waterfront Industry	40 cpa.
j.	School	25 gpcd.**
k.	Institution (hospital, etc.)	200 gpcd.

* cpa. = capita per acre
** gpcd. = gallon per capita per day

22.2.3 Average Wastewater Flow: The average wastewater flow is the sum of the applicable wastewater flow obtained in Sections 22.2.1 and 22.2.2 above.

22.2.4 Maximum Wastewater Flow: The maximum wastewater flow is obtained by multiplying the average flow by a flow factor. Except as noted in Section 11.1.5, Figure 22.2.4 shall be used to obtain the flow factor for the maximum rate of wastewater flows.

22.2.5 Dry Weather Infiltration/Inflow (I/I): The following rates of dry weather I/I shall be used in the design of sewers:

a. 35 gcd - sewers laid below the normal ground water table.

b. 5 gcd - sewers laid above the normal ground water table.

22.2.6 Design Average Flow: The design average flow is the sum of the average wastewater flow and the applicable dry weather infiltration/inflow rate.

22.2.7 Design Maximum Flow: The design maximum flow is the sum of the maximum flow and the applicable dry weather infiltration/inflow rate.

22.2.8 Wet Weather Infiltration/Inflow: The following rates shall be used in the design of sewers:

a. 2750 gad - sewers laid below the normal ground water table.

b. 1250 gad - sewers laid above the normal ground water table.

22.2.9 Design Peak Flow: The design peak flow of wastewater is the sum of the applicable quantities obtained from Sections 22.2.7 and 22.2.8.

22.2.10 Organization of Computation: Figure 22.2.10 shows the format desired for tabulating the results of computations for the design of sewers.

23. Hydraulics of Sewers

All gravity sewers shall be designed to carry the peak flow of wastewater without surcharging and to transport suspended solids in such a manner that deposits in sewers and odor nuisances therefrom are kept to a minimum.

23.1 Formula and "n" Values: All sewer design shall be based on the Manning Formula ($V = \frac{1.486}{n} r^{2/3} s^{\frac{1}{2}}$) using the "n" values given below:

23.1.1 0.015 -All pipes up to and including 18 inches in diameter.

23.1.2 0.013 - All pipes larger than 18 inches in diameter.

23.1.3 0.015 - Cast-in-place reinforced concrete conduit.

23.2 Velocities: All sewers shall be designed to give mean velocities of not less than 2.0 feet per second when flowing full. The following minimum slopes are to be used for the different sized pipes:

DIAMETER (inches)	MINIMUM SLOPE (ft. per ft.)
6	0.0060
8	0.0044
10	0.0032

DIAMETER (inches)	MINIMUM SLOPE (ft. per ft.)
12	0.0028
15	0.0020
18	0.0016
21	0.0010
24	0.0008

In the design of a sewer, ~~an attempt~~ shall be made to obtain adequate scouring veleocities at average flow. Where the initial flows are small or soil conditions are poor, adjustment in the minimum slope may be necessary. The maximum velocity generally permitted is 10 feet per second. Where velocities greater than this are unavoidable, special provisions shall be made to protect against erosion and displacement by shock. Specific approval of the City shall be obtained when these higher velocities are used.

23.3 Transitions: Whenever there are changes in size, grades, or alignment of sewers, the invert of the downstream sewer shall be designed to allow for transitional, manhole, and bend losses.

24. Design of Sewer System

24.1 Minimum Size: The minimum sizes permitted for sewers for as follows:

24.1.1 8 inch diameter for mains and branch mains in roadway areas.

24.1.2 6 inch diameter for branch mains in easements, provided such branch mains shall serve not more than 10 residential lots and there are no possibilities of future extensions.

24.1.3 6 inch diameter for laterals.

24.2 Alignment and Grades: Sewers less than 36 inches in diameter shall be laid with constant grades and straight alignment between manholes. Sewers 36 inches and larger in diameter may be laid on a curved alignment. The minimum curve radius shall be four times the inside diameter of the pipe. The maximum curve radius shall be approximately 10 diameters. A manhole shall be placed immediately before or after a segment of curved sewer.

24.3 Depth of Sewers: In general, sewers shall be designed deep enough to serve all properties within the tributary area and to drain all basements when it is economical to do so. All properties which are considered unsewerable by gravity because of the designed depth of sewer shall be clearly shown on the plans as UNSEWERABLE BY GRAVITY.

24.4 Minimum Cover Over Sewers: The following minimum cover should be provided over all sewers:

24.4.1 4 feet in paved areas.

24.4.2 3 feet in sidewalk areas.

24.4.3 2 feet in easements in private property not subjected to vehicular loads.

Where the required minimum cover is not provided, additional protection shall be provided by means of jacketing or other means acceptable to the City.

24.5 Easement Widths: Wherever possible, sewers shall be laid within roads or where existing easements are available. Where the former is unavailable or where new easements are necessary, the following widths shall be considered as the standard widths for easements.

24.5.1 Lateral and Branch Sewers: 6 feet for 6 in. and 8 in. diameter pipes.

24.5.2 Trunk and Interceptor Sewers:

a. 6 feet for 8 in. and 10 in. diameter pipes.

b. 10 feet for 12 in. to 21 in. diameter pipes.

c. 15 feet for 24 in. to 36 in. diameter pipes.

d. 20 feet for 42 in. to 60 in. diameter pipes.

e. 25 feet for 66 in. diameter or larger pipes.

24.5.3 Variations: The widths of easements specified in Sections 24.5.1 and 24.5.2 may be modified by the City when unusual conditions exist.

24.6 Manhole Location and Spacing: Manholes shall be installed at the end of each line, at all changes in grade, size, or alignment and at all points where sewer lines intersect except as specified in Section 24.2. When manhole spacing is not controlled by the preceeding limitations, they shall be spaced as equally as possible but not at a distance greater than that described below:

24.6.1 350 feet - pipes up to and including 36 inches in diameter in street areas.

24.6.2 250 feet - pipes up to and including 18 inches in diameter in easement areas.

24.6.3 350 feet - pipes larger than 18 inches and up to and including 36 inches in diameter in easement areas.

24.6.4 600 feet - pipes larger than 36 inches in diameter. Manhole locations in low points subject to flooding such as in gutters are to be avoided. Junction manholes may be omitted when a side sewer 8 inches or smaller joins an interceptor sewer 30 inches or larger which is on a straight alignment and when the addition of a manhole at this location would give a spacing of less than 50 feet from the nearest interceptor manhole and less than 300 feet from the other manhole. When the junction manhole on the interceptor is omitted, a manhole on the side sewer shall be provided at a distance of not more than 15 feet from the interceptor sewer.

24.7 Drop Manholes: A drop manhole or shallow drop manhole should be provided where a sewer enters a manhole at a height of 18 inches or more above the manhole invert, or where a smooth grade transition cannot be accomplished within the manhole.

24.8 Lateral Sewers: Laterals shall not exceed 100 feet in length. All laterals should end with an appropriate reducer (usually 6" x 4") at the property line.

24.9 Chimneys: Chimneys shall be provided for lateral connections if the sewer is deeper than 10 feet (top of pipe to ground line). The maximum height of chimneys shall be 12 feet. The chimney should extend to approximately 6 feet below the ground surface.

24.10 Protection of Water Systems:

24.10.1 Water Supply Interconnections: There shall be no physical connection between a public or private potable water supply system and a sewer, or appurtenance thereto which could permit the passage of any wastewater into the potable water supply.

24.10.2 Relation to Water Works Structures: While no general statement can be made to cover all conditions, it is generally recognized that sewers shall be kept remote from any public water supply wells or other water supply sources and structures.

24.10.3 Relations to Water Mains:

a. Horizontal separation: Sewers shall be laid at least 6 feet, horizontally, from any existing or proposed water main. When conditions prevent a lateral separation of 6 feet, a sewer may be laid closer than 6 feet to the water main under the following condition:

1. It is laid in a separate trench or it is laid in the same trench with the water main located to one side on a bench of undisturbed earth.

2. The elevation of the top (crown) of the sewer is at least 6 inches below the bottom (invert) of the water main.

3. Other alternatives such as a concrete jacket shall be considered.

b. Vertical separation: Whenever a sewer line crosses water mains, the sewer line must be jacketed with reinforced concrete for a minimum of 5 feet on both sides of the point of crossing if the sewer is above the water main and for 3 feet on both sides if the sewer is below the water main. However, jacketing may be eliminated if the sewer line is below the water main and the separation is greater than 18 inches and structural requirements are met.

25. Appurtenances

25.1 Manholes: A standard 48 inch diameter manhole shall be provided for pipes less than 30 inches in diameter. Special manholes shall be provided for pipes 30 inches and larger in diameter. Manholes for these larger pipes may be of shapes other than round. However, the access shaft shall have a minimum dimension of 48 inches.

25.1.1 Material Types:

a. Brick manholes: The maximum height of brick manholes shall be 10 feet. It shall not be used below the normal ground water table.

b. Cast-in-place concrete manholes: This manhole may be used in all locations and at any depth.

c. Precast manholes: The use of precast manholes is permitted below the ground water table if it is made water tight. Its use is not permitted in easements and/or in areas not accessible to equipment unless the upper 4 feet is made of brick to facilitate future height adjustments.

25.1.2 Functional Types:

a. Plain manhole: A plain manhole can be used where the difference in elevation between the incoming sewer and the manhole invert is less than 18 inches.

b. Shallow drop manhole: A shallow drop manhole shall be provided where a sewer enters a manhole at an elevation in the range of 18 inches to 5 feet above the manhole invert.

c. Drop manhole: A drop manhole shall be provided where a sewer enters a manhole at an elevation of over 5 feet above the manhole invert.

25.1.3 Watertightness: In manhole locations where flooding is unavoidable, provide for minimizing inflow through the cover. Manhole walls below the ground water table shall be watertight.

25.1.4 Flow Channel: The flow channel through manholes shall provide for smooth transitions taking into consideration the shape and slope of the incoming and outgoing sewers.

25.1.5 Manhole Cover: Type "SA" cast iron manhole frames and covers (22 inch opening) shall be used for all sewers with pipes 21 inches or less in diameter. For lines 24 inches and larger, Type "SB" manhole frames and covers (31½ inch opening) shall be required. Special junction structures shall be provided with at least one Type "SB" manhole frame and cover.

25.1.6 Manhole Connections: Each pipe entering or leaving manholes shall have a stub not exceeding 24 inches long. The stub may be omitted where a resilient connection is approved and provided.

25.2 Other Junction Structures: Where large lines meet, junction chambers shall be used. These are specially designed and are not considered to be standard. These structures shall be provided with an access manhole and ventilation shaft(s).

25.3 Ventilation Shaft: Ventilation shafts shall be provided for wetwells and special structures. Ventilation shafts shall be at least 24 inches in diameter. More than one shaft may be required in special cases.

25.4 Siphons: Siphons shall have not less than 2 barrels, with a minimum pipe size of 6 inches and shall be provided with necessary appurtenances for convenient flushing and maintenance. The manholes shall have adequate clearances for rodding. In general, sufficient head shall be provided and pipe sizes selected to secure velocities of at least 3 feet per second for design flows but not more than 10 feet per second at maximum flows. The inlet and outlet details shall be arranged so that: 25.4.1 The normal flow is diverted to one barrel.

25.4.2 Any barrel may be cut out of service.

26. Materials

26.1 Pipes: Any generally accepted material for sewers will be given consideration, but the material selected should be adapted to local conditions such as character of industrial wastewater, possibility of septicity, soil characteristics, external loadings, abrasion, ground water conditions, leakage, and similar problems. All sewers shall be designed to safely carry the superimposed loads. Proper allowance for loads on the sewer shall be made because of the width and depth of the trench.

Corrosion resistant lining, coating, and wrapping shall be used when extra corrosion protection is required. The following materials have been accepted and approved for use in the sanitary sewer system in the City and County of Honolulu within the limitations described:

26.1.1 Vitrified Clay Sewer Pipe - Extra Strength: Used for gravity sewers only.

26.1.2 Reinforced Concrete Pipe: Used for gravity lines 15 inches and larger. Reinforced concrete pressure pipe may be used for siphons.

26.1.3 Cast Iron or Ductile Iron Pipe (Cement lined and coated): Used for siphons, and for gravity sewer where unusual loads are expected, such as over or under streams.

26.1.4 Cast-In-Place Concrete Conduits: Used in special cases when conditions restrict the use of pipes.

26.1.5 Polyvinyl Chloride (PVC) Plastic Pipe: Used only for gravity sewers in agricultural, residential, and apartment zoned areas and in sizes from 6 inches to 12 inches in diameter. It shall also be used only in suitable soils. Additional design requirements are applicable.

26.1.6 Concrete Cylinder Pipe: Used for siphons. The pipe shall be made of a welded sheet-steel cylinder with circumferential reinforcement and shall be lined with centrifugally cast cement mortar. The exterior shall be coated with mortar. All joints shall be sealed with O-ring gaskets and all steel surfaces shall be protected with approved products. Corrosion resistant linings shall be used when extra corrosion protection is required.

26.2 Joints: All joints shall be designed to minimize infiltration or exfiltration. Flexible joints shall be used for gravity sewers. Double rubber gaskets may be used for larger diameter pipes to facilitate construction and testing.

27. Structural Considerations

27.1 Maximum Cover: The maximum allowable cover over sewers shall be determined by type of pipe, bedding condition, soil conditions, and other conditions and shall be determined by calculations. Where the maximum allowable cover is exceeded, additional protection shall be provided. The protection may be jacketing, substitution of a stronger pipe, or any other approved means.

27.2 Loads Imposed by Other Utilities: Sewer lines which cross over or under other conduits and utilities may require protection from extra loading. When the sewer crosses a conduit and the clearance is less than 12 inches, the sewer line should be jacketed with reinforced concrete for a distance of 5 feet (inside diameter plus 5 feet if conduit is over 24 inches inside diameter). Where the clearance is greater than one foot but less than 2 feet, a plain concrete jacket may be used. Final determination of structural requirement will be made by the City.

27.3 Other Imposed Loads: Consideration shall be given to all imposed loads (vehicles, retaining walls, drainage structures, etc.) on the pipes.

27.4 Pipe Cradles: All sewer pipes shall be supported by crushed rock cradles. However, as an alternate, the pipes may be supported by plain concrete cradles, reinforced concrete cradles, reinforced concrete cradles on piles or other approved means.

Where unstable soil conditions exist, the underlying unstable soils shall be replaced with crushed rock. The determination of the depth of unstable soils to be removed shall be made by the design engineer and approved by the City. If an agreement cannot be reached, the design engineer shall engage, at his cost, the services of a registered professional engineer qualified in soil mechanics for recommendations.

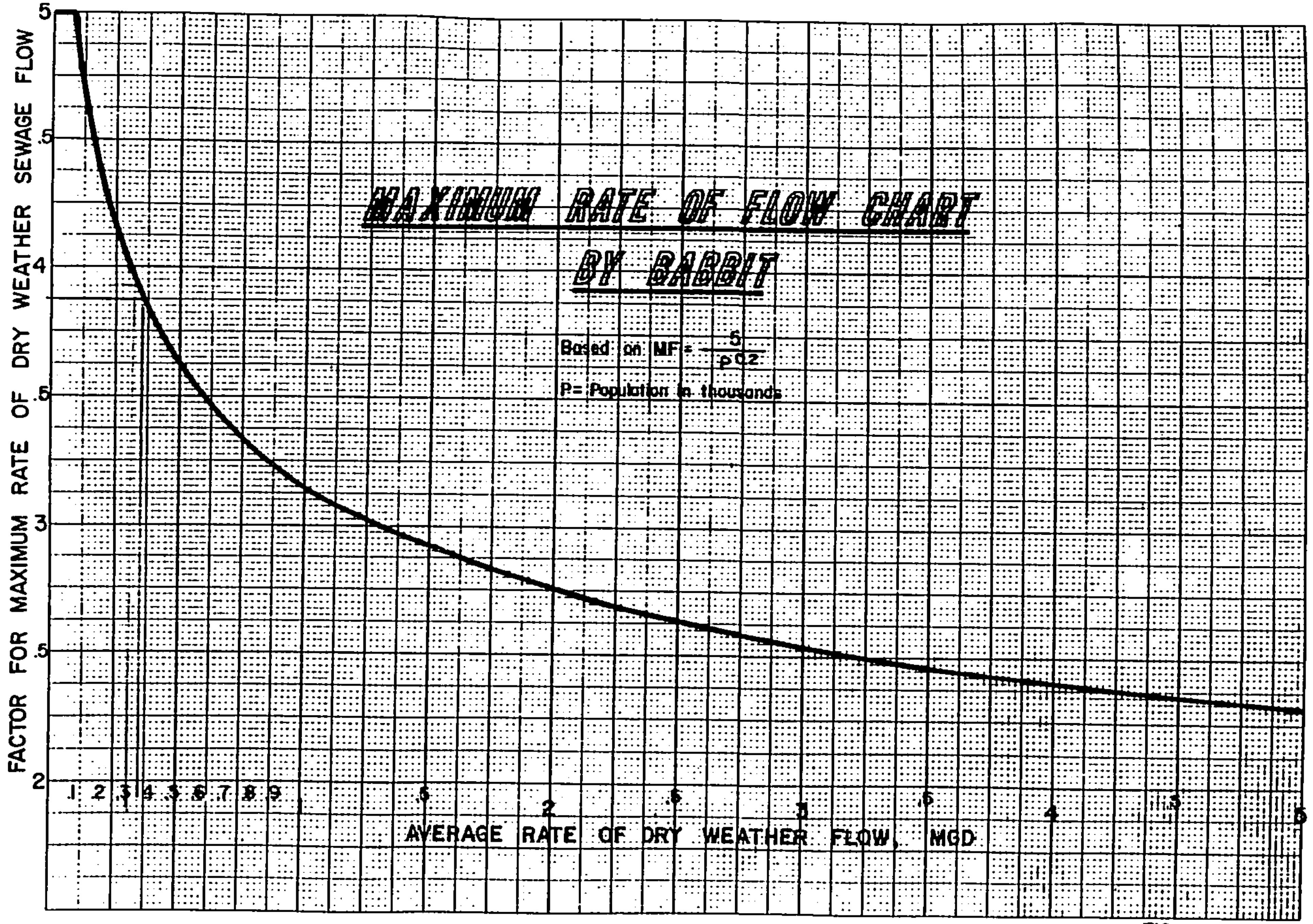

MAXIMUM RATE OF FLOW CHART
BY BABBIT
Based on MF = 5 / P^0.2
P= Population in thousands
FACTOR FOR MAXIMUM RATE OF DRY WEATHER SEWAGE FLOW
AVERAGE RATE OF DRY WEATHER FLOW, MGD
5
.5
4
.5
3
.5
2
.1 .2 .3 .4 .5 .6 .7 .8 .9
.5
2
.5
3
.5
4
.5
5

FIG. 22.2.4

DEPARTMENT OF HEALTH

Adoption of Chapter 11-62
Hawaii Administrative Rules

NOVEMBER 14, 1988

SUMMARY

Chapter 11-62, Hawaii Administrative Rules, entitled "Wastewater Systems," is adopted.

TABLE I

Type of Establishment	Gallons Per Person Per Day (Unless Otherwise Noted)	Wastewater Strength Lbs. BOD_5 Per Person Per Day
Airports (per passenger)	5	0.06
Bathhouses and swimming pools	10	0.06
Camps:		
Campground with central comfort stations	35	0.10
With flush toilets, no showers	25	0.06
Construction camps (semi-permanent)	50	0.15
Day camps (no meals served)	15	0.12
Resort Camps (night and day) with limited plumbing	50	0.12
Luxury camps	100	0.17
Cottages and small dwellings with seasonal occupancy (2 persons per bedroom minimum)	100	0.17
Country clubs (per resident member)	100	0.12
Country clubs (per non-resident member present)	25	0.03
Dwelling (2 persons per bedroom minimum)	100	0.17
Factories (gallons per person, per shift, exclusive of industrial wastes)	35	0.10
Hospitals (per bed space)	250+	0.20
Hotels with private baths (2 persons per bedroom minimum)	100	0.17
Hotels without private baths	50	0.17
Institutions other than hospitals (per bed space).	125	0.17
Laundries, self-service (gallons per wash, i.e., per customer)	50	0.25
Mobile home parks (per space)	250	0.17
Motels with bath, toilet, and kitchen wastes (per bed space)	50	0.15
Motels (bed space)	60	0.12
Picnic parks (toilet wastes only) (per picnicker)	5	0.06
Picnic parks with bathhouses, showers, and flush toilets	10	0.10
Restaurants (toilet and kitchen wastes per patron)	10	0.06
Restaurants (kitchen wastes per meal served)	3	0.03
Restaurants additional for bars and cocktail lounges	2	0.02
Schools:		
Boarding	100	0.17
Day, without gyms, cafeteria, or showers	15	0.04
Day, with gyms, cafeteria, and showers	25	0.08
Day, with cafeteria, but without gyms, or showers	20	0.06
Service stations (per vehicle served)	10	0.06
Swimming pools and bathhouses	10	0.06
Theaters:		
Movie (per auditorium seat)	5	0.03
Drive-in (per car space)	5	0.03
Travel trailer parks without individual water and sewer hook-ups (per space)	50	0.12
Travel trailer parks with individual water and sewer hook-ups (per space)	100	0.17
Workers:		
Construction (at semi-permanent camps)	50	0.15
Day, at schools and offices (per shift)	15	0.06

TABLE I

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Institutions other than hospitals (per bed space).	125	0.17
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Motels with bath, toilet, and kitchen wastes (per bed space)	50	0.15
Motels (bed space)	60	0.12
Picnic parks (toilet wastes only) (per picnicker)	5	0.06
Picnic parks with bathhouses, showers, and flush toilets	10	0.10
Restaurants (toilet and kitchen wastes per patron)	10	0.06
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Service stations (per vehicle served)	10	0.06
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Movie (per auditorium seat)	5	0.03
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Workers:		
Construction (at semi-permanent camps)	50	0.15
Day, at schools and offices (per shift)	15	0.06

STORM DRAINAGE SYSTEM

Ref. M&E Pacific EIS Report for O'oma II 9/86

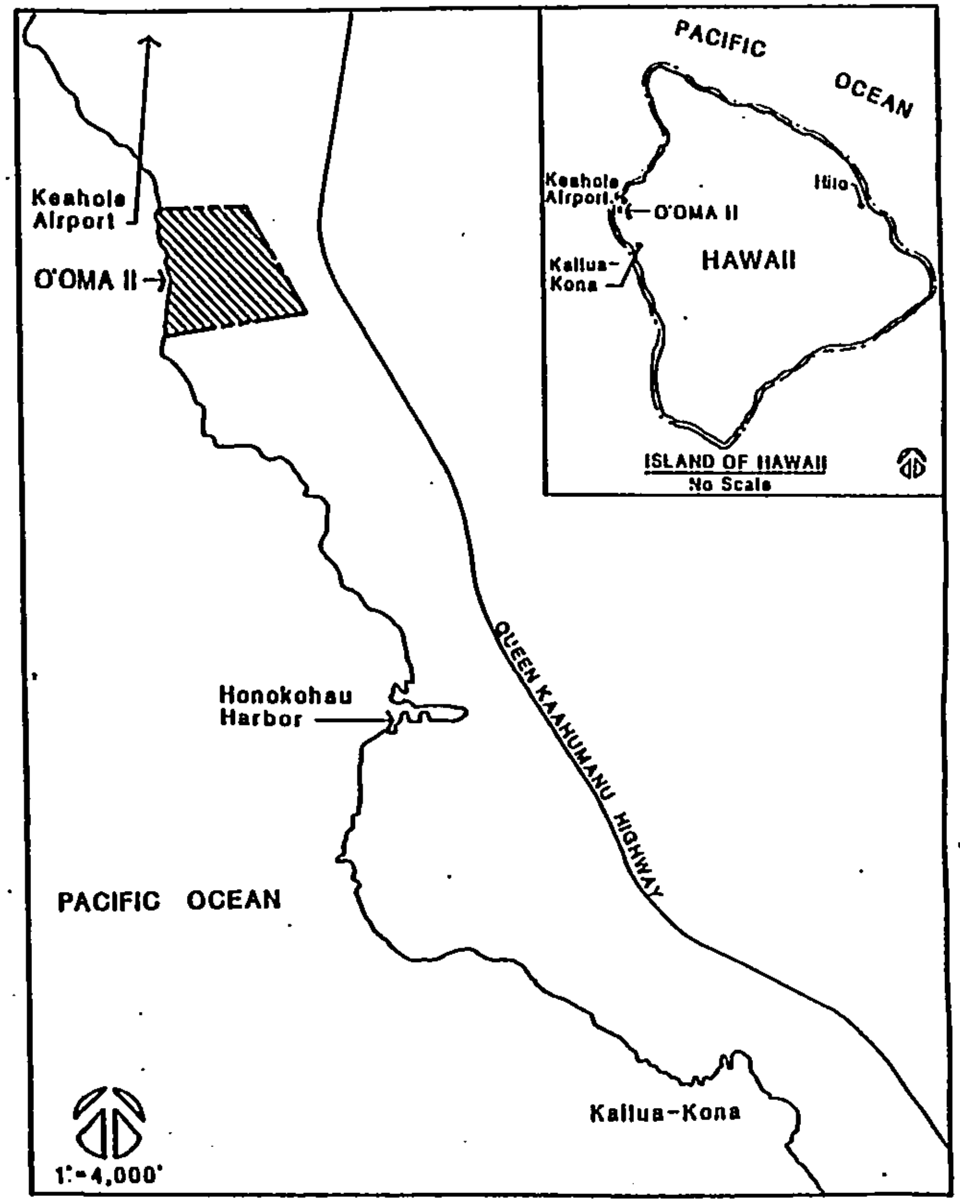
CHAPTER I
INTRODUCTION

PURPOSE

This report has been prepared as a support document on utilities infrastructure for an environmental impact statement, a land use district boundary amendment petition, and any other required permit for the proposed O'oma II Development. The information presented herein is based on public and private documents related to the project as well as the North Kona region of Hawaii.

PROJECT SITE

The proposed project is sited on the leeward coast of the Island of Hawaii, between Keahole Airport and the town of Kailua-Kona (see Figure 1). The project site is currently in its natural state, consisting largely of near-barren lava fields with poorly vegetated areas.



Location Map
O'OMA II
Kahala Capital Corporation
M & E PACIFIC, INC.
Figure: 1

CHAPTER II
STORM DRAINAGE

O'OMA II WATERSHED

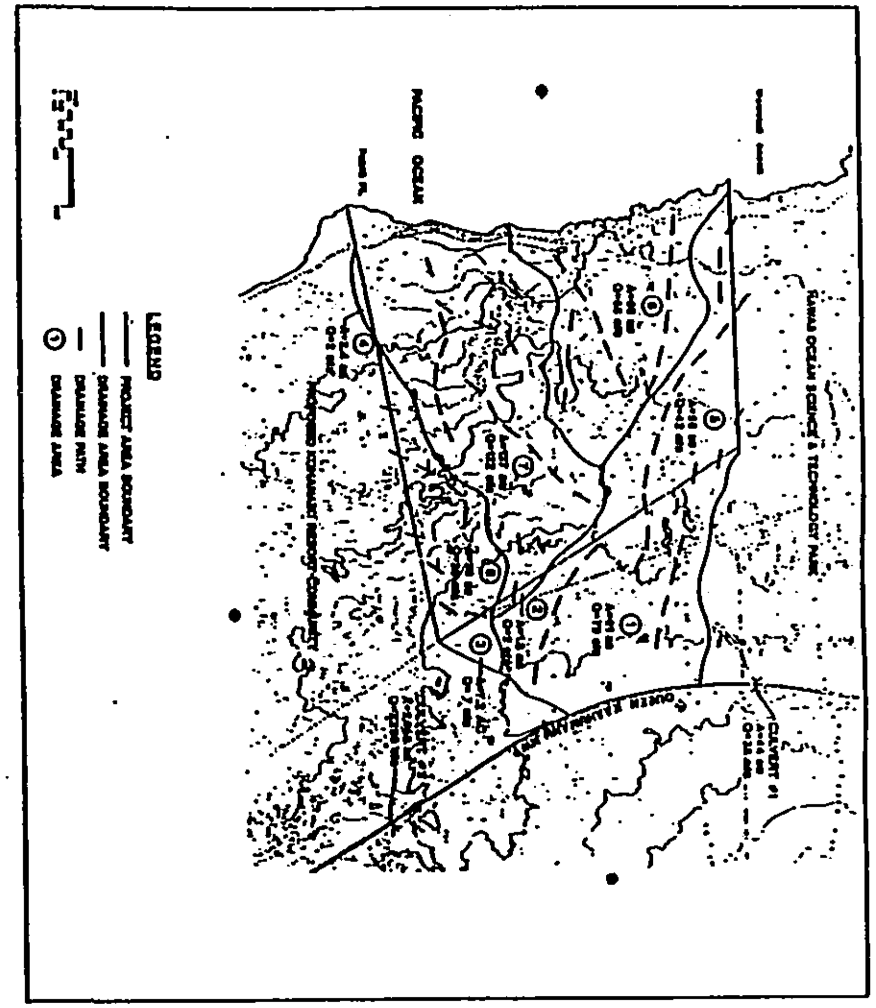
The existing O'oma II watershed contains an area of approximately 482 acres and extends from the western slopes of Hualalai volcano to the coast (see Figure 2). Elevations in the watershed range from 280 feet to mean sea level and ground slope varies from 5 percent in the upper elevations to 1 percent near the coast. Average ground slope in the watershed is approximately 3 percent.

Soil cover within the watershed consists of lava originating from eruptions at Hualalai. The lava is very porous and highly permeable, as evident by the numerous cracks, fissures, and tubes embedded in the surface layer. Dry grasses and shrubs grow sparsely throughout the lava flows and natural soil erosion is minimal.

The project site, located on the semi-arid leeward side of the island, is sheltered from the rain-producing northeast tradewinds by Mauna Loa, Mauna Kea, and Hualalai. The mean annual rainfall within the coastal project site is less than 20 inches. The wettest period of the year extending from May to September receives more than half of the total annual rainfall.

METHODOLOGY

The estimated storm runoff quantities herein have been based on the Storm Drainage Standards, Department of Public Works, County of Hawaii. Peak flows from drainage areas greater than 100 acres were determined from design curve Zone D on Plate 6, which is based upon maximum recorded flood peaks in the region. For drainage areas less than 100 acres, runoff quantities were determined according to the rational method, based upon a recurrence interval of 10 years.



Existing Drainage

O'OMA II

Kahala Capital Corporation

M & E PACIFIC, INC.

Figure 2

EXISTING DRAINAGE

Offsite Drainage to Queen Kaahumanu Highway

There are no perennial streams of well-defined water courses in the watershed due to a combination of meager rainfall and the lava landscape. Storm water primarily sheet flows downward from the upper parts of the watershed to Queen Kaahumanu Highway. A drainage ditch along the mauka side of the highway intercepts this runoff and conveys it to a culvert south of the O'oma II drainage basin. Another culvert, located just north of O'oma II, discharges runoff away from the project district.

Onsite Drainage

The O'oma II watershed, shown on Figure 2, extends west to east from the coastline to Queen Kaahumanu Highway. To the north and south, the watershed is bound by the project district boundary. The basin is divided into eight principal drainage areas (DA), with their respective areas, peak storm runoff, and flow patterns illustrated on Figure 2.

DA 1 occupies a 91-acre area between the eastern boundary of the O'oma II project district and Queen Kaahumanu Highway. The 79 cfs of storm runoff enters the project district across the eastern boundary and combines with the 42 cfs runoff from DA 5. Runoff from DA 1 and the 56-acre DA 5 drains across the northern project boundary.

On the southern side of the project, runoff from offsite DA 3 and onsite DA 8 drains away from the project site through the southern boundary. The 7.2-acre DA 3 discharges 7 cfs of runoff across the eastern project boundary into DA 8, which generates 26 cfs of runoff from its 38-acre area.

The coastline, forming the western project boundary, receives a total of 194 cfs of runoff from onsite and offsite areas. The onsite areas include the 80-acre DA 6 and the 137-acre DA 7, which contribute 68 and 122 cfs respectively. The 2 cfs of runoff produced by the 1.8-acre offsite DA 2

flows across the eastern boundary and into onsite DA 7. Offsite area DA 4 also drains into DA 7, contributing 2 cfs from its 2.4 acres.

In summary, a total runoff of 90 cfs enters the project site from the eastern and southern boundaries and 268 cfs of runoff is generated within the 313-acre project area. The O'oma II coastline receives 190 cfs of runoff from onsite areas and 4 cfs from offsite areas. The remaining 164 cfs of onsite and offsite runoff flow across the northern and southern project district boundaries and into the adjacent HOST Park and Kohanaiki properties.

MODIFIED DRAINAGE

The modified O'oma II drainage pattern consists of 26 onsite and 4 offsite drainage areas as shown on Figure 3. The runoff quantities and flow pattern are dictated by changes in land use, the prevailing slope of the land, and locations of the discharge points.

The overall drainage scheme would protect developed areas by intercepting storm runoff from open and offsite areas by means of a network of cut-off ditches, inlets, and drain pipes. The drain pipes, located within the roads, form the major artery for collecting and transporting onsite runoff to ultimate disposal points. Offsite runoff would be intercepted by cut-off ditches along the project district boundary. Within the project area, swales and ditches would prevent runoff from the golf course and open areas from entering the condominium, hotel, and other developed sites. The use of unlined channels wherever possible would allow infiltration of runoff into the porous lava rock and thus minimize flows at the discharge points.

All of the offsite and 75 percent of the onsite runoff would be transported to the two drainage outlets, located at the north and south ends of the O'oma II coast, and discharged into the ocean. Because these two outlets each drain an area in excess of 100 acres, their respective discharge flow rates, shown on Figure 3, were determined by reference to the County Storm Drainage Standards (County of Hawaii, 1970). Thus, the north outlet would carry a peak discharge of 500 cfs from 209 acres and the south outlet 400 cfs from 139 acres.

The remaining 25 percent of onsite runoff would either be disposed of into dry wells or allowed to drain naturally. Runoff from the hotel (DA 18) and the Marine Park and Visitor Center (DA 21) would be disposed of into dry wells located on their respective properties. The marine park receives an additional 5 cfs of runoff from the undeveloped parcel (DA 20) along its mauka border. Given a 4 cfs capacity per dry well, eleven dry wells would be required for the 43 cfs peak runoff from DA 20 and 21. Similarly, DA 18 would require eight dry wells for disposal of 30 cfs of runoff.

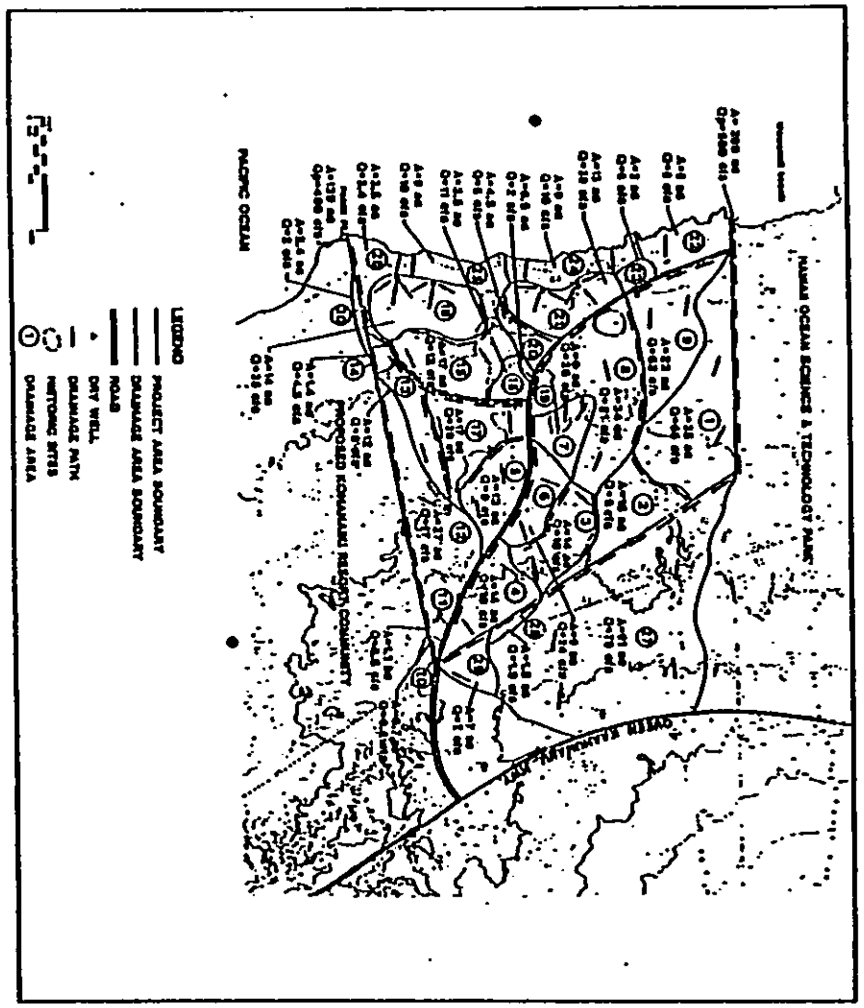
Based on the existing topography, the dry wells would be concentrated in the locations indicated on Figure 3. The 37 cfs runoff generated by the coastal and beach front areas (DA 22 to 26) would drain naturally by sheet flow into the ocean and by percolation into the soil.

IMPACTS OF MODIFIED DRAINAGE

The change in land use created by the proposed O'oma II development is expected to increase storm runoff within the 313-acre project site from 260 cfs to 450 cfs. However, land use and runoff potential from offsite DA 27 to 30 are not expected to change from their existing states.

Under existing drainage conditions (Figure 2), 190 cfs of runoff flows to the O'oma II coastline. The proposed drainage modifications would reduce sheet flow into the coastal area to only 37 cfs. This would be a result of concentrating the runoff to two points located at the northern and southern ends of the shoreline where impacts of the runoff to the prime beach front area would be minimized.

Potential impacts to the HOST Park warm water intake pipes near the north drainage outlet are expected to be minimal and infrequent. A 147-acre area of the O'oma II basin naturally drains into the shoreline near the HOST Park warm water intake pipes. By comparison, the area draining



Modified Drainage
O'OMA II
Kahala Capital Corporation
M & E PACIFIC, INC.
Figure: 3

into the north outlet under modified drainage conditions totals 209 acres, or an increase of 42 percent. Referring to the County Storm Drainage Standards (County of Hawaii, 1970), a 147-acre area would generate 400 cfs and a 209-acre area 500 cfs, an increase of only 25 percent. Additionally, storm runoff of the design magnitude should not be a factor in the normal operations of the HOST Park warm water intake pipes due to the design rain storm statistically occurring once every one hundred years.

APPENDIX S

TRAFFIC IMPACT ANALYSIS

The Traffic Management Consultant

TRAFFIC IMPACT ANALYSIS REPORT
FOR THE PROPOSED

O'OMA II

PREPARED FOR

HELBER, HASTERT, & FEE

JULY 29, 1991

PREPARED BY

TMC **THE TRAFFIC MANAGEMENT CONSULTANT**

RANDALL S. OKANEKU, P. E. • PRINCIPAL

1188 BISHOP STREET, SUITE 1907
HONOLULU, HAWAII 96813

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EXHIBITS

TRAFFIC IMPACT ANALYSIS REPORT FOR THE PROPOSED

O'OMA II

I. INTRODUCTION

A. Purpose of Study

The purpose of this study is to assess the traffic impacts resulting from the proposed O'oma II Master Plan in North Kona, Hawaii. This report presents the findings and recommendations of the study.

B. Scope of Study

The scope of this study includes:

1. Description of the proposed project.
2. Description of the study area and existing land uses.
3. Evaluation of existing roadway and traffic conditions.
4. Estimation of future traffic without the proposed project.
5. Analysis of future traffic conditions and the evaluation of roadway improvements to meet future highway needs without the proposed project.
6. Development of trip generation characteristics for the proposed project.
7. Superimposing the site-generated traffic over future traffic conditions.
8. The identification and analysis of traffic impacts resulting from the proposed project.
9. Recommendation of improvements that would mitigate the traffic impacts resulting from the development of the proposed project.

II. PROJECT DESCRIPTION

A. Location

O'oma II is located on the makai (west) side of Queen Kaahumanu Highway, approximately 2.1 miles south of the Keahole Airport in North Kona, Hawaii. The Hawaii Ocean Science & Technology (HOST) Park is located immediately to the north of the 300 acre site project. The proposed Kohanaiki Resort is located immediately to the south of the project site. The project vicinity is shown on Exhibit 1.

B. Site Characteristics

1. Site Plan

The proposed O'oma II project contains a variety of land uses located along a collector roadway, intersecting Queen Kaahumanu Highway near the site's southern boundary. The site plan is shown in Exhibit 2.

2. Proposed Land Use Intensity

O'oma II is a mixed use development containing a variety of land use activities. These include: an 18-hole golf course covering approximately 176 acres; a 550-room hotel; a 50-room inn; a commercial project consisting of 35,000 square feet of floor area; a 12-acre ocean science center and a 3-acre conference center; a 19-acre water recreation park; 70 single-family residential lots; and 230 multi-family residential dwelling units.

For the purpose of the trip generation analysis, certain assumptions on occupancy of the residential units were made, based upon marketing analysis. Of the 70 single-family lots: 42 units are expected to be occupied by full-time residents; 21 units are expected to be "second" or recreational homes; and 7 units are expected to be visitor accommodations. Of the 230 multi-family units: 58 units are expected to be occupied by full-time residents; 57 units are expected to be "second" or recreational homes; and 115 units are expected to be visitor accommodations. The additional visitor-oriented dwelling units brings the total visitor accommodations to 722 rooms. The recreational homes total 78 dwelling units.

For the purpose of this study, the project is analyzed at full build out condition by the Year 1998.

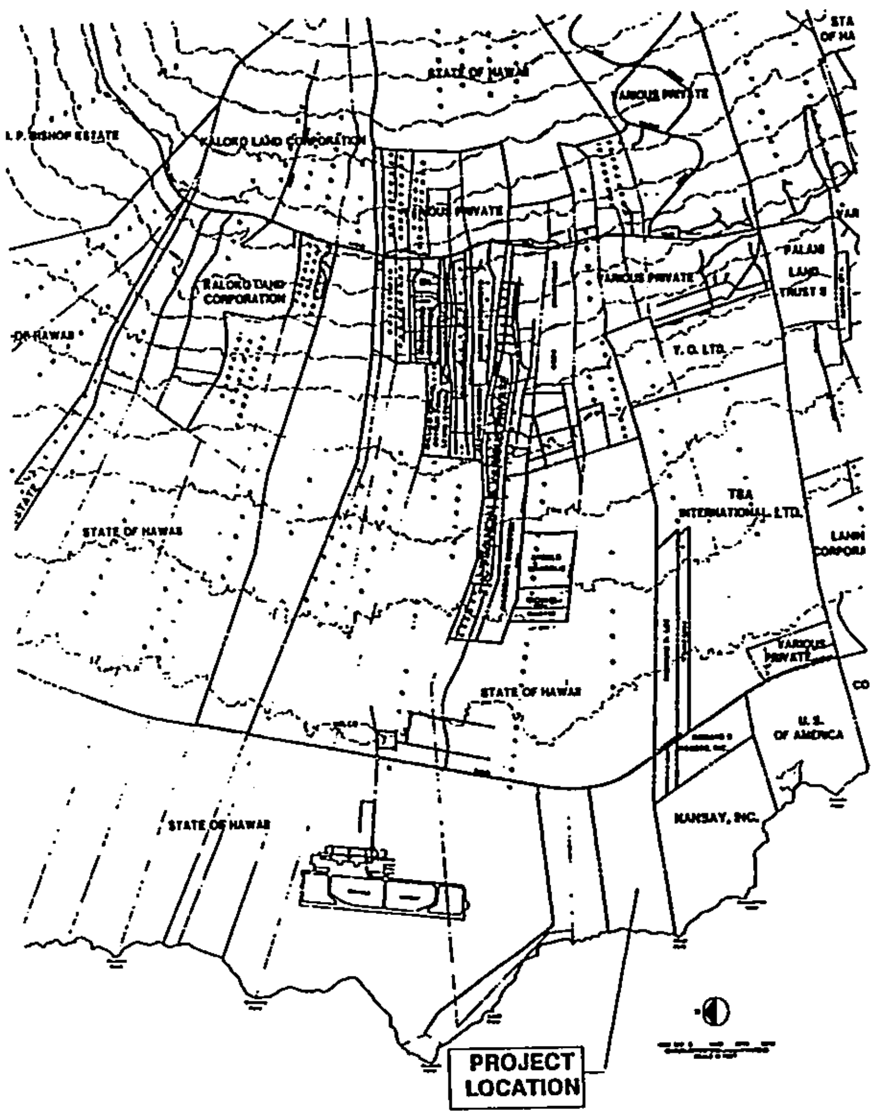


EXHIBIT 1 - VICINITY MAP

-3-

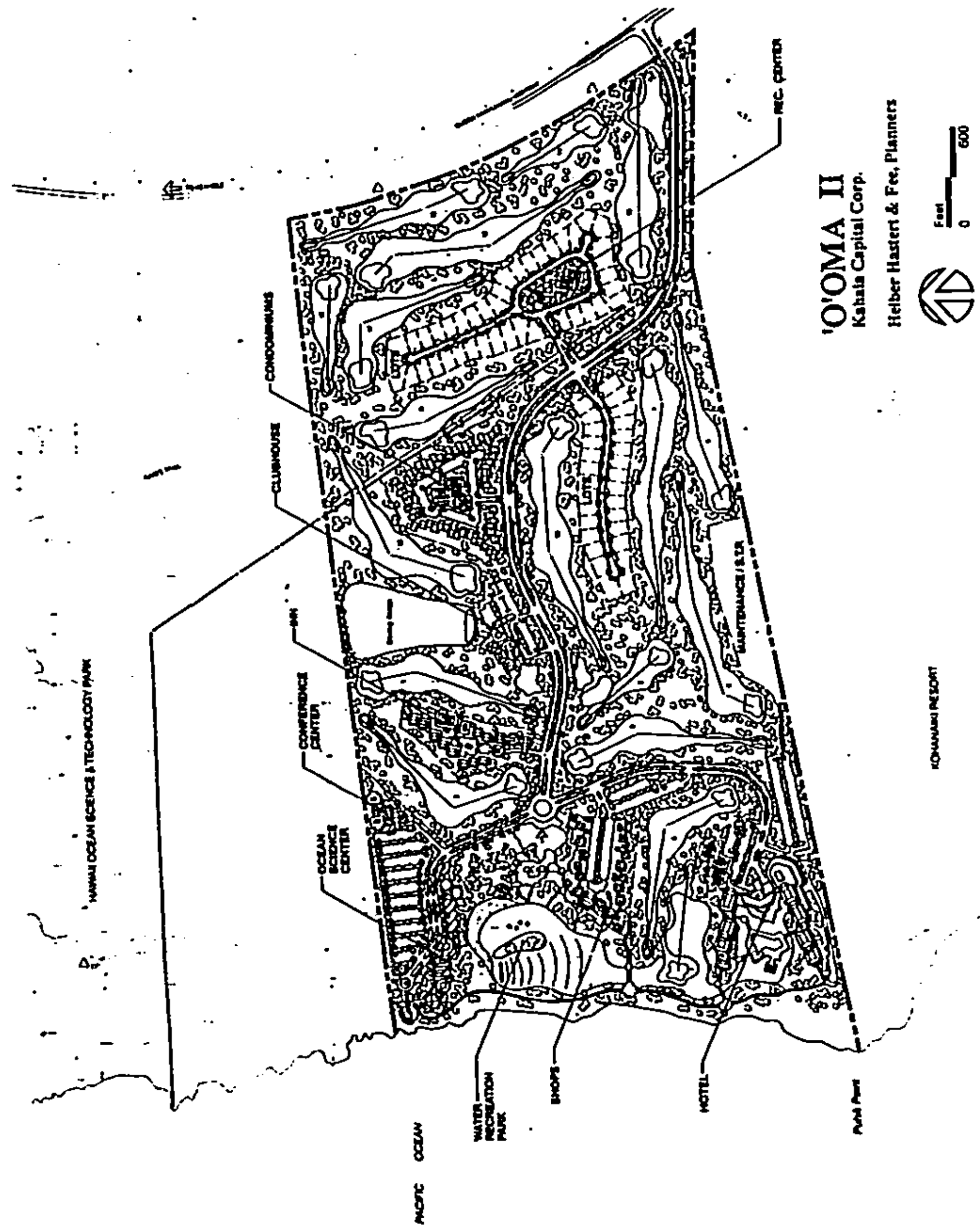


EXHIBIT 2 - SITE PLAN

-4-

III. STUDY AREA CONDITIONS

A. Study Area

1. Area Of Influence

The study area is defined along Queen Kaahumanu Highway between the Keahole Airport Access Road and the project access road. The State Department of Transportation's long range plan for Queen Kaahumanu Highway is to develop a controlled-access four lane highway. It includes an interchange at Keahole Airport Access Road, and a system of frontage roads to provide access to properties along the highway. However, because this plan is beyond the time frame of this study, it is assumed that interim access to the project would be provided at a channelized at-grade intersection shown on Exhibit 2.

2. Anticipated Future Development

West Hawaii is experiencing rapid growth, as several major projects are presently in the plan approval process. These include the Lands of Kau residential project and the Queen Liliuokalani Trust project. Because these projects are still in the plan approval stages, it is difficult to quantify the growth in traffic resulting from each of these proposed projects. Furthermore, these projects are being developed independently according to its own schedule, however, the actual timing and sequence of the developments cannot be determined. Proposed projects that are further along in the approval process have been included in the travel forecast for this study. These include the Kohanaiki Resort, a portion of the State Housing project at Kealekehe, and the Waikoloa Village and Resort.

IV. EXISTING TRAFFIC CONDITIONS

A. Area Roadway System

Queen Kaahumanu Highway is the primary arterial highway in the region. Queen Kaahumanu Highway is a high quality, two lane, two way State highway between Kawaihae and Kailua. Mamalahoa Highway is another arterial highway servicing the region, located mauka (east) of Queen Kaahumanu Highway. However, the only existing connection between the two arterials, in the project vicinity, is Kaiminani Drive, a residential collector roadway. For the purpose of this analysis, it is assumed that Mamalahoa Highway would not be significantly impacted by the proposed project.

B. Traffic Volumes and Conditions

1. General

a. Field Investigation

The field investigation was conducted in June, 1990 to establish the existing baseline traffic conditions. Additional 1989 and 1990 traffic data collected for other studies in the region were obtained and updated to the baseline conditions. Traffic count data also were obtained from the State Department of Transportation (DOT).

b. Capacity Analysis Methodology

The highway capacity analysis performed for this study is based upon procedures presented in the "Highway Capacity Manual", Special Report 209, Transportation Research Board, 1985 and the "Highway Capacity Software", Federal Highways Administration. Capacity analysis calculations are included under a separate cover.

Level of Service (LOS) is a quantitative and qualitative assessment of traffic operations. Levels of Service are defined by LOS "A" through "F", LOS "A" being the best operating condition and LOS "F" the worst operating condition.

"Volume-to-capacity" (v/c) ratio is another measure that shows the relative traffic demand to the road carrying capacity. A v/c ratio of 1.00 indicates that the roadway is operating at 100% of its capacity. A v/c ratio greater than one (1.00) means that the projected traffic demand exceeds the road's traffic handling capacity.

Intersection operations under signalized conditions are defined in self-explanatory terms; "under capacity", "near capacity", and "over capacity".

2. Existing AM Peak Hour Traffic Analysis

The AM peak hour of traffic in the study area occurs between 7:00 AM and 8:00 AM. The existing AM peak hour traffic volumes and capacity analysis are shown on Exhibit 3.

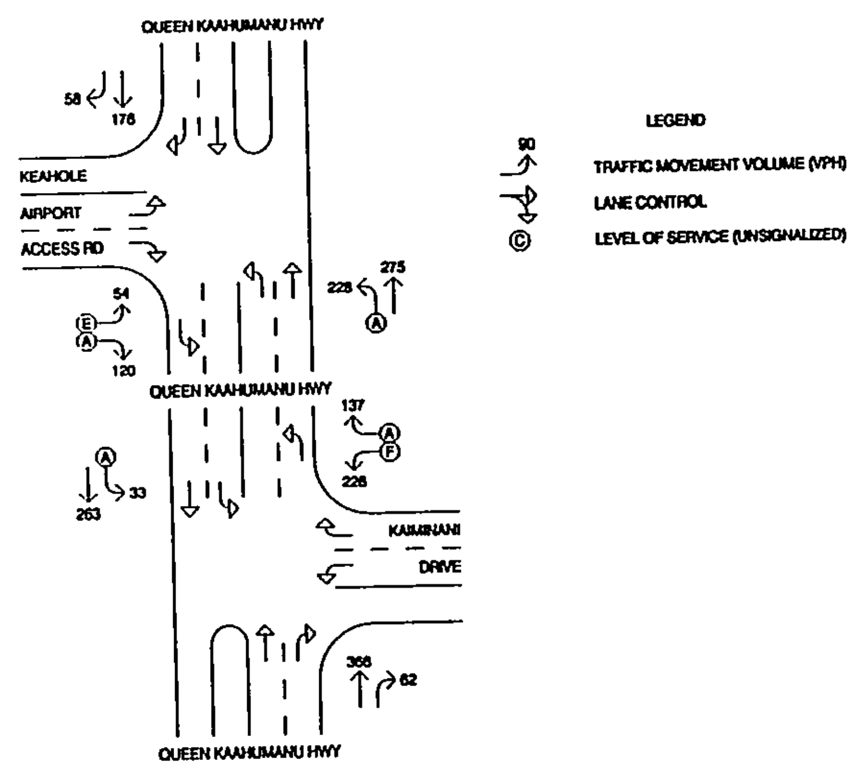


EXHIBIT 3 - EXISTING AM PEAK HOUR CONDITIONS

The left turn movement, from the Keahole Airport Access Road to northbound Queen Kaahumanu Highway, operates at LOS "E" during the AM peak hour of traffic. The remaining traffic movements operate at satisfactory LOS.

The left turn movement, from Kaiminani Drive to southbound Queen Kaahumanu Highway, operates at LOS "F" during the AM peak hour of traffic. The remaining traffic movements operate at satisfactory LOS. During the AM peak hour of traffic, Queen Kaahumanu Highway, south of Kaiminani Drive, operates at LOS "D" and at a v/c ratio of 0.43.

3. **Existing PM Peak Hour Traffic Analysis**

The PM peak hour of traffic in the study area occurs between 3:45 PM and 4:45 PM. The existing PM peak hour traffic volumes and capacity analysis are shown on Exhibit 4.

The left turn movement, from the Keahole Airport Access Road to northbound Queen Kaahumanu Highway, operates at LOS "E" during the PM peak hour of traffic. The remaining traffic movements operate at satisfactory LOS.

The left turn movement, from Kaiminani Drive to southbound Queen Kaahumanu Highway, operates at LOS "F" during the PM peak hour of traffic. The remaining traffic movements operate at satisfactory LOS. During the existing PM peak hour of traffic, Queen Kaahumanu Highway, south of Kaiminani Drive, operates at LOS "D" and at a v/c ratio of 0.50.

V. PROJECTED TRAFFIC

A. Site-Generated Traffic

1. Trip Generation Methodology

The trip generation methodology used in this study is based upon generally accepted techniques developed by the Institute of Transportation Engineers (ITE) and published in "Trip Generation", 5th Edition, 1991. The ITE trip rates for residential and commercial projects are developed empirically, by correlating the vehicle trip generation data with various land use characteristics, such as vehicle trips per dwelling unit.

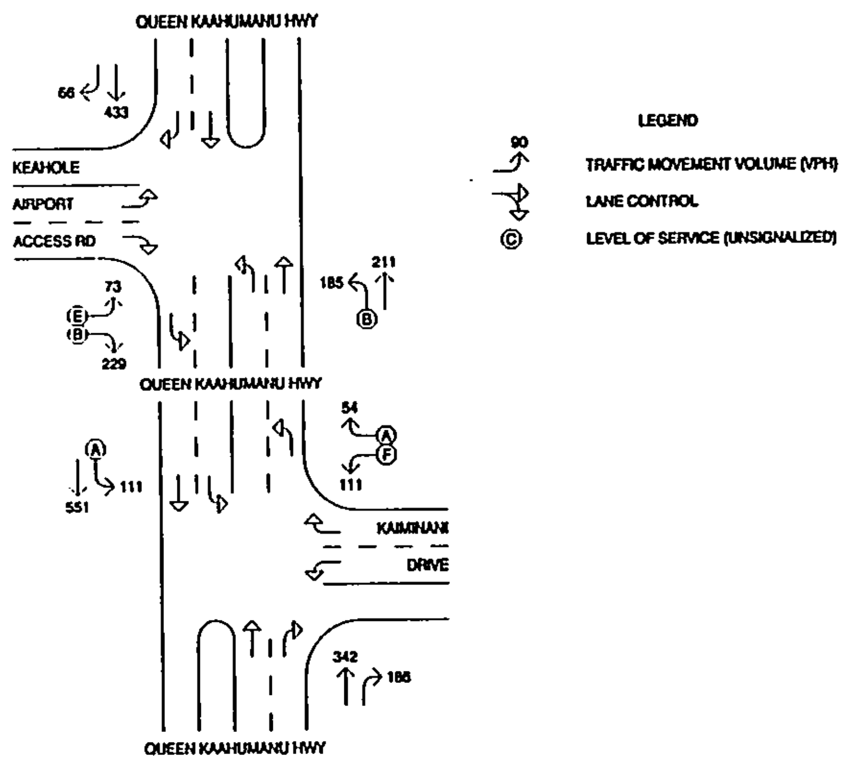


EXHIBIT 4 - EXISTING PM PEAK HOUR CONDITIONS

2. **Trip Generation Characteristics**

The trip generation characteristics are summarized in Table 1.

TABLE 1. TRIP GENERATION SUMMARY

Land Use	Land Use Intensity	AM Peak Hour (Vph)			PM Peak Hour (Vph)		
		Enter	Exit	Total	Enter	Exit	Total
Single - Family Dwellings	42 DU	10	28	38	32	18	50
Multi - Family Dwellings	58 DU	6	28	34	26	14	40
Recreational Homes	78 DU	34	17	51	28	28	56
Visitor Accommodations	722 Rooms	254	169	423	221	188	409
Commercial	35,000 SF GFA	45	32	87	168	168	336.
Golf Course	18 Holes	48	10	58	31	29	60
Ocean Science Center	12 Acres	10	1	11	44	28	72
Conference Center	3 acres	3	1	4	11	7	18
Water Recreation Park	19 Acres	16	2	18	70	45	115
O'oma II Totals		436	288	724	631	525	1,156

B. External Traffic

1. **General**

The State DOT and the County of Hawaii has recently completed the "Island of Hawaii Long Range Highway Plan". In the State/County study a travel forecast for the Year 2010 was developed. The travel forecast is based upon a land use forecast for the Year 2010, developed by the County of Hawaii. The State/County forecasts account for regional development expected to occur during the time frame of this study, exclusive of the O'oma II Project. Using the State/County forecast, a growth factor of 1.70 was estimated in projecting traffic demands on Queen Kaahumanu Highway to the Year 1998, using the Year 1990 as the base year.

2. Total Traffic Volumes Without Project

The Year 1998 traffic projections without the proposed project are shown on Exhibits 5 and 6. By the Year 1998, the intersections of Queen Kaahumanu Highway at Keahole Airport Access Road and at Kaiminani Drive would require traffic signalization. During the 1998 AM and PM peak hours of traffic without the project, the left turn movements from both side streets would operate at LOS "F" under unsignalized operations. At the Keahole Airport Access Road intersection, the right turn movement from the Access Road to southbound Queen Kaahumanu Highway, and the left turn movement from northbound Queen Kaahumanu Highway to the Airport Access Road would also operate at LOS "F" during the PM peak hour.

South of Kaiminani Drive, the two lane Queen Kaahumanu Highway would operate at LOS "E" during both peak periods. During the AM peak hour of traffic, Queen Kaahumanu Highway would operate at a v/c ratio of 0.66. During the PM peak hour of traffic, the roadway would operate at a v/c ratio of 0.90.

C. Total Traffic With Project

Exhibits 7 and 8 show the AM and PM peak hour traffic with the project-generated traffic. The capacity analysis is shown for both unsignalized and signalized conditions. Furthermore, the peak hour traffic conditions with the project-generated traffic are analyzed assuming Queen Kaahumanu Highway is widened to four lanes by the Year 1998. The traffic impact analysis with the project-generated traffic is discussed in the next section.

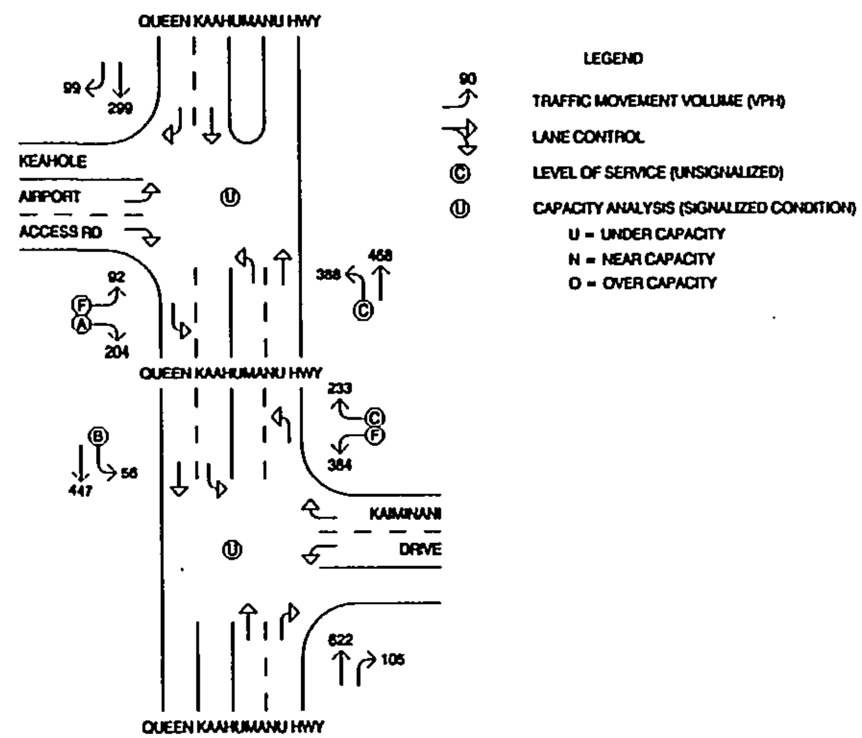


EXHIBIT 5 - 1998 AM PEAK HOUR CONDITIONS W/O PROJECT

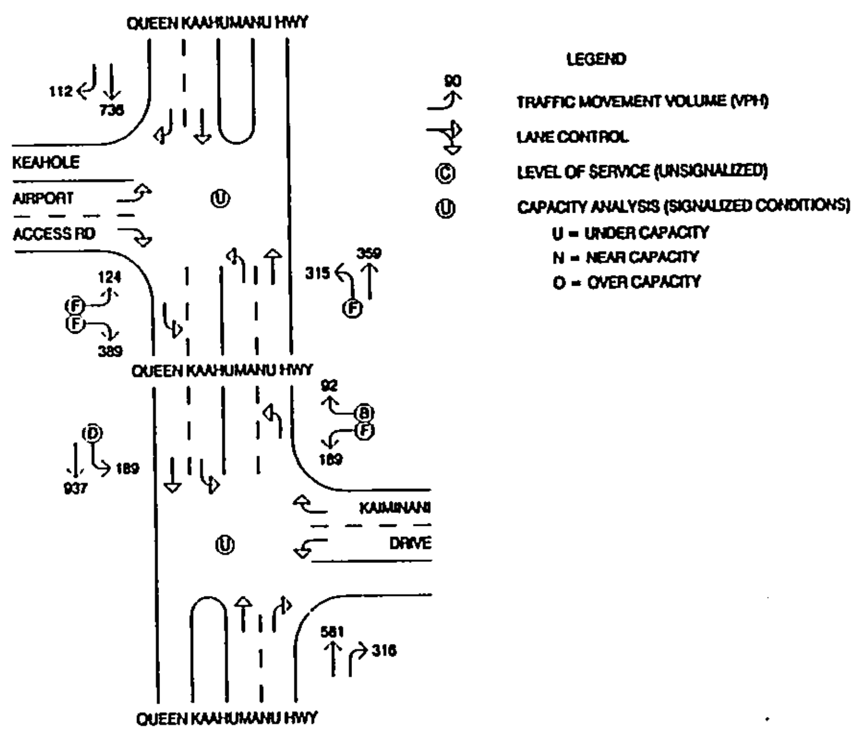


EXHIBIT 6 - 1998 PM PEAK HOUR CONDITIONS W/O PROJECT

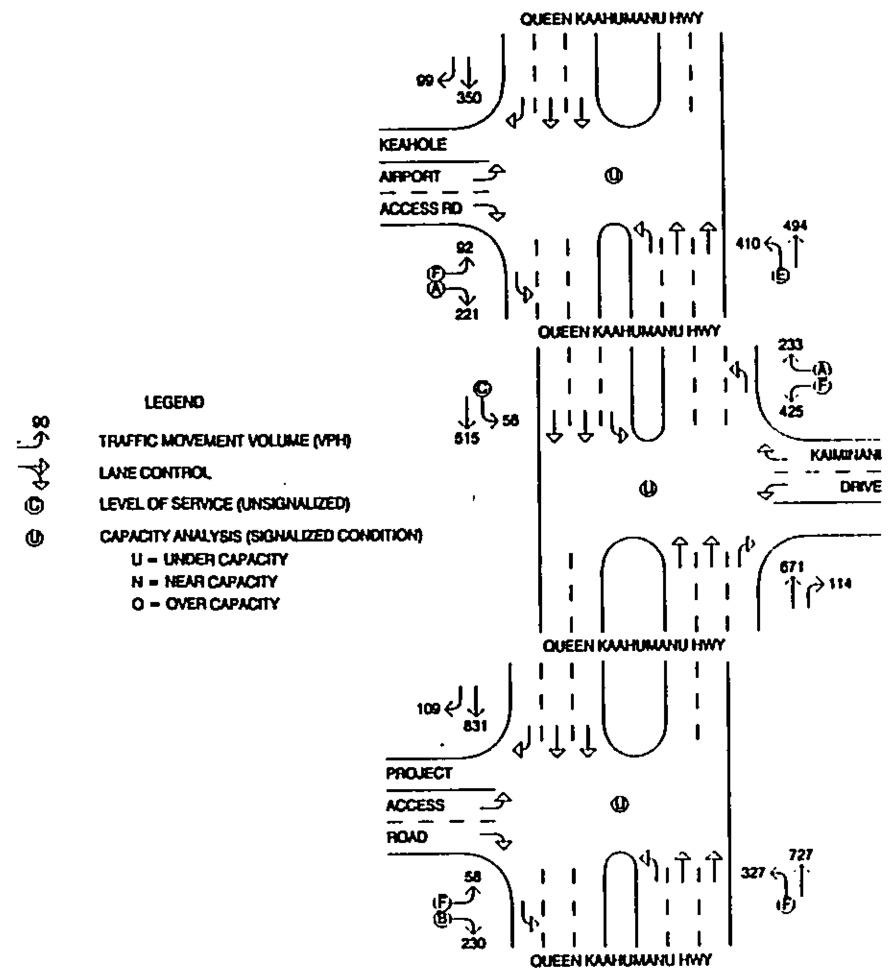


EXHIBIT 7 - CUMULATIVE AM PEAK HOUR CONDITIONS W/PROJECT

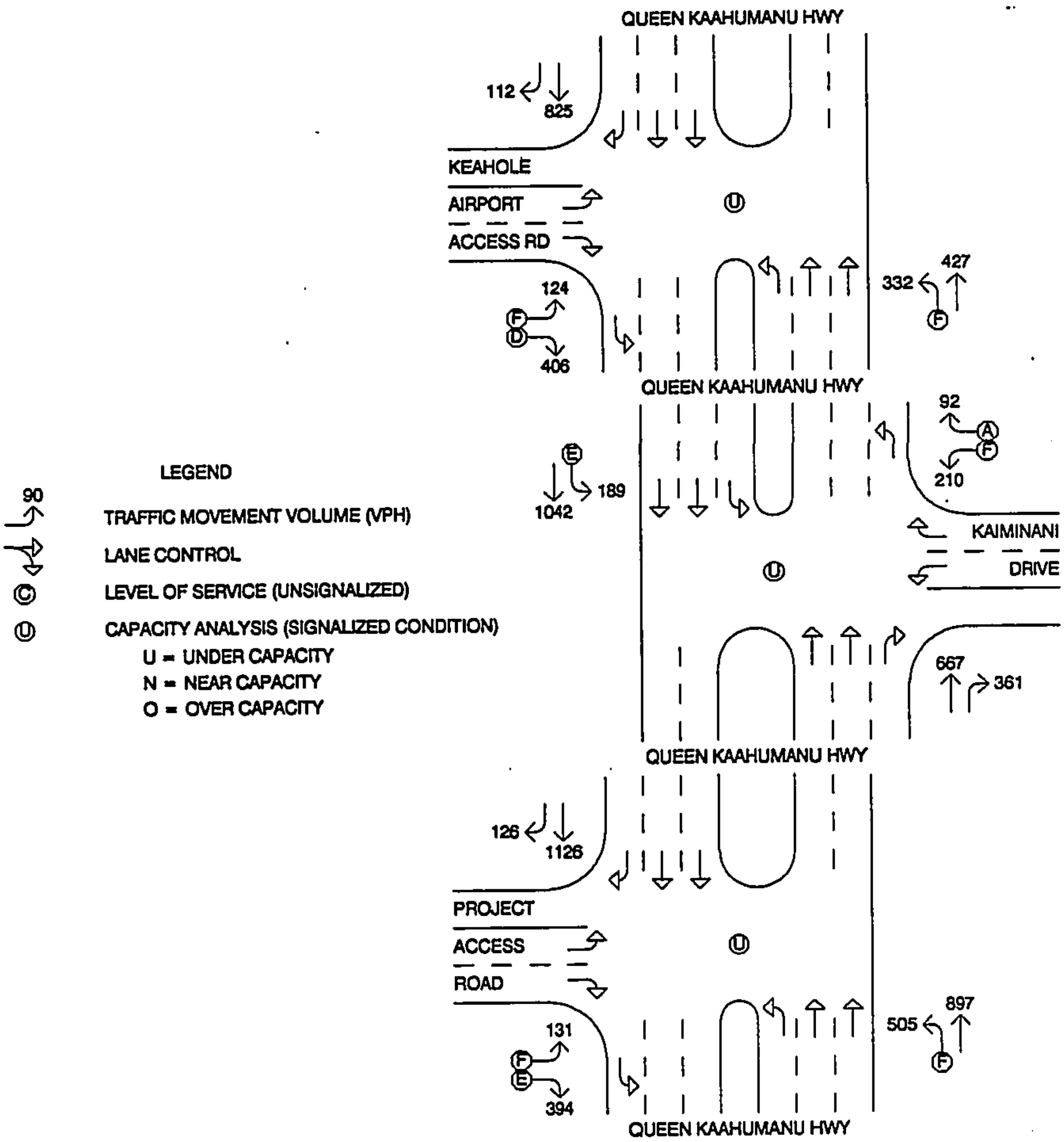


EXHIBIT 8 - CUMULATIVE PM PEAK HOUR CONDITIONS W/PROJECT

VI. TRAFFIC IMPACT ANALYSIS

A. Capacity Analysis

1. AM Peak Hour Traffic With Project

During the AM peak hour with the project-generated traffic, the Queen Kaahumanu Highway intersections at the Keahole Airport Access Road and Kaiminani Drive would operate at "under capacity" conditions under signalized operations. The project access road intersection also would operate at "under capacity" conditions under signalized operations.

2. PM Peak Hour Traffic With Project

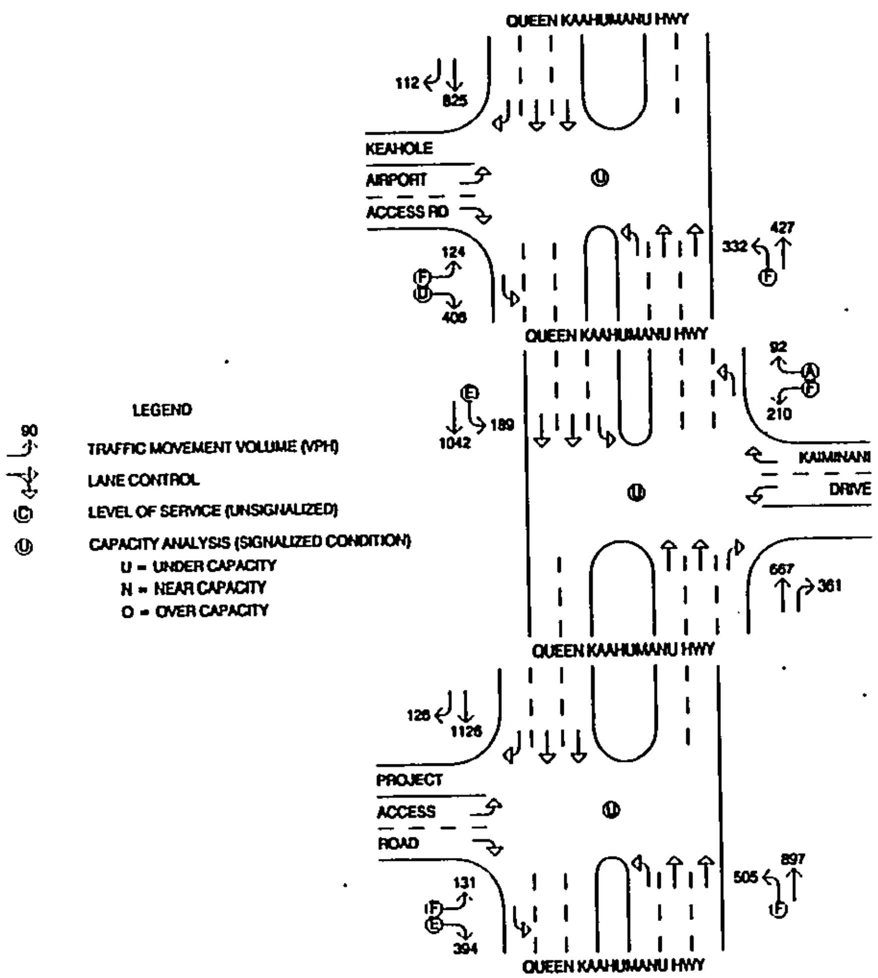
During the PM peak hour with the project-generated traffic, the Queen Kaahumanu Highway intersections at the Keahole Airport Access Road and Kaiminani Drive would continue operate at "under capacity" conditions. The project access road intersection would operate at "under capacity" conditions.

VII. PROPOSED HIGHWAY IMPROVEMENTS

A. Improvements to Accommodate the Year 1998 Highway Deficiencies Without Project

Queen Kaahumanu Highway would require widening to four lanes with traffic signals at each intersection within the study area, based upon the highway deficiency critieria established in the State/County Long Range Highway Plan. The State/County Plan recommends the widening of Queen Kaahumanu Highway to a four lane, divided, controlled access highway, i.e., a freeway.

The State is currently in the process of developing an implementation plan for the Queen Kaahumanu Highway improvement. The first phase of the four lane widening would likely extend between Palani Road and Keahole Airport Access Road. The State study would also determine the number and location of interchanges that would be allowed on Queen Kaahumanu Highway. Until the proposed interchanges and frontage road system are constructed, at-grade access should be provided at a channelized intersection under traffic signal control, when warranted.



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B. Site Access Improvements

The proposed access road intersection for the O'oma II Project should provide for a left turn storage lanes (northbound), a right turn deceleration lane (southbound), and a right turn acceleration lane (southbound) on Queen Kaahumanu Highway. Traffic signals should be installed at this channelized intersection, when warranted. These improvements would be implemented on an interim basis, with the understanding that direct access to Queen Kaahumanu Highway would eventually be eliminated and replaced with a system of frontage roads leading to the proposed interchanges, located to the north and south of the project site.

VIII. CONCLUSIONS

With the implementation of the road improvements recommended in this study, the proposed O'oma II Project should not have any significant impacts on traffic within the time frame of this study. The proposed channelized intersection should accommodate the project access needs until the State DOT's long range plan for Queen Kaahumanu Highway is implemented.

It is anticipated that, initially, Queen Kaahumanu Highway would be widened to a four lane, divided highway with at-grade signalized intersections at warranted locations. As traffic continues to increase and the at-grade intersections reach capacity, grade-separated interchange facilities would be constructed. The O'oma II Project access would then be relocated to a frontage road system leading to interchanges, located to north and south.