1993-05-08-OA-FEA - Ala Wai Canal Improvements

Environmental Assessment and Negative Declaration

ALA WAI CANAL IMPROVEMENT

Honolulu, Oahu, Hawaii

Job No. 31-OL-I

for State of Hawaii
Department of Land
and Natural Resources
Division of Water and
Land Development

Edward K. Noda & Associates, Inc.

in association with

KRP Information Services

April, 1993

NOTICE OF DETERMINATION: Negative Declaration

FOR: Job No. 31-OL-I
Ala Wai Canal Improvement
Honolulu, Oahu, Hawaii

BY: Division of Water and Land Development
Department of Land and Natural Resources

The proposed action will have no significant effect on the environment and therefore does not require the preparation of an Environmental Impact Statement. This Notice of Determination and Environmental Assessment are being filed as a Negative Declaration.

Environmental Assessment and Negative Declaration

PROJECT: ALA WAI CANAL IMPROVEMENT

LOCATION: WAIKIKI , HONOLULU DISTRICT
CITY AND COUNTY OF HONOLULU
Tax Map Keys: 2-3-34, 35; 2-7-35, 36;
2-6-10 to 17, 20-21, 24-25, 28-29

AGENCY: DIVISION OF WATER AND LAND DEVELOPMENT
DEPARTMENT OF LAND AND NATURAL RESOURCES
P. O. BOX 373
HONOLULU, HAWAII 96809

PREPARED BY: EDWARD K. NODA & ASSOCIATES, INC.
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Measurements and Abbreviations Used in This Document

cfs	cubic feet per second (448.83 gallons per minute)
ft	feet
ft^2	square feet
ft^3	cubic feet
fw	fresh water
gpm	gallons per minute
kW	kilowatt
l or L	liter
m	meter
m^3	cubic meter
mg	milligram
mL or ml	milliliter
MLLW	mean lower low water
mgd	millions of gallons per day
msl	mean sea level
ppt	parts per thousand (used for measuring salinity)
T_{50}	time it takes for the concentration of a substance to decrease by 50% of its initial value
T_{90}	time it takes for the concentration of a substance to decrease by 90% of its initial value
µg	microgram
µg/l	micrograms per liter

5

CHAPTER 1

DESCRIPTION OF THE PROPOSED ACTION

Description of the Proposed Project

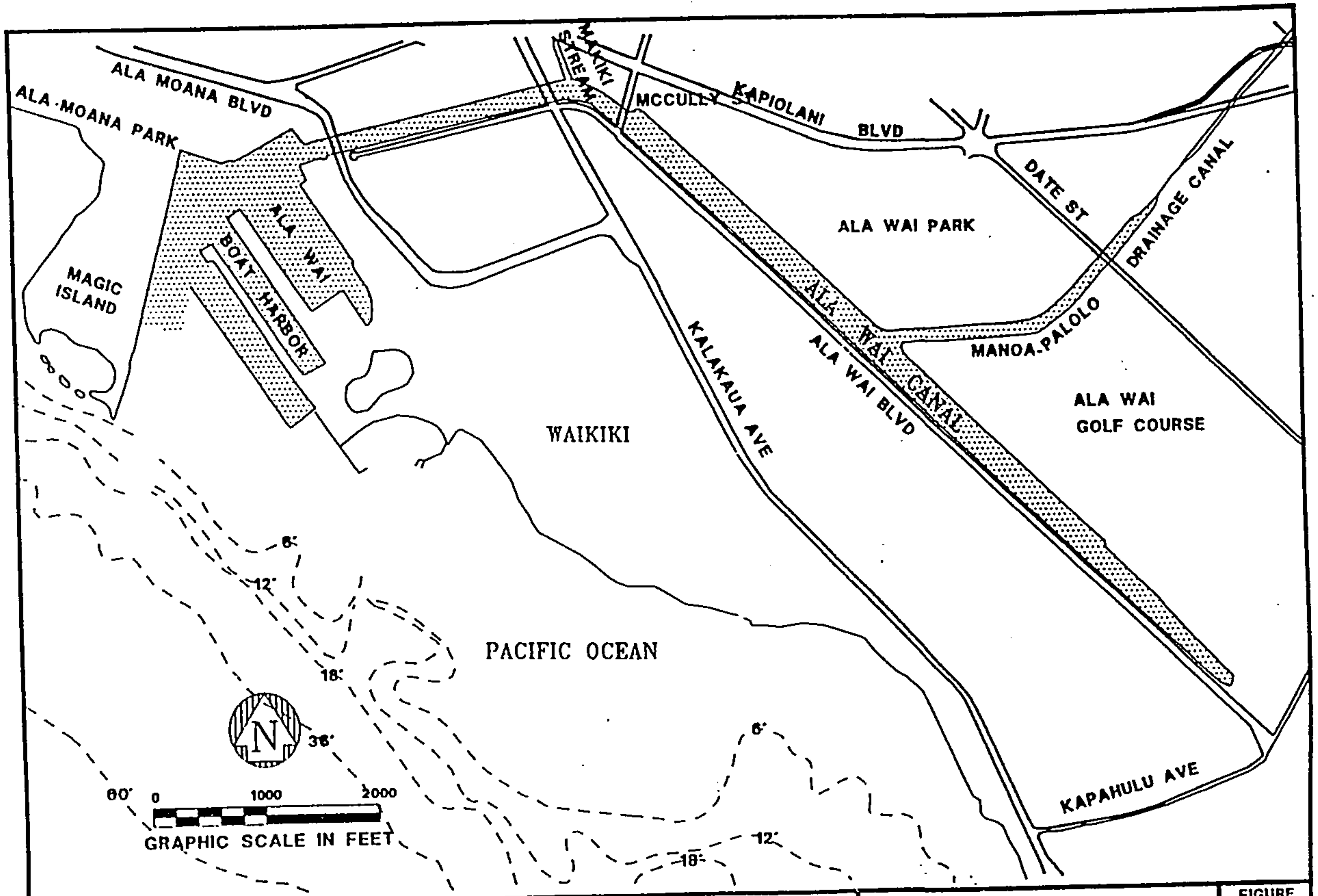
The Ala Wai Canal is a 2-mile long manmade waterway with widths ranging from 200 to 250 feet and average cross-sectional depths ranging from 3 to 8 feet, with spot depths ranging from 1 to 12 feet. The Ala Wai Canal was constructed between 1921 and 1928 and is the major drainage system for the Waikiki District of Honolulu. It also conveys surface runoff from the watersheds directly mauka of the canal, including the areas of Makiki, Manoa, St. Louis Heights, Palolo, Moiliili, Kapahulu, and parts of Kaimuki and Diamond Head. The Ala Wai Canal is used for a number of recreational purposes including canoeing, kayaking, fishing and some motor boating. The Ala Wai Canal system is shown in Figure 1-1.

The Department of Land and Natural Resources of the State of Hawaii proposes to improve the water quality in the Ala Wai Canal to standards acceptable for water-based recreational activities. The specific objectives of the proposed project are to:

- Increase water flow and circulation in the canal while addressing environmental concerns.
- Decrease sources of pollutants through improved watershed management.
- Establish routine maintenance and management practices for the canal.

Three reports have been prepared as part of this project. The principal document is the *Ala Wai Canal Improvement Feasibility Report* prepared by Edward K. Noda and Associates, Inc. (October, 1992). It responds primarily to the first objective listed above. The results associated with the second objective are provided in a separate report entitled *A Management Plan for the Ala Wai Canal Watershed* developed by the East-West Center, Program on Environment (Fox et al., October, 1992). The third objective results are provided in another separate report entitled *A Maintenance Plan For The Ala Wai Canal*, developed by Edward K. Noda and Associates, Inc. (October, 1992). The main body of the feasibility report (without its appendices) is included as an appendix to the environmental assessment.

Only the proposed improvements that will increase water flow and circulation are being proposed and assessed at this time. Implementation of the watershed management plan is not within the jurisdiction of the Department of Land and Natural Resources. It will require a joint effort involving the Department of Health, the City and County of Honolulu, Neighborhood Boards and other groups.



ALA WAI CANAL IMPROVEMENT PROJECT | Edward K. Noda and Associates, Inc. | ALA WAI CANAL SYSTEM | FIGURE 1-1

Implementation of the maintenance plan will also require a joint effort of the Department of Land and Natural Resources, which has jurisdiction over the Ala Wai Canal, and the City and County of Honolulu, which has jurisdiction over the Manoa–Palolo Drainage Canal.

Project History

This project is the outgrowth of the Physical Environment Committee of *Waikiki Tomorrow*, an effort undertaken in the late eighties by the Waikiki Improvement Association and the Office of State Planning. *Waikiki Tomorrow* evolved from concerns that Waikiki, the major tourist destination area in Hawaii, was not keeping pace with other visitor destination areas in other states and countries. Because the Ala Wai Canal plays such a major role in defining Waikiki and improving its physical attributes would have significant benefits, an ad hoc committee of concerned citizens followed up on recommendations of *Waikiki Tomorrow* by going to the State Legislature for funding in 1990. The funding was provided to DLNR to pursue the present study. At DLNR's request, the ad hoc group of supporters became the Ala Wai Cleanup Technical Committee. They have assisted the Department in developing the scope of work and reviewing interim work products as the project has developed. Members of the Technical Committee are listed in Chapter 5.

Technical Characteristics

The primary focus of the feasibility study is on the physical, biological and water quality conditions in the Ala Wai Canal. The initial task efforts of this study involved extensive field measurement programs including a bathymetry survey, current measurements within the canal and in the nearshore coastal areas, a dye flushing test, tidal measurements, and biological and water quality surveys. As a result of these studies and extensive computer model runs, it was determined that the addition of 20 to 30 cubic feet per second (cfs) seawater inflow into the Kapahulu end of the Ala Wai Canal would achieve the objective of water clarity.

Two options were determined to be technically feasible and to warrant further feasibility analysis and conceptual design evaluations. These are:

1. Injection of 20 to 30 cfs seawater inflow into the Kapahulu end of the Ala Wai Canal through a pipeline. For this option, two design concepts were considered:

    - A 12,500 foot long, 42 inch diameter submerged pipeline, laid and partially buried in the Ala Wai Canal, with an intake structure located in the entrance channel to the Ala Wai Boat Harbor at a water depth of about 40 feet; a 4,000 foot long, 40 inch diameter suction pipeline; a submerged pump station located adjacent to Magic Island, and a discharge manifold located across the canal at the Kapahulu end.

◇ A 7,000 foot long, 40 to 42 inch diameter "non-trenched" underground pipeline constructed using directionally controlled drilling technology, extending from a pump station located at the Kapahulu end of the canal, to an intake location offshore of Waikiki Beach in a water depth of about 40 feet. A discharge manifold would distribute seawater across the canal.

2. Injection of 20 to 30 cfs of groundwater from 5 deep wells drilled to depths of 250 feet or greater, located at the Ala Wai Golf Course, with the water discharged through a discharge manifold located across the canal. The deep groundwater wells must produce salinity and nutrient concentrations similar to coastal seawater.

For the three alternative concepts described above, conceptual designs and construction and annual operating and maintenance (O&M) cost estimates were developed. The submerged pipeline laid in the canal and the deep groundwater well supply options proved to be technically feasible. The directionally drilled pipeline construction option was considered to be beyond the present state-of-the-art, with significant risks associated with this methodology. Moreover, the construction cost estimate for the directionally drilled pipeline option was over $28 million, which is considerably larger than the other feasible options.

Based on the limited available historic geologic strata data, the technical feasibility of drawing the required 20 to 30 cfs of deep groundwater appears promising. Since the construction cost of this option is significantly less than the submerged pipeline concept, it is proposed that the deep groundwater well supply system be selected for further feasibility evaluations. To proceed with this concept evaluation, a prototype production well drilling and testing program is proposed in order to: (1) confirm the expected subsurface geologic strata and water quality in the Ala Wai Golf Course area; (2) estimate the potential groundwater flow yield from coral layers at this depth; (3) demonstrate that such high capacity pumping can be accomplished without adverse effects; (4) and develop other design parameters. The estimated cost for this well test program is approximately $300,000.

If the prototype production well test program confirms the technical and environmental feasibility of the deep groundwater well supply concept, an up-date and revision of the present conceptual design and construction cost estimate for the saltwater well supply system will be performed. The new construction cost estimate will then be evaluated for implementation.

If the prototype production well test program indicates that the deep groundwater well supply concept is not feasible, the alternative of the submerged pipeline system laid in the Ala Wai Canal will be considered for implementation.

Deep Groundwater Well System

The evaluation of the deep groundwater well system was performed by Tom Nance Water Resources Engineering (TNWRE). This concept first required an evaluation of the available historic data on the sub-surface geologic structure in order to determine the feasibility of the Ala Wai Golf Course site to produce the required flow rate of deep, ocean-salinity water. If this feasibility assessment yielded positive results, the subsequent task effort was to develop a conceptual design of the groundwater well system and from this design provide a construction cost estimate.

The evaluation indicates that the first 20 to 30 feet of caprock sequence is generally comprised of lagoonal deposits, coralline debris, terrestrial alluvium, and/or imported fill. This layer is generally poorly permeable and can be very compressible if subject to dewatering. A pervasive, 10 to 30 foot thick coral ledge lies immediately below this first caprock layer, and is underlain by layers of coral and sand, in some places interrupted by a lens of coralline mud or alluvium of limited thickness and areal extent.

At depths of 80 to 120 feet below the surface, a layer of later stage volcanics occurs which is typically 50 to 80 feet thick. This layer apparently underlies the entire east end of the canal and pinches out toward the west. Although there are only a few drill logs available for borings which have penetrated through this volcanic layer into the formations below, these logs suggest that a layered sequence of corals, sands, calcareous muds, and "clays" (of unidentified origin) exists below the later-stage volcanics. The volcanic basement is likely to be 600 to 700 feet below the surface on the mauka side of the canal, which means that the sequence of corals, sands, and clays between the two volcanic layers is about 400 to 500 feet thick.

From a technical view point, while it may be possible to withdraw groundwater at the flow rates required from the uppermost coral ledge, it is likely that dewatering of the overlying lagoonal deposits would occur, causing subsidence problems as has occurred during various construction projects in the Waikiki area. Moreover, the groundwater from this uppermost coral ledge would not have the high salinity and low nutrient levels required by the water quality modeling results.

An option that looks optimistic is to withdraw water from the lower coral layers below the later stage volcanic layer, at withdrawal depths between 130 to 200 feet below the surface. The later stage volcanics, particularly the Diamond Head tuff formation at the east end of the canal, may function as an aquitard, which is a layer that is relatively impermeable and resists the through-flow of groundwater. In this situation, the aquitard layer would provide an effective hydraulic separation from the uppermost coral layer and its overlying lagoonal deposits, thereby greatly minimizing the potential for dewatering of the uppermost lagoonal deposits with its attendant subsidence problems. A calcareous mud layer below the later-stage volcanics may also function as an aquitard. Figures 1-2 and 1-3 show the subsurface geologic structure based on available data from wells drilled in the area.

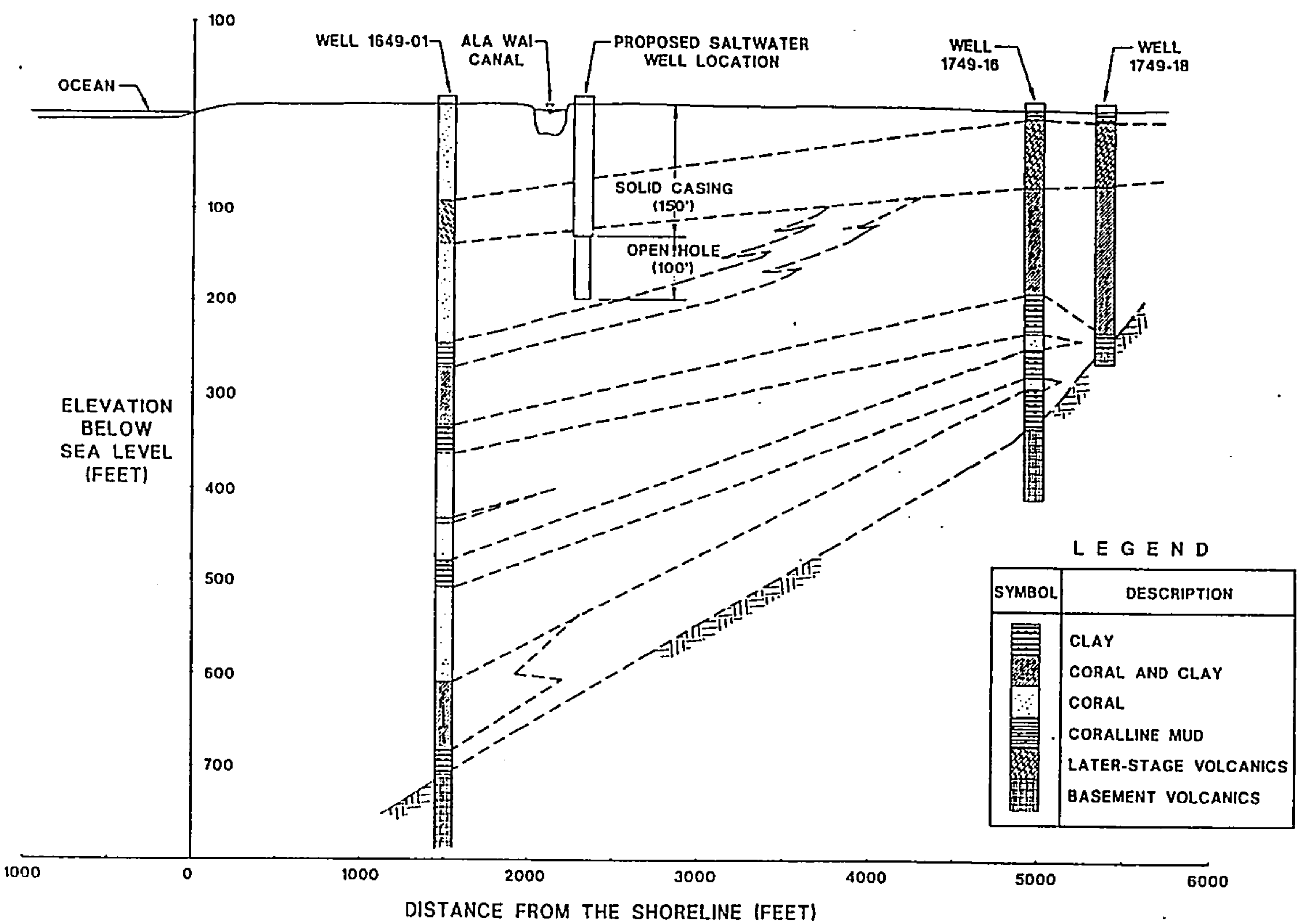


Figure 1-2

MAUKA-MAKAI GEOLOGIC SECTION 1 - 1'

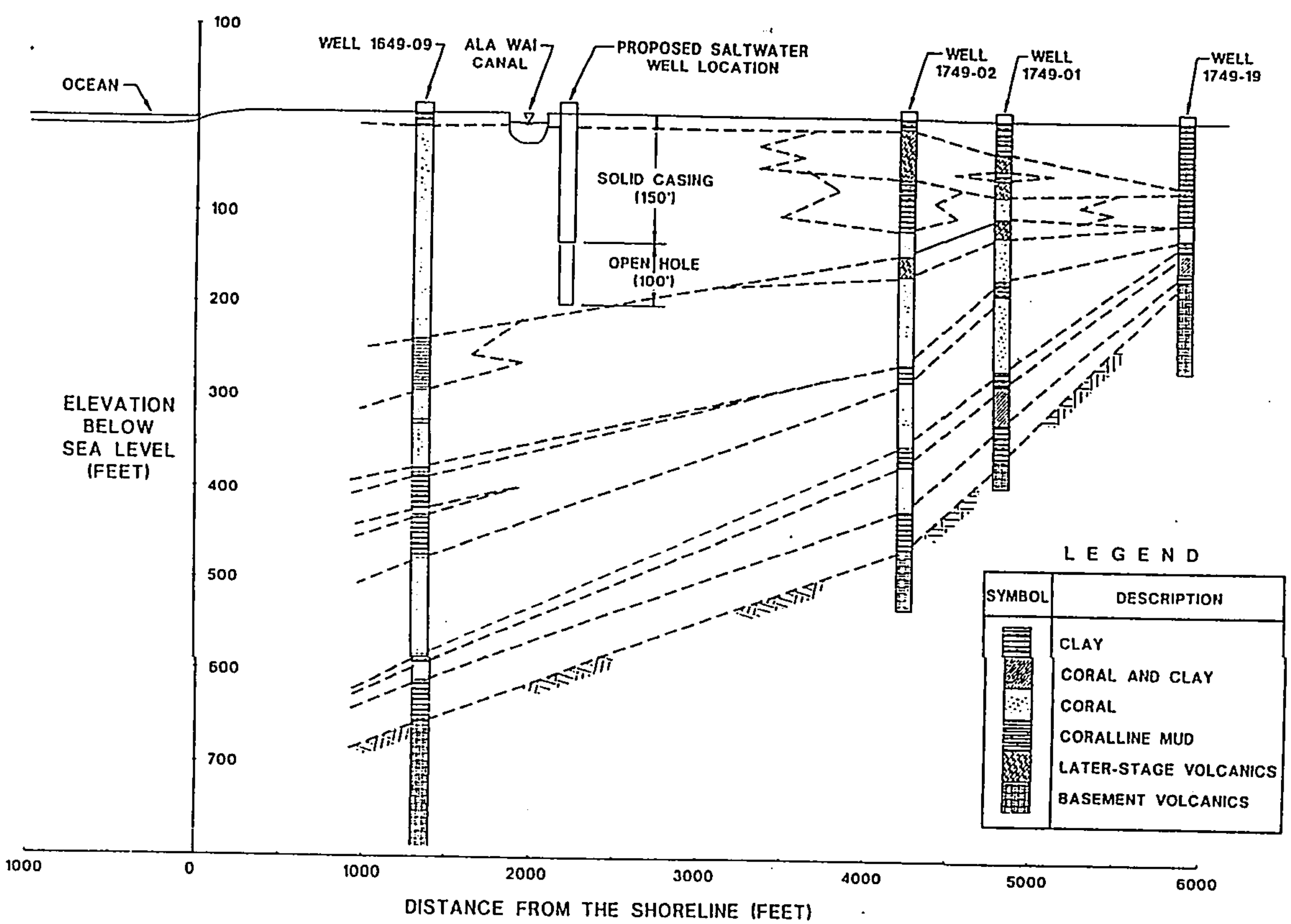


Figure 1-3

MAUKA-MAKAI GEOLOGIC SECTION 2 - 2'

The deep groundwater well is likely to produce water with a salinity of 32 to 35 parts per thousand (ppt), little or no dissolved oxygen, and major ions differing from seawater only by the ion exchange which occurs in passage through the coral formation. There is some risk of organic contamination from lagoonal deposits, possibly resulting in high ammonia and sulfides concentrations, but this can probably be avoided through proper well design. It is likely that aeration of the deep saline water would be necessary but no other treatment would be required.

Very little use is presently made of water from this aquifer and none of it occurs at the 200 foot depth of plumage of the proposed deep groundwater well. For these reasons, the deep groundwater well supply proposed above is expected to have no adverse effects on either existing potable water supplies or the existing groundwater supply used for irrigation of the Ala Wai Golf Course.

The TNWRE report analyzed two pumping schemes: high volume, low head propeller pumps together with an aeration system; and an air lift pumping system. The propeller pumping system is proposed because it offers greater flexibility and is considered a more realistic concept than the air lift system. Figure 1-4 shows a schematic description of the propeller pumps, mechanical aeration to increase the dissolved oxygen from 0 to 5.0 mg/liter, and the across-canal diffuser system. Figure 1-5 provides a conceptual design layout of the proposed seawater supply wells at the Ala Wai Golf Course.

The conceptual design for construction cost estimating purposes consists of five 200 foot deep wells with the upper 130 feet comprised of an 18 inch diameter solid casing pipe grouted in-place and the remaining 70 feet of open hole. Each well has been designed to deliver 2,500 gpm and the wells have been spaced 200 feet apart. A central aeration system has been included to increase the dissolved oxygen concentration of the saline water from an expected 0 to 5.0 mg/liter. The aerated saltwater would then be discharged into a diffuser system across the canal width.

While the prospects for obtaining the required seawater supply from deep groundwater wells located at the Ala Wai Golf Course appear optimistic, a prototype production well drilling and testing program will be necessary to confirm the expected subsurface geologic strata and water quality, estimate the potential yield from coral layers at depth, demonstrate that such high capacity pumping can be accomplished without adverse effect, and to develop other design parameters. Figure 1-6 shows a schematic design of the prototype production well. A pilot borehole would be drilled, using rotary drilling equipment, to a depth of approximately 250 feet (or deeper if required by the strata encountered). Based on the geologic strata results, the casing depth would be selected, and the open hole completed as described in Figure 1-6. Full scale pumping tests would then be conducted. Placement of sounding tubes to various depths in the annular space would enable the effects of pumping on overlying layers to be measured, thereby demonstrating that pumping could occur without de-watering the overlying surficial lagoonal deposits.

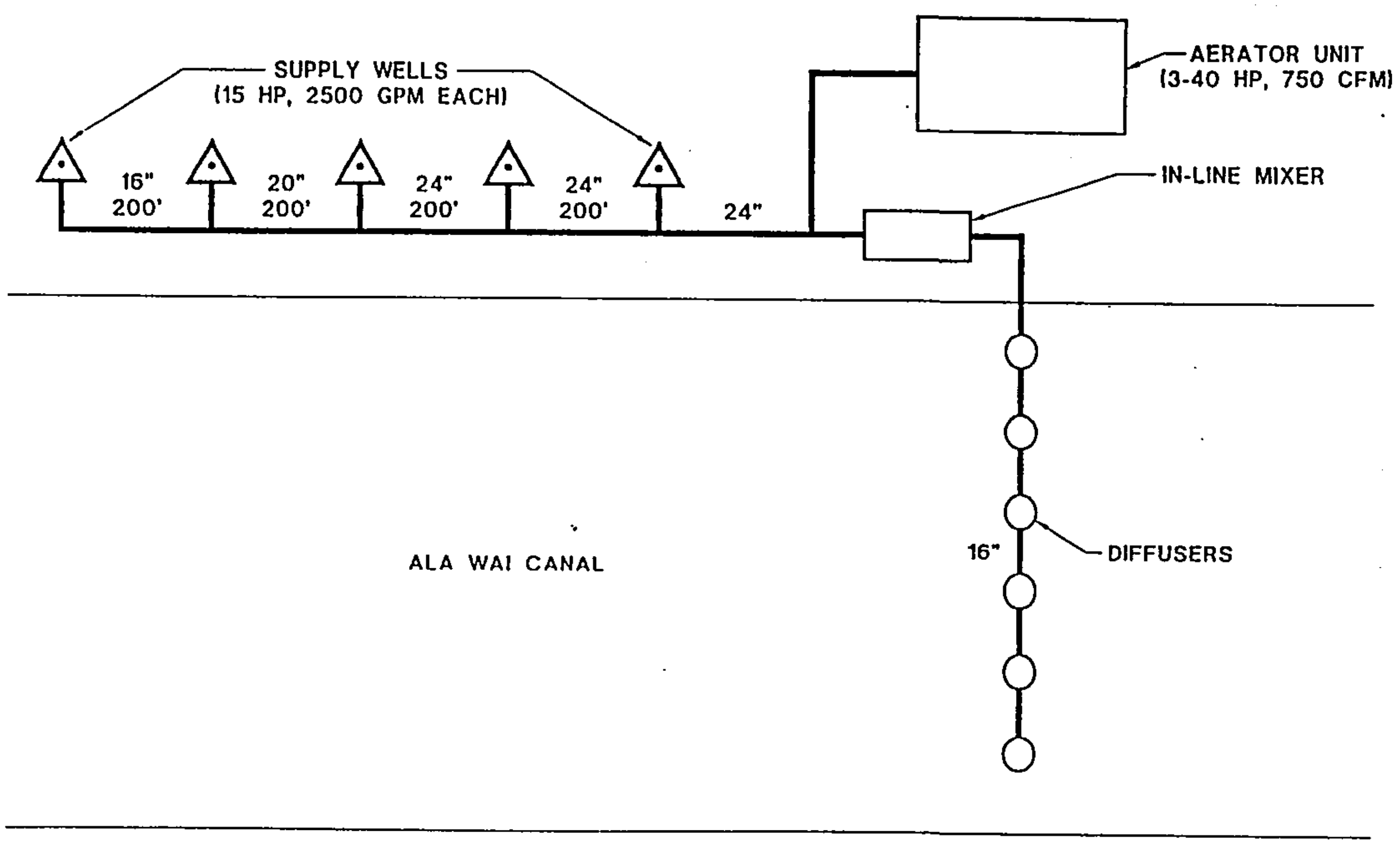
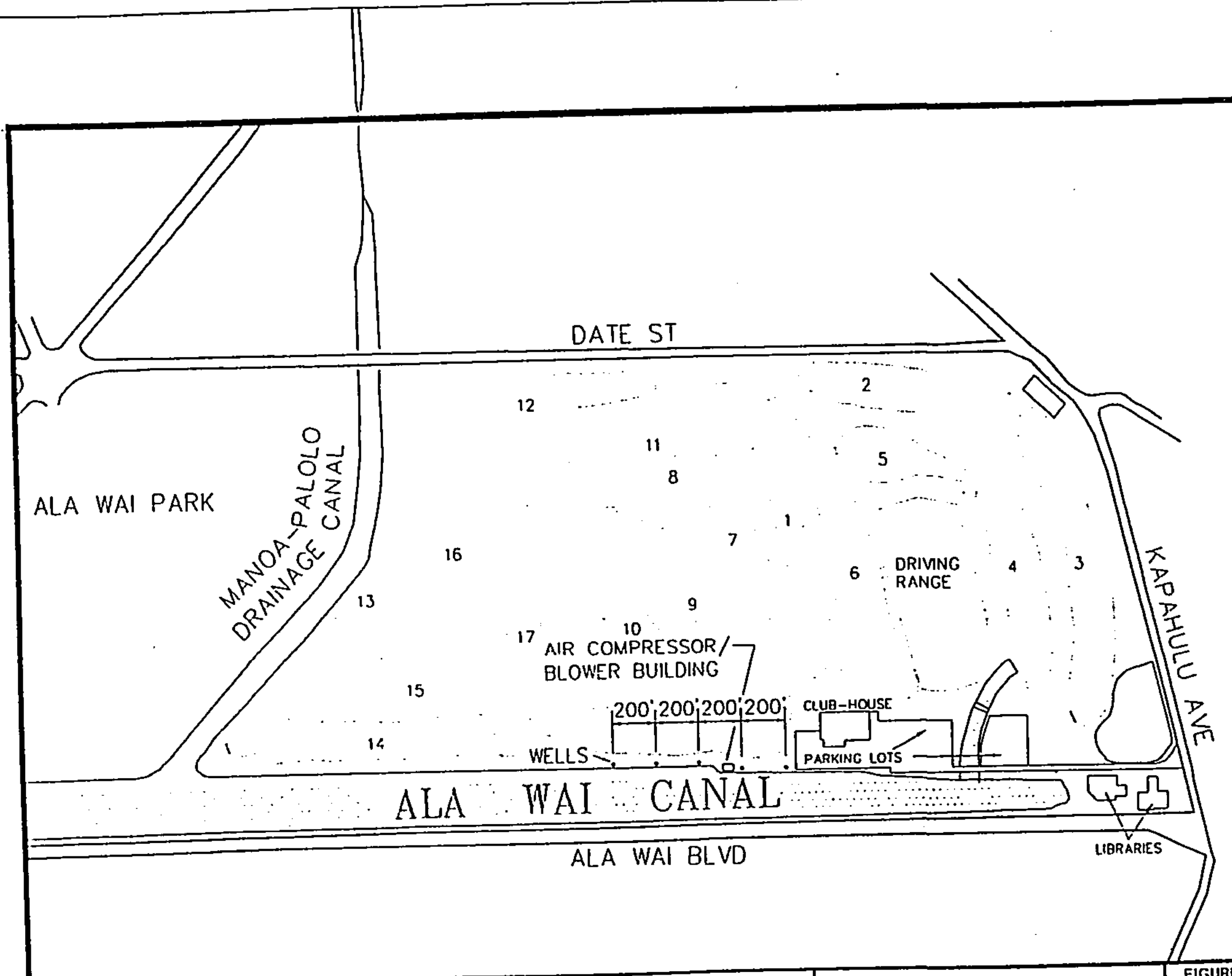


Figure 1-4

PROPELLER PUMPS, MECHANICAL AERATION, AND DIFFUSER DISCHARGE



ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	PROPOSED LOCATIONS OF THE FIVE 2500 GPM SALTWATER SUPPLY WELLS	FIGURE 1-5

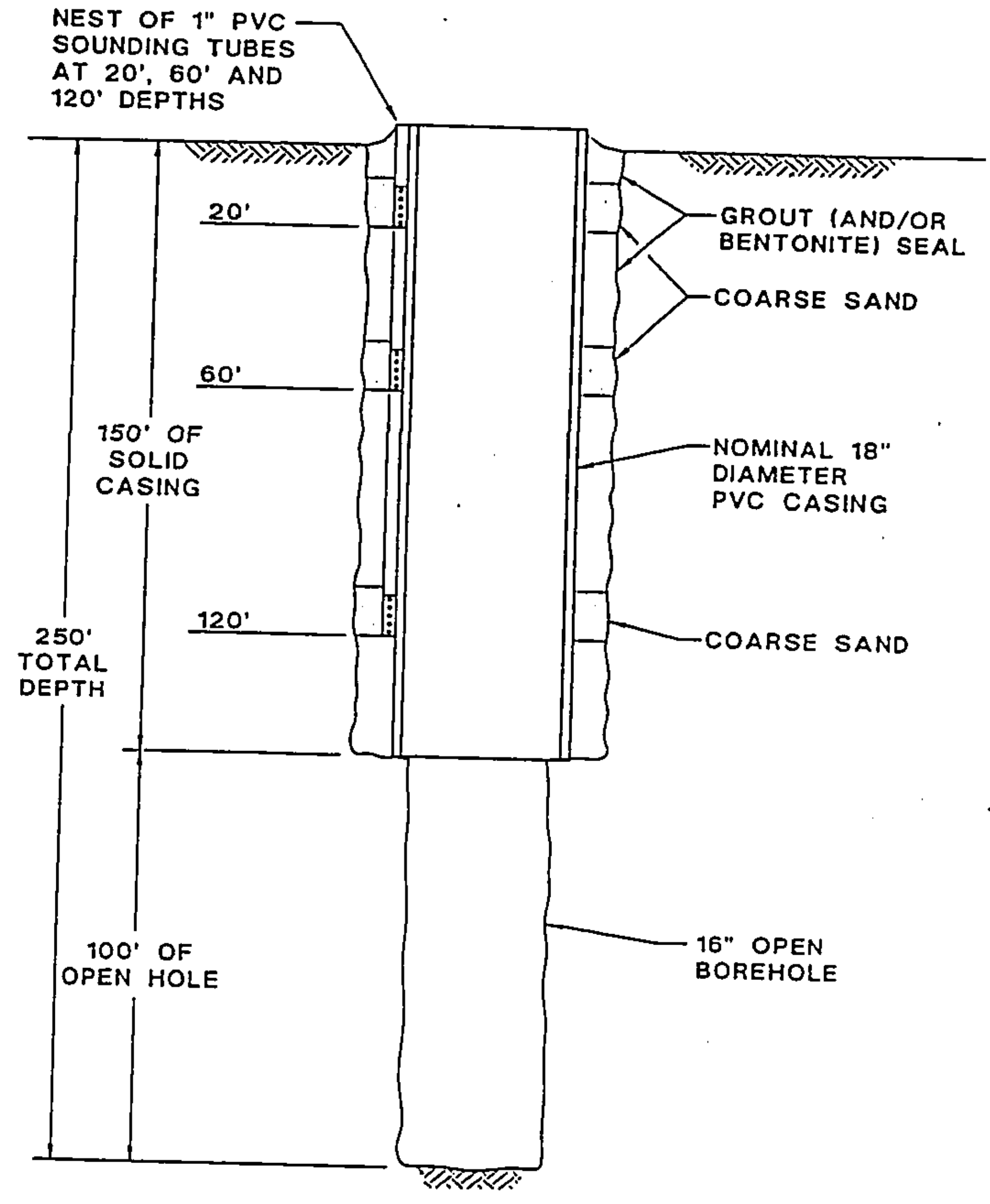


Figure 1-6

PROTOTYPE PRODUCTION WELL
SCHEMATIC PROFILE

In addition to the drilling and testing of the prototype production well, four smaller diameter boreholes will also be drilled to depths of about 250 feet in order to confirm the subsurface geologic strata of the entire proposed groundwater source area at the Ala Wai Golf Course.

Finally, to confirm and ensure that the proposed groundwater sources have the necessary and required water quality to serve as flushing waters for the canal, both water quality and toxicity tests will be performed.

Submerged Pipeline System

The conceptual design and cost estimates for the submerged pipeline system with the intake in the entrance channel of the Ala Wai Boat Harbor were carried out by Makai Ocean Engineering, Inc. (MOE). Figure 1-7 schematically describes the two ocean water source alternatives that were evaluated by MOE. Alternative No. 1 represents the submerged pipeline with an intake in the Ala Wai Boat Harbor entrance channel, and Alternative No. 2 represents the directionally drilled pipeline with an intake off Waikiki Beach. (Alternative No. 2 is not recommended at this time.)

The proposed system, (Alternative No. 1), consists of a pipeline which intakes seawater from the Ala Wai Boat Harbor entrance channel, at a depth of about 40 feet, and discharges the flow at the Kapahulu end of the Ala Wai Canal. In addition to the suction and discharge pipelines and the required intake and discharge manifolds, a submerged pump station with a minimum pumping capacity of 20 cfs (9,000 gpm) and a maximum pumping capacity of 30 cfs (13,000 gpm) is located near the entrance of the Ala Wai Canal adjacent to Magic Island.

A preliminary optimization analysis was performed to determine the optimum size of the suction and discharge pipelines and components. The optimum sizes have been defined as those which would produce the smallest total costs (capital plus operational) over the life of the pipeline (assumed 30 years in this preliminary analysis). It was found that large diameter pipes and small pumps provide the best combination to minimize total costs over the lifetime of the system. As the size of the pipe diameter decreases, capital costs decrease due to the fact that the cost of the pipe, weights needed to hold the pipe down, and dredging requirements decrease. However, a smaller pipe diameter means that, for a given operational flow, the friction losses during operation will be larger. Larger friction losses increase capital costs since larger pumps and motors are required, but primarily increase operational costs since more electricity is needed to drive the pumps to achieve the desired flow rates. At this conceptual design level, a 40 inch, 4,000 foot long suction pipe and a 42 inch, 12,500 foot long discharge pipe have been selected, together with a submersible, three pump system (2 main and 1 back-up).

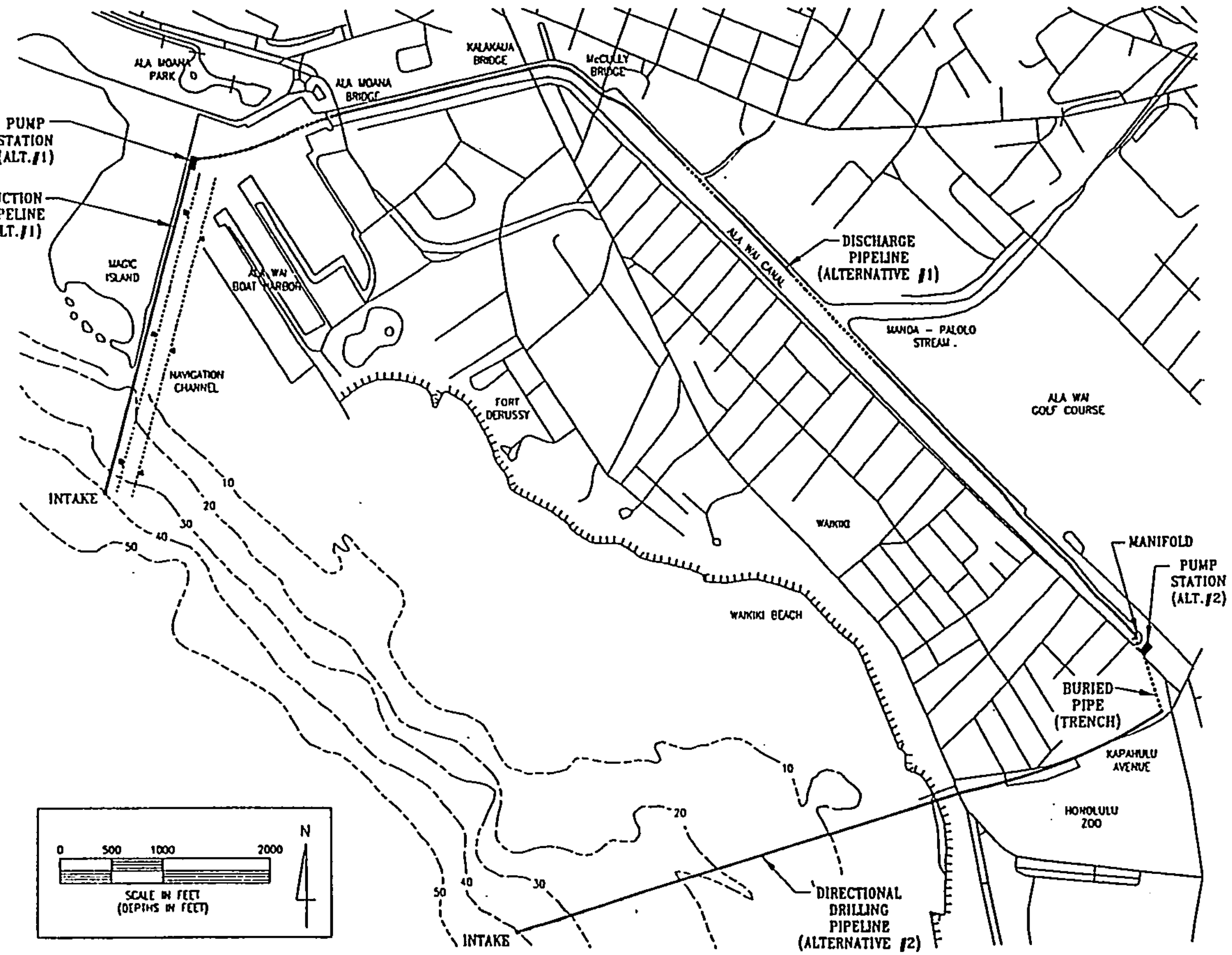


Figure 1-7 GENERAL SITE LOCATION SHOWING ALTERNATIVES ANALYZED

Polyethylene pipes have been selected for this alternative. Polyethylene is a very rugged and cost effective material with a long life in marine applications. In addition, polyethylene is an inert material which does not corrode and does not promote growth of marine organisms. Although the presence of some fouling organisms will be inevitable, the pipe will be designed to insure that fouling will not significantly affect the required flow rates.

The pipeline route inside the Ala Wai Canal has been selected to be on the mauka side of the canal, 15 to 35 feet from the side wall, in water depths of approximately 5 feet. The main advantages of laying the discharge pipe on the mauka side of the canal are:

- On the mauka side of the canal between the McCully Bridge and the Kapahulu end of the canal are a golf course, a public park and a school. Large public spaces are available is this area to store, assemble and deploy the pipeline. The makai side has a high density of apartments, commercial, and resort areas, which would make the construction, deployment, and maintenance operations more difficult.

- Noise during construction would be minimal for the residents of Waikiki.

- Access is easier for large construction equipment.

- Minimize visual impact during construction and traffic congestion that would be created if the pipeline is assembled and deployed on the makai side. The same is applicable for maintenance operations.

- While the pipeline may be partly visible underwater in some areas when viewed directly overhead, the visual impact from the Waikiki area would be non-existent.

It has been assumed that the pipeline will be laid after maintenance dredging of the Ala Wai Canal is completed. With the exception of the crossing of the existing streams along the mauka side of the Ala Wai Canal and the crossing of the Ala Wai Boat Harbor, where the pipe is completely buried underground, the pipeline is laid partially above the canal bottom. This approach minimizes the capital cost associated with the required dredging, facilitates maintenance and re-deployment of the pipe in another location (if ever needed), and does not considerably affect boating and other recreational activities in the Ala Wai Canal. At the same time, boats of the size now in use in the Ala Wai Boat Harbor would not represent a threat to the integrity of the pipeline. A minimum clearance of about three feet has been established between the top of the pipeline and the water surface in the canal.

The suction pipe will lay on the bottom along the wall of Magic Island, parallel to the existing navigation channel of the Ala Wai Boat Harbor and will extend from the end of the navigation channel offshore to a depth of approximately 40 feet. The last portion of this pipe will be properly protected and weighted/anchored against the action of waves and currents.

The implementation of this alternative is technically feasible and simple. Construction and deployment of the pipe and installation of the pump station involve minimum risks. During operations, the pumps are the only component in the system that can break down, and the addition of a back-up pump minimizes chances of interrupting operations.

The following listing summarizes the conceptual design for this alternative.

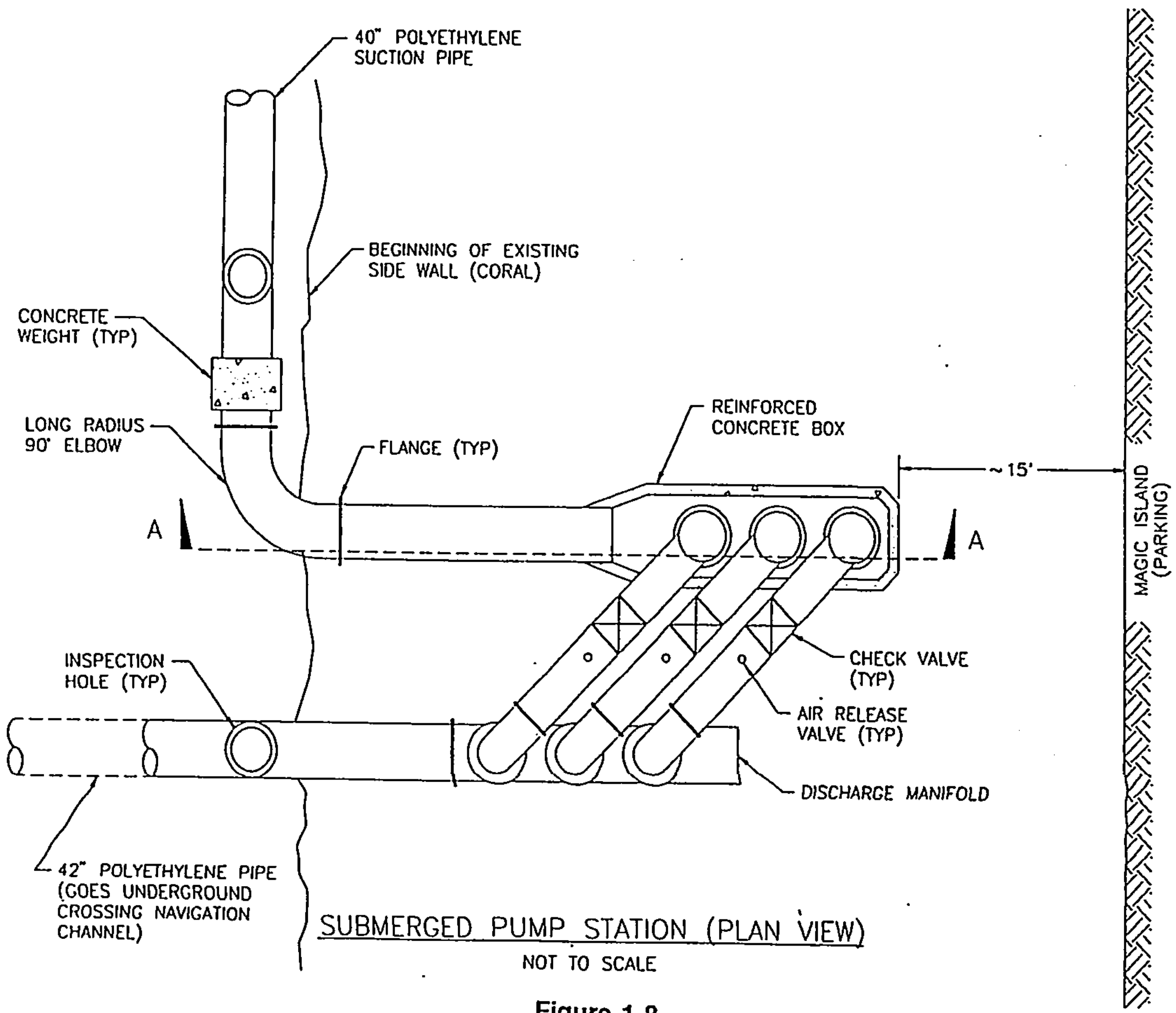
◇ Operational flow of 20 cfs (9,000 gpm) with a maximum flow rate of 30 cfs (13,500 gpm). Three submersible pumps (Figures 1-8 and 1-9) located at a submerged pump station adjacent to Magic Island are proposed, with one pump capable of producing 20 cfs, two pumps producing about 30 cfs and the third pump used as a back-up.

◇ 40 inch diameter, 4,000 foot long suction pipeline extending from the intake structure to the submerged pump station, and a 12,500 foot long. 42 inch diameter discharge pipeline extending from the submerged pump station to the Kapahulu end of the canal. High density polyethylene (HDPE) material has been selected for both suction and discharge pipelines. To minimize interference with future dredging programs, the discharge pipeline would be constructed within 15 to 35 feet from the mauka wall of the canal and the pipeline would not be deeply buried to minimize the risk of undermining the existing wall structure as shown in Figure 1-10.

◇ The discharge pipeline will be buried across the Manoa-Palolo Stream outlet with the top of the pipe at –13 feet MSL, and from the Ala Moana Bridge to the pump station, where the top of the pipe will be 3 feet below the existing bottom. Figures 1-11 and 1-12 schematically illustrate the stream crossing conceptual design.

◇ An intake manifold (Figure 1-13) will be located in a bottom depth of about 40 feet with the top of the manifold about 25 feet below the water surface. Two inlet heads are proposed, consisting of 360 3-inch diameter holes each, which would diffuse the intake flow and provide horizontal inflow circulation in order to minimize ingestion of marine life and to minimize danger to divers. For the maximum 30 cfs flow rate, the inlet velocities are less than 1 ft/sec (0.6 knots).

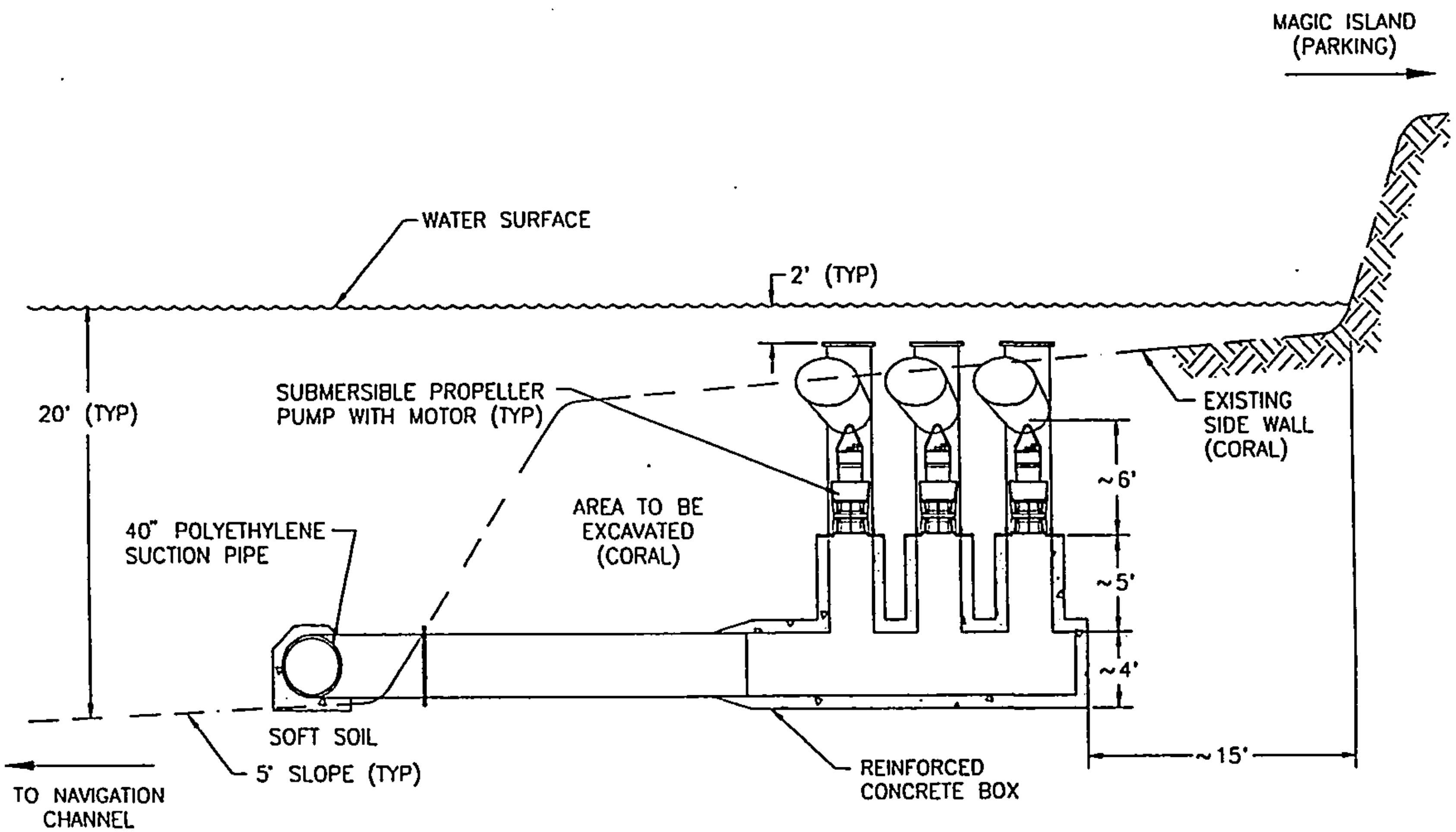
◇ A discharge manifold, comprised of a 28 inch diameter HDPE pipeline, will distribute and diffuse the outflow waters laterally across the Kapahulu end of the canal. A total of 32 equally spaced holes, 5.5 inches in diameter oriented at



SUBMERGED PUMP STATION (PLAN VIEW)

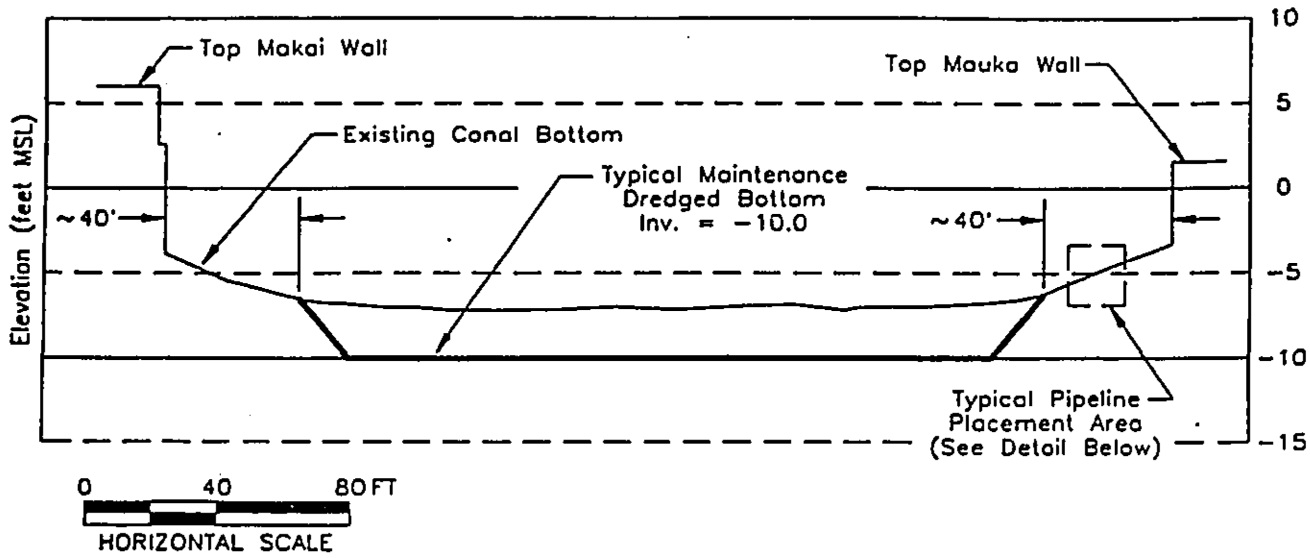
NOT TO SCALE

Figure 1-8

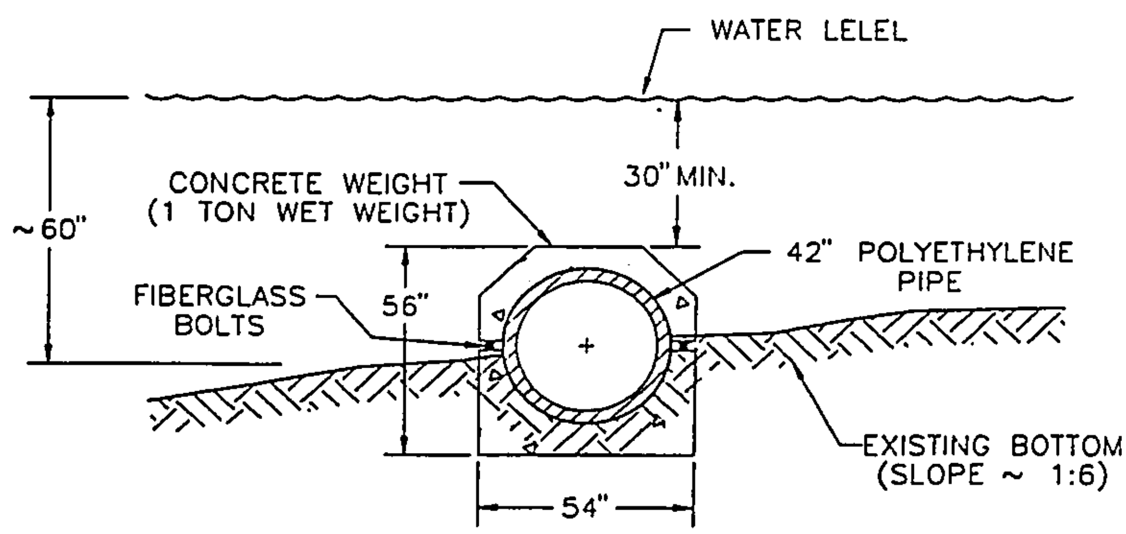


SUBMERGED PUMP STATION
SECTION A–A
NOT TO SCALE

Figure 1-9



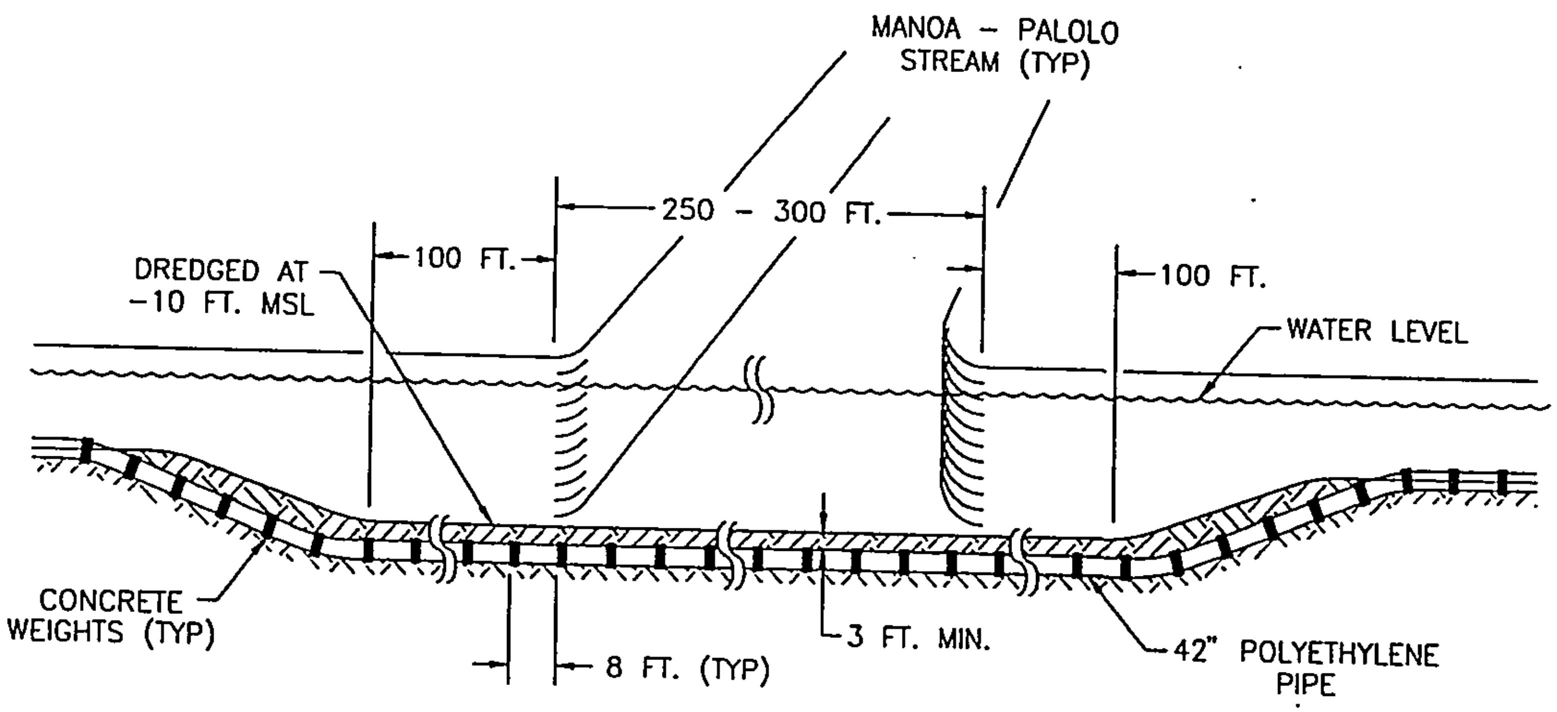
TYPICAL ALA WAI CROSS SECTION



CROSS SECTION
NOT TO SCALE

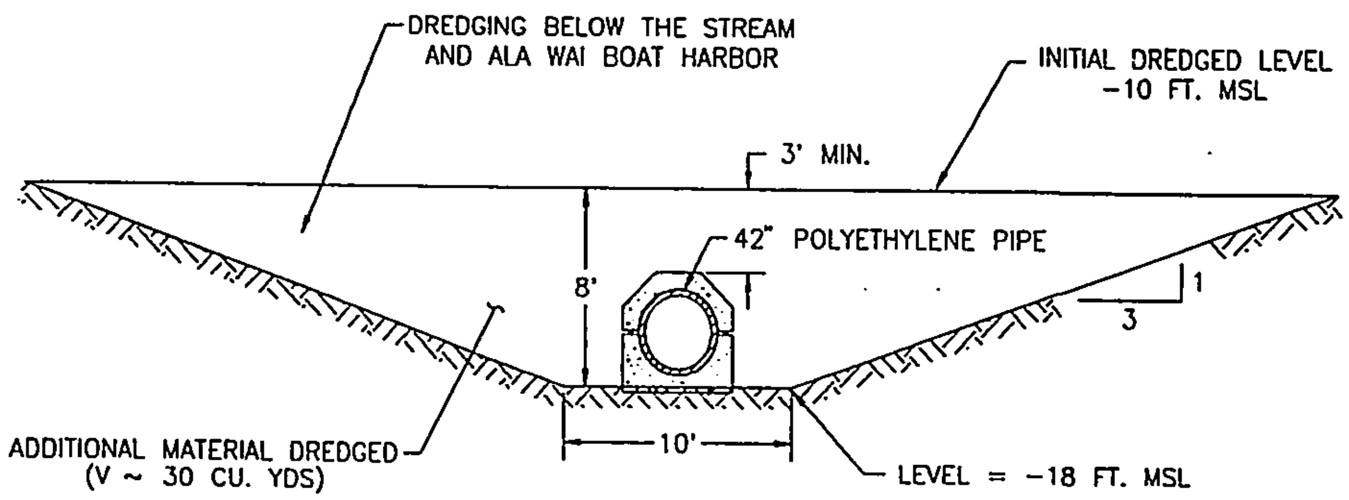
TYPICAL PIPE BOTTOM PLACEMENT ALONG THE ALA WAI CANAL
NOT TO SCALE

Figure 1-10



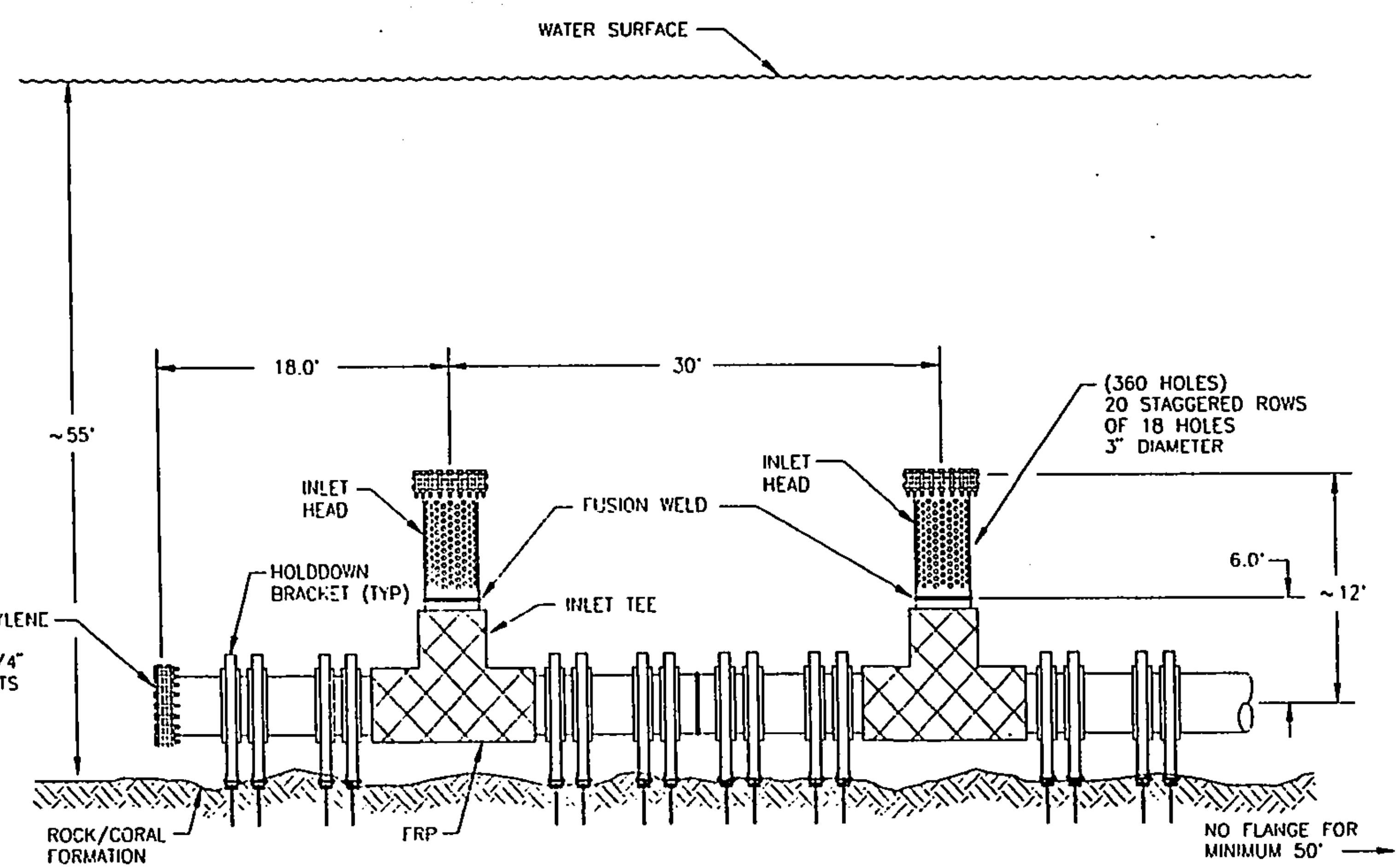
PIPELINE CROSSING STREAM ENTRANCE
NOT TO SCALE

Figure 1-11



CROSS SECTION OF PIPELINE CROSSING
STREAM ENTRANCE
NOT TO SCALE

Figure 1-12



ALA WAI FLUSH INLET CONCEPT

NOT TO SCALE

Figure 1-13

60° from the horizontal will distribute water uniformly across the canal width, with a discharge velocity of about 4 ft/sec for the operational flow of 20 cfs. Figure 1-14 shows a plan view of the proposed manifold and Figure 1-15 shows a side view and detailed cross-section.

The conceptual design for the ocean seawater source intake and submerged pipeline is technically feasible, involves minimal risks, and fabrication of the pipeline system and its deployment are considered to be relatively uncomplicated tasks. If the well testing program indicates that the deep groundwater well supply concept is not feasible, then it is recommended that the submerged pipeline system in the Ala Wai Canal be considered for implementation.

Social Characteristics

The Ala Wai Canal forms the boundary of the Waikiki District, separating Waikiki from the Makiki, Moiliili and Ala Moana areas of Honolulu. Since its construction in 1928, the canal has been used for recreational purposes which include boating (motoring) rowing, and canoe paddling) and fishing. It has recently been placed on the Hawaii National Register of Historic Places.

The length of the makai (ocean) side of the canal is spanned by a concrete tree-lined sidewalk which is a popular site for jogging. Between Kalakaua and Ala Moana bridges there is a tree-lined footpath on each side of the canal. Sixteen stairwells on the makai side of the canal drop down from the sidewalk to the canal's surface.

Despite the problems of pollution, the Ala Wai Canal is heavily used for recreation by Waikiki residents and visitors, with an estimated daily year-round use of some 4,000 people in 1986. The 1992 Waikiki Master Plan envisions a "Grand Promenade" offering uninterrupted pedestrian access around the entire perimeter of Waikiki. There are plans for enhancement of the makai side of the canal that would provide additional public access, landscaping and sidewalk cafes. Improving water quality in the canal is prerequisite to installing these improvements.

Economic Characteristics

The construction cost estimate for the submerged pipeline laid in the Ala Wai Canal is about $8.5 million with an annual O&M cost of about $72,000. The construction cost estimate for the deep groundwater well supply system is about $3.3 million with an annual O&M cost of about $190,000. Benefits from the improvements would accrue mainly to residents and visitors in Waikiki, property owners adjacent or in close proximity to the canal, users of the canal and users of public facilities on the mauka side of the canal. Because of the importance of Waikiki to the economy of Oahu and the State of Hawaii, residents of the City and the State would also benefit.

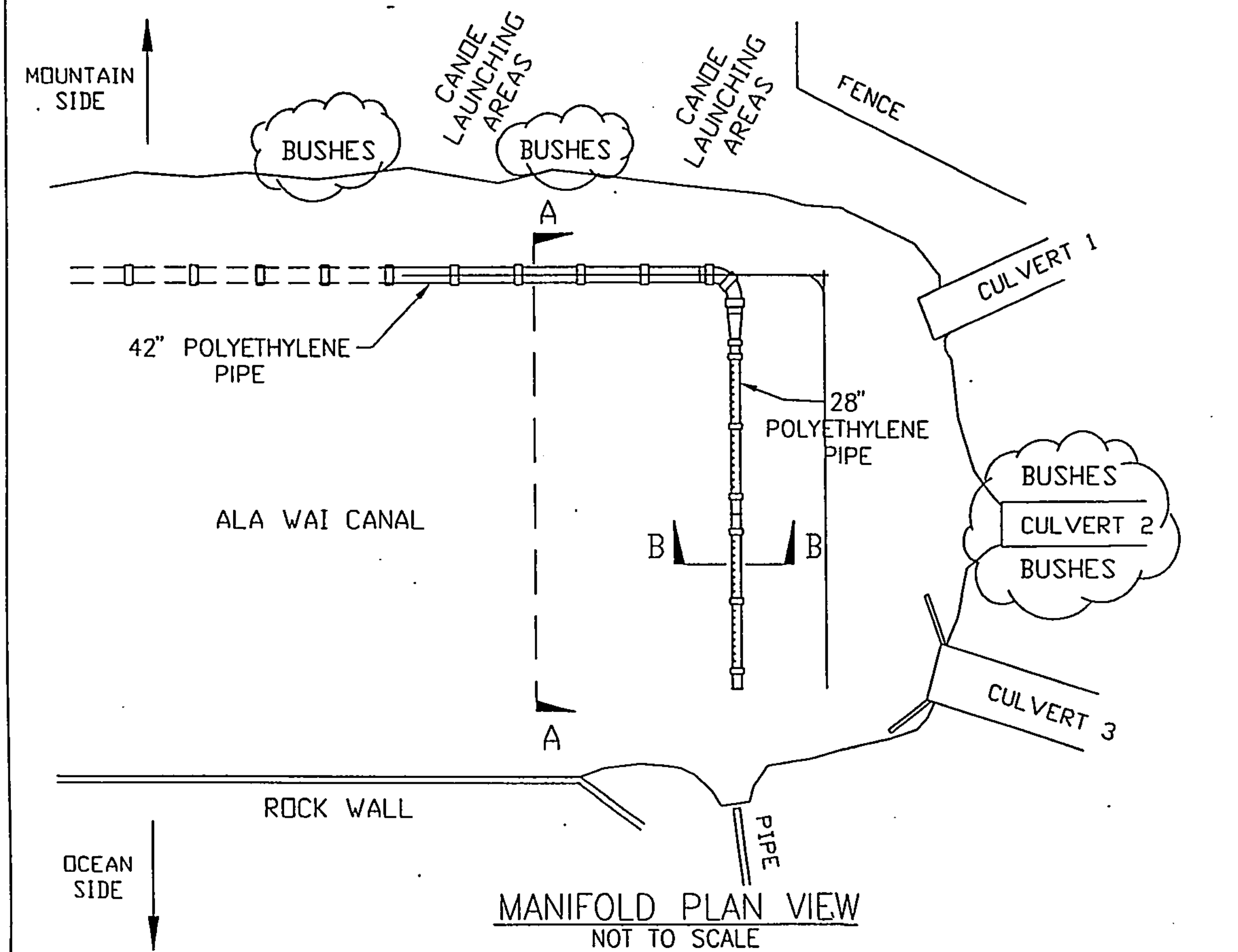

MOUNTAIN
SIDE
BUSHES
CANOE
LAUNCHING
AREAS
BUSHES
CANOE
LAUNCHING
AREAS
FENCE
CULVERT 1
A
A
42" POLYETHYLENE
PIPE
28"
POLYETHYLENE
PIPE
ALA WAI CANAL
B
B
BUSHES
CULVERT 2
BUSHES
CULVERT 3
ROCK WALL
PIPE
OCEAN
SIDE
MANIFOLD PLAN VIEW
NOT TO SCALE

Figure 1-14

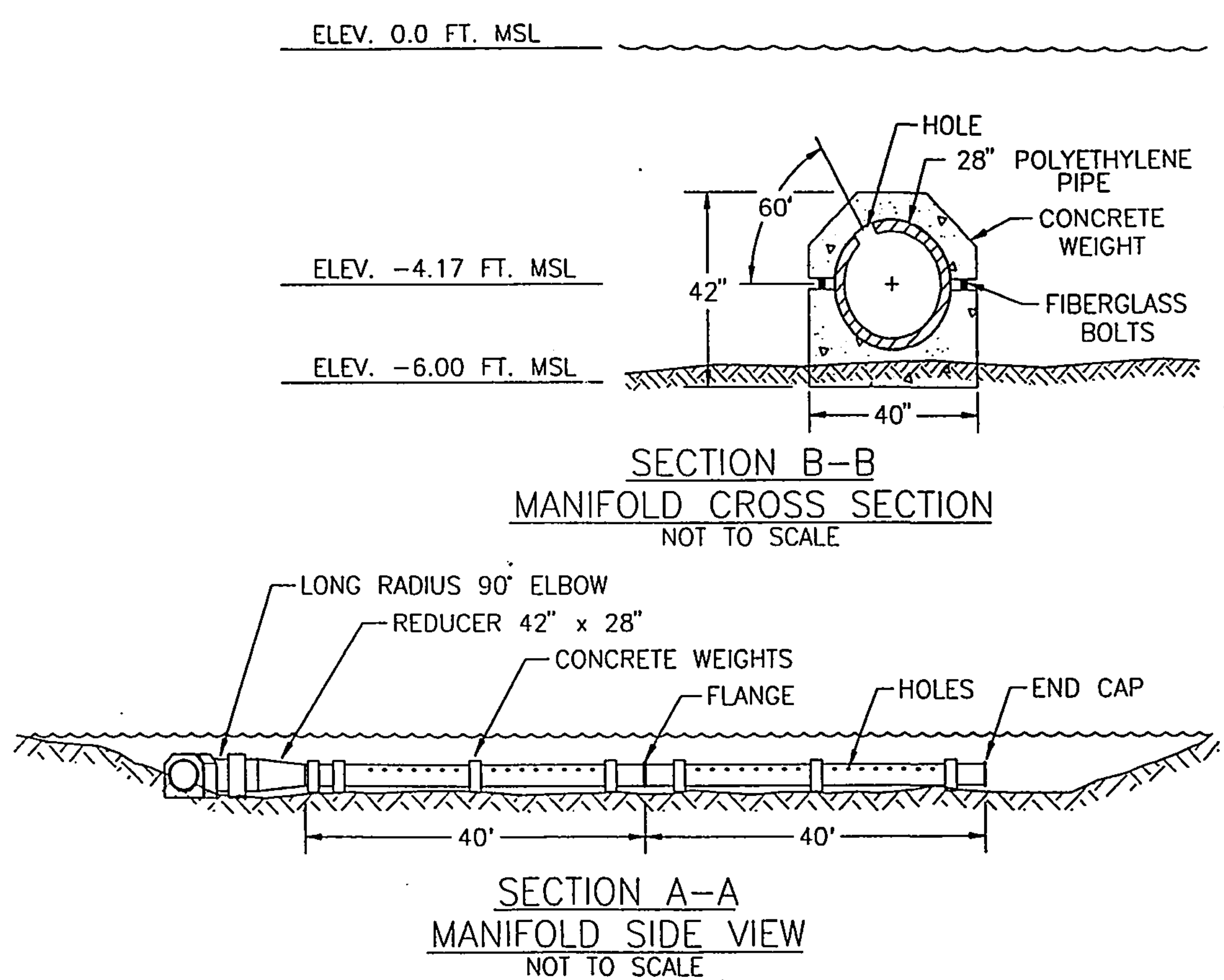

ELEV. 0.0 FT. MSL
ELEV. -4.17 FT. MSL
ELEV. -6.00 FT. MSL
HOLE
28" POLYETHYLENE PIPE
CONCRETE WEIGHT
FIBERGLASS BOLTS
60°
42"
40"
SECTION B-B
MANIFOLD CROSS SECTION
NOT TO SCALE
LONG RADIUS 90° ELBOW
REDUCER 42" x 28"
CONCRETE WEIGHTS
FLANGE
HOLES
END CAP
40'
40'
SECTION A-A
MANIFOLD SIDE VIEW
NOT TO SCALE

Figure 1-15

Environmental Characteristics

The Ala Wai Canal provides an important drainage conduit for surface water runoff. It collects nutrients from surface runoff waters and from other non-point sources such as groundwater. The canal was also designed to serve as a sediment deposition basin in order to minimize the discharge of sediments into the nearshore coastal waters through the Ala Wai Boat Harbor entrance channel.

Water quality in the canal is determined by its source waters (nearshore ocean water, groundwater, streams), mixing and tidal exchange, and input from the accumulated sediment via resuspension and regeneration. "New" nutrients (not recycled *in situ*) are derived from groundwater and the streams. The murky green discoloration of the canal waters results from excessive phytoplankton growth, due to significant incident sunlight, and long residence times within the canal system. During and immediately after periods of heavy rain, the canal waters display a distinct brown discoloration due to the suspended sediments which are entrained in the surface runoff, and possible re-suspended bottom sediments.

Biological and water quality surveys were made as part of the field studies for the project. One of the most important water quality criteria, and the one which was used to evaluate the performance of alternative water quality improvement designs for the canal, was water clarity. For the worst case situation, when very little rainfall-runoff flows into the canal, the combination of high nutrients, strong and consistent sunlight, and long water residence times promotes active phytoplankton growth which results in high chlorophyll concentrations and organic turbidity, producing poor water clarity. The key parameter for increasing water clarity is the reduction of chlorophyll concentrations in the water column. Based on water clarity analysis, a target chlorophyll concentration of 5 micrograms per liter (μg/l) was selected, with a maximum concentration of 10 μg/l imposed as a not-to-exceed criteria for selection of the proposed design flushing alternatives. At this level, visibility is about 10 to 12 feet, and the water clarity goal should be achieved.

The data acquired from the water quality surveys were extensively used in the calibration and verification of a two dimensional hydrodynamic and water quality computer model. The model was used to evaluate design options to achieve the objective of improved water quality. The design options included injecting either flushing seawater or groundwater into the Kapahulu end of the canal; connecting the Kapahulu end of the canal to Waikiki Beach using a covered channel; and various dredging options to improve circulation in the existing canal. The criteria for evaluating the technical feasibility of any of the tested design options, was whether the chlorophyll concentrations were about 5 μg/l with a maximum value of 10 μg/l. For any potentially feasible option, simulations were run which included variation in wind speed and direction (tradewind and Kona wind), and tidal range variations.

Based on the results from the extensive computer model runs, it was determined that the addition of 20 to 30 cfs seawater inflow into the Kapahulu end of the Ala Wai Canal would reduce the chlorophyll concentrations sufficiently to achieve the water clarity objective. This will have an insignificant effect on the mean water velocities in the canal. In the area between the McCully Bridge and the Kapahulu end of the canal where most of the canoe racing is performed, typical mean water speeds due to the maximum 30 cfs seawater inflow will increase by only 0.016 - 0.046 ft/sec (0.011 - 0.032 miles/hour). These water current speed changes would essentially be imperceptible to the recreational users of the canal. The maximum mean current flow speed increase of 0.032 miles per hour would be equivalent to the effects of a 1 mile per hour wind velocity blowing on the water surface.

The environmental impacts associated with both the deep groundwater well supply system and the submerged pipeline laid in the canal have been evaluated. The assessments indicate that while there will be some temporary impacts (noise, visual, odor, turbidity) during construction, the overall adverse environmental impacts after the completion of construction are very minimal, and in fact, there will be a measurable water clarity and quality improvement to the Ala Wai Canal waters. Improvements to water quality in the canal will also improve water quality in the adjacent nearshore waters, specifically the Waikiki Yacht Club.

Construction of the facility will result in depletion of labor, energy and natural resources that provide manpower and materials for construction. There will also be a temporary increase in noise and air pollution during construction. Approximately 864 kW of electricity per day will be required to operate the pumps at 20 cfs, and 1296 kW at 30 cfs. This is equivalent to that used by 36 single-family households at 20 cfs, and 54 households at 30 cfs.

Management Plan for the Ala Wai Canal Watershed

The *Management Plan for the Ala Wai Canal* seeks to decrease sources of pollutants through improved watershed management. The plan identifies activities which will be useful immediately. These include cleaning up litter debris and bulky items from streambanks and streets, reducing erosion rates through improved enforcement of grading permit regulations, and expanded hazardous waste and toxic substance collection and disposal. In the longer term, the plan notes that watershed management can improve water quality through the control of pesticides and heavy metals.

The plan recommends that the State enter into a contractual relationship with a qualified non-profit organization to lead the implementation of a community-based public/private program of watershed management activities. Four major tasks are identified:

- Developing and leading community participation in cleaning up and maintaining the Ala Wai Canal watershed.

- Planning and coordinating an immediate action program of watershed management measures.

- Developing proposals for funding from the U. S. Environmental Protection Agency, foundations, and private sources.

- Promoting monitoring and research.

State appropriations of $100,000 for each of the fiscal years 1993-94 and 1994-95 are recommended for the direct expenses of the non-profit organization, with outside funding assumed for activities beyond FY 1994-95. The plan also recommends that the State provide seed money to the University of Hawaii to begin monitoring and research activities where they are known to be inadequate and where progress in planning and development of further management actions is known to be impeded by a lack of baseline or trend data. An initial appropriation of $50,000 in each of the fiscal years 1994-95 to 1996-97 is recommended to fund these activities.

Maintenance Plan for the Ala Wai Canal

The *Maintenance Plan for the Ala Wai Canal* has three purposes. These are to 1) describe the existing conditions/problems in the canal; 2) describe the existing State/City & County agency measures and responsibilities for the canal; and 3) develop a maintenance plan that builds on 1) and 2). The plan notes that many of the maintenance tasks on the Ala Wai Canal are presently initiated only at the urging of residents to what is perceived as a serious problem, such as their petitioning state legislators to allocate funds for the last maintenance dredging.

Maintenance is also complicated by the number of different agencies with various responsibilities that are involved. For example, the Manoa-Palolo Drainage Canal is the major source of sediment, trash, and debris in the Ala Wai Canal. While the Ala Wai Canal is owned by the State of Hawaii and maintained by the Division of Water and Land Development (DOWALD) of the State Department of Land and Natural Resources, the Manoa-Palolo Drainage Canal is the responsibility of the City and County of Honolulu Department of Public Works (DPW). However, DLNR acknowledges maintenance dredging responsibility for Manoa-Palolo between the Ala Wai and the Date Street bridge. Until July 1, 1992, the Harbors Division of the Department of Transportation (DOT) was also a major player. This changed officially on that date with the transfer of boating programs and projects to a new DLNR Division of Boating and Outdoor Recreation (DBOR). The program continues to be operated by DOT under a contractual agreement until the transfer can be completed. Owners of property bordering the canal also have responsibilities for shoreline areas. These include the State Department of Education (DOE), the City Department of Recreation (DPR) and private property owners.

To prevent objectionable conditions from occurring, responsible agencies need to monitor prevailing conditions and plan accordingly. Different tasks will require different scales of monitoring, and major maintenance cost items should be anticipated and pre-programmed in agency budgets. The plan identifies six categories of maintenance activities and recommends a schedule for monitoring and maintenance. These activities and the agencies responsible for implementation are described in the order of the frequency of effort, from most frequent to least frequent, as follows:

◇ Inspect debris trap(s) and clean as necessary (2-4 weeks and prior to major storms)	State DLNR (DBOR)
◇ Intensive cleanup of vegetative and urban debris from streambanks & shoreline areas (6 months – spring and fall)	City & County DPR & DPW, State DOT & DOE, private property owners
◇ Inspect canal walls; schedule repairs as necessary (yearly in the spring)	State DLNR (DBOR)
◇ Survey canal bottom for debris; schedule debris removal as necessary (yearly in the spring)	State DLNR (DBOR)
◇ Maintenance dredging of sediments from Manoa-Palolo Drainage Canal (3 years)	State DLNR (DOWALD)
◇ Maintenance dredging of sediments from Ala Wai Canal (10-12 years)	State DLNR (DOWALD)

The plan includes schedules and cost estimates for maintenance dredging for both the Manoa-Palolo Drainage Canal and the Ala Wai Canal. The Ala Wai Canal has been dredged twice: in 1966 by the City and County of Honolulu and in 1978 by the State. Both maintenance dredging actions were undertaken out of necessity because sedimentation had become serious enough to render the canal a health and safety problem. The average rate of sedimentation of the canal has been consistent at about 9,000 to 11,000 cubic yards per year. At this rate, major dredging approximately every 10 to 12 years is mandatory. The present shoaled condition necessitates removal of about 135,000 cubic yards of sediment to restore the Ala Wai Canal depth to -10 feet MSL. The estimated cost is $5.4 million.

The plan recommends that the Manoa-Palolo Canal also be dredged to provide a transition between the dredged depth of the Ala Wai and the presently shoaled depths in the Manoa-Palolo Canal. During the last dredging, a 200-foot reach of the Manoa-Palolo Canal was dredged to provide the transition. Approximately 55,000 cubic yards need to be removed to achieve the -10 feet MSL. This would cost approximately $2.3 million if the work is performed separately from the Ala Wai dredging.

For the future, the plan recommends that the Manoa-Palolo Canal be dredged every three years so that it can serve as a sediment basin. Removing an estimated 30,000 cubic yards would cost approximately $1.3 million. There is no real cost saving in more frequent dredging ($1.3 million every 3 years versus about $5 million every 10-12 years) but it would be easier to budget for in a maintenance program and it would reduce impacts on the Ala Wai Canal because of minimal, or at least much reduced, sedimentation.

CHAPTER 2

DESCRIPTION OF THE AFFECTED ENVIRONMENT

Physical Characteristics

Location

The Ala Wai Canal is a man-made tidal estuary located in the Waikiki District of Honolulu. It serves as a boundary of the Waikiki District, separating Waikiki from the Makiki, Moiliili, and Ala Moana areas of the city. The canal serves as the major drainage conduit for the Waikiki District of Oahu as well as the approximately 16.3 square mile watershed directly mauka of the canal (Makiki, Manoa, St. Louis Heights, Palolo, Moiliili, Kapahulu and parts of Kaimuki and Diamond Head). The canal is approximately 2 miles long with widths ranging from 200 to 250 feet. Its average cross-sectional depths range from 3 to 8 feet, with spot depths ranging from 1 to 12 feet.

Three bridges span the canal. The Kalakaua bridge, built in 1929, was the first permanent bridge crossing the canal. Subsequently the McCully bridge and the bridge at Ala Moana Boulevard were added.

Ala Wai Boulevard and a concrete tree-lined sidewalk border the makai side of the canal from its interior end at Ainakea Way near Kapahulu Avenue to the Kalakaua Bridge. The Ala Wai Municipal Golf Course, Ala Wai Elementary School, and the Ala Wai Ballpark and Playground border the canal on the mauka side to McCully Street. Several high rise condominium buildings have been constructed mauka of the park. Between the Kalakaua and Ala Moana bridges there are tree-lined footpaths on both sides of the canal.

The Waikiki Master Plan prepared by Department of General Planning of the City and County of Honolulu describes the Ala Wai Canal as

> "poorly maintained, and its abutting park land are inaccessible from Waikiki. Together, the Ala Wai Canal and abutting park lands constitute a major open space asset, which today is under-utilized. The canal itself is dirty, and the mauka bank is eroding. Bicyclists and joggers compete for space on the narrow makai bank. The mauka bank's substantial park lands are inaccessible by foot from Waikiki and are entirely reserved for active sports."

Climate

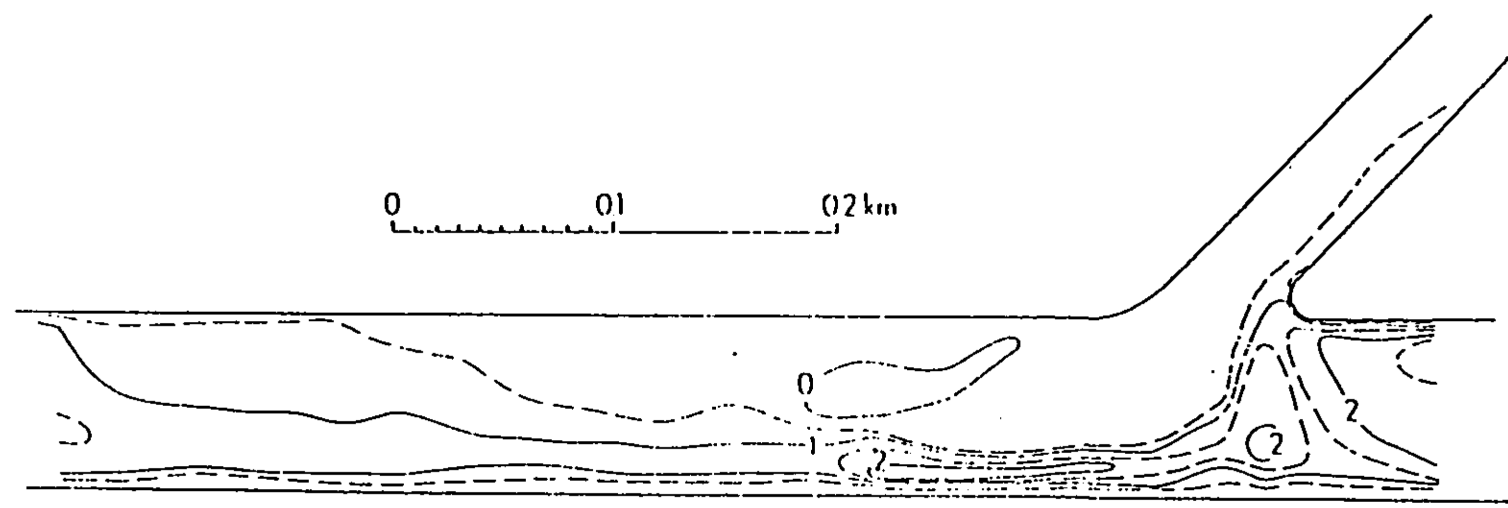
The average rainfall in the area is 30 inches per year. The predominant wind regime is an approximately 10-knot tradewind with a somewhat strong easterly component. Kona conditions can be expected to occur about 15 to 20 percent of the time. The predominant wind direction is roughly aligned with the longest section of the canal, thus increasing the wind-induced water transport.

Bathymetry

The Ala Wai Canal was originally dredged in sections. The section extending from the Ala Moana Bridge seaward for about 500 feet was dredged to a depth of about 25 feet. The section from the Ala Moana Bridge to the 45° bend at the Makiki Stream confluence was dredged to depths between 10 to 13 feet, while the landward section between the Makiki Stream and the Kapahulu end of the channel was dredged to depths between 10 to 20 feet. Since the completion of construction in 1928, sediment deposition has significantly altered bathymetry in most of the channel sections. The Ala Wai Canal has been dredged twice since its construction, the initial dredging in 1966 and the second dredging in 1978.

In May 1965 the City & County of Honolulu carried out a bathymetry survey of a portion of the canal, in preparation for the first maintenance dredging of the canal (see Figure 2-1). Sunn, Low, Tom & Hara, Inc. (SLTH) in 1977 developed a Preliminary Engineering Report for the second maintenance dredging of the canal, which includes a bathymetry survey of the canal. It shows very similar patterns to the 1965 results.

The results shown in the 1965 and 1977 bathymetry surveys indicate that most sections of the canal exhibit a relatively slow bottom sediment deposition rate. The area of the canal which is most affected by sediment deposition is between the McCully Bridge and the Manoa–Palolo Stream confluence. The Manoa-Palolo Stream drains the Manoa and Palolo watersheds, which represent an area of about 7,200 acres, the largest watershed area that drains into the canal. The Manoa–Palolo watersheds include part of the Honolulu Watershed Forest Reserve area, which is an area of steeply sloped, undeveloped forests which generate significant sediment loads during typical and major rainfall runoff events. The sediment laden flow enters the canal at a 45° angle towards the ocean and flows seaward. Since the width and average depth of the canal is significantly larger than the Manoa–Palolo Stream counterparts, there is a substantial decrease in the mean velocity of the entering flow. This velocity reduction allows much of the larger size suspended sediment to fall out of the fluid and to deposit on the seaward side of the stream confluence forming a "sill." In both the 1966 and 1978 maintenance dredging programs, this sill area was the only section of the canal that was dredged.



DEPTH CONTOURS IN METERS, MLLW

ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	BATHYMETRY OF A SECTION OF THE ALA WAI CANAL, MAY 1965, FROM GONZALEZ (1971).	FIGURE 2-1

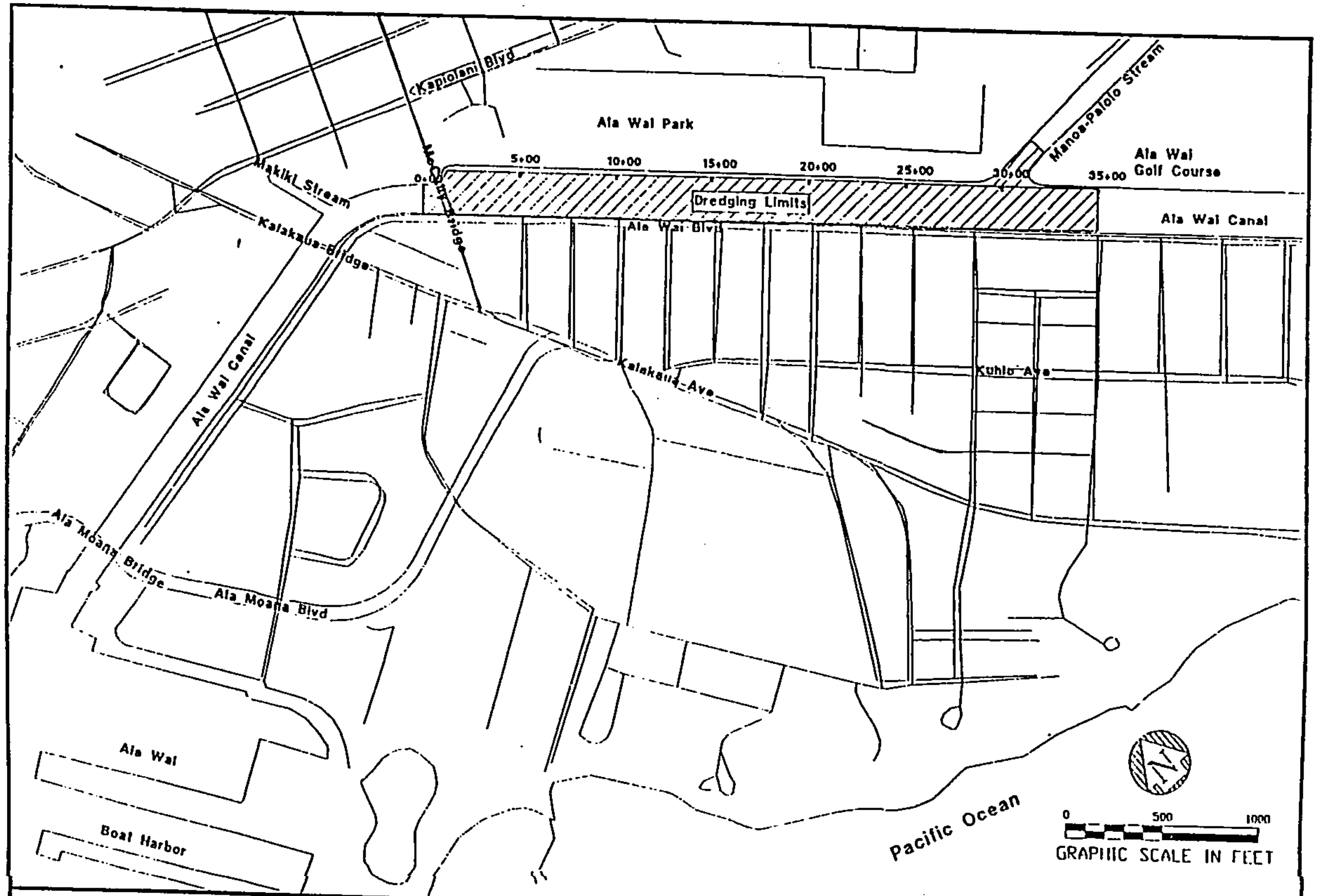
The 1966 maintenance dredging operations encompassed a 1,750 feet section of the canal, starting from the Kapahulu side of the Manoa–Palolo Stream confluence and extending 1,750 feet towards the ocean entrance. In addition, the Manoa–Palolo Stream was dredged a distance of 500 feet upstream from the canal confluence. The required dredge depth was –6 feet mean sea level (MSL).

During the 1978 maintenance dredging program, a 3,500 feet section of the canal was dredged to a depth of –10 feet MSL, beginning about 100 feet seaward of the McCully Bridge and extending up the canal to a location about 400 feet past the Manoa–Palolo Stream confluence as shown in Figure 2-2. To provide a smooth transition with the Manoa–Palolo Stream, the invert depth was varied from –10 feet MSL at the confluence, to daylight at the existing stream bottom depth at about 200 feet upstream from the confluence. The initial plans provided an option to dredge the last 400 feet of the canal at the Kapahulu end to a depth of –5 feet MSL. Due to budget limitations, this option was not exercised.

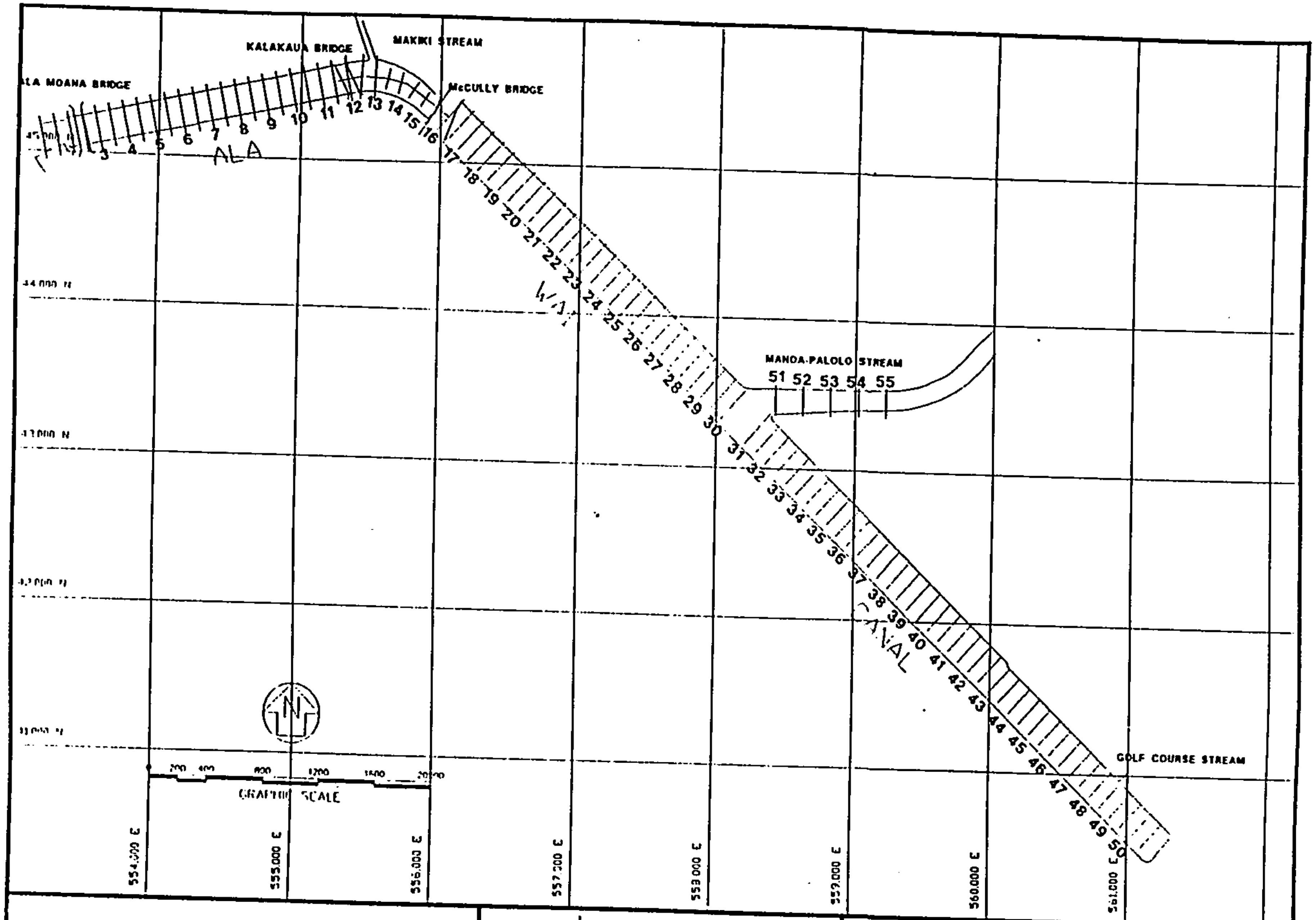
A new bathymetry survey was performed as part of the current project to provide an accurate map of the existing bottom depths within the entire canal. This information was part of the input data for the hydrodynamic and water quality model of the canal. When the present bathymetry data is compared to the last 1978 dredging design, the rate of sediment deposition in the Ala Wai Canal is calculated to be 10,300 cubic yards per year. This sedimentation rate generally agrees with previous calculations and indicates a relatively consistent rate over the last 25 years. Figure 2–3 shows cross-section numbers beginning at the seaward end of the canal. The cross-sections are spaced at 200-foot intervals. Figure 2-4 shows bottom profiles referenced to MLLW (mean lower low water) where the middle profile is along the center axis of the canal, the upper quarter represents a profile one-quarter width distance from the mauka bank, and the lower quarter represents a profile one-quarter width distance from the makai bank. The methodology and results of the bathymetric survey are described in more detail in the project feasibility report.

Tides

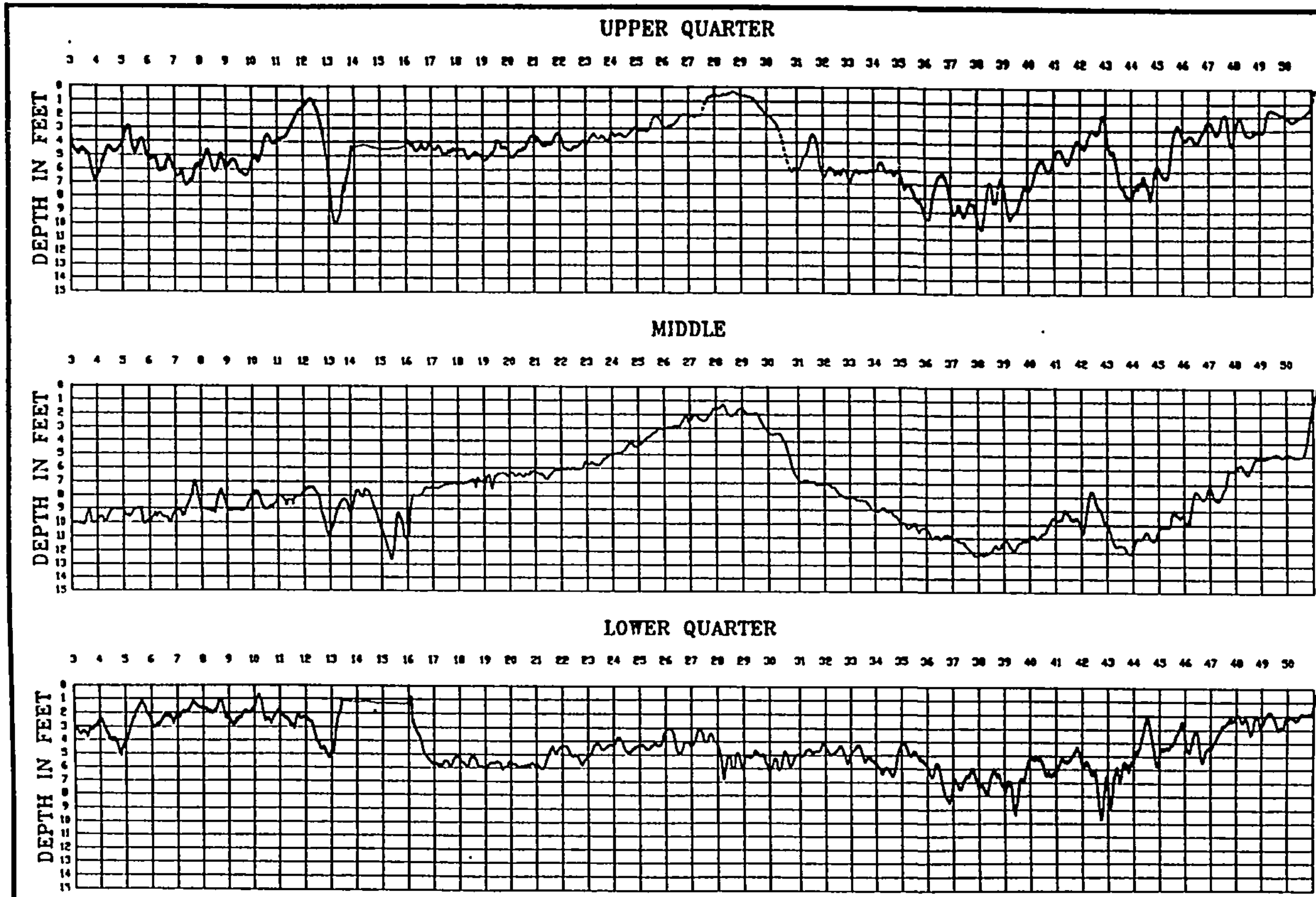
High resolution tide measurements at the entrance channel to the Ala Wai Boat Harbor and at the Kapahulu end of the canal were obtained for a one-month period. The tide measurement stations are shown in Figure 2-5. For comparison purposes, tide measurements obtained by the National Oceanic and Atmospheric Administration (NOAA) at the Honolulu Harbor tide reference station were also acquired for the one-month measurement period. All three tide data sets, when superimposed, show very little amplitude and phase differences. Computer analysis of the tidal time-histories between the entrance and end of the canal indicates that the tide at the Ala Wai Golf Course lags behind the tide at the Ala Wai Boat Harbor entrance channel by about 73 seconds. Analytical analysis confirmed that a standing tide-wave system exists, and that the small time delay is due to friction. This result was then used to calibrate the hydrodynamic model by adjusting the bottom friction factor to obtain the required time delay.



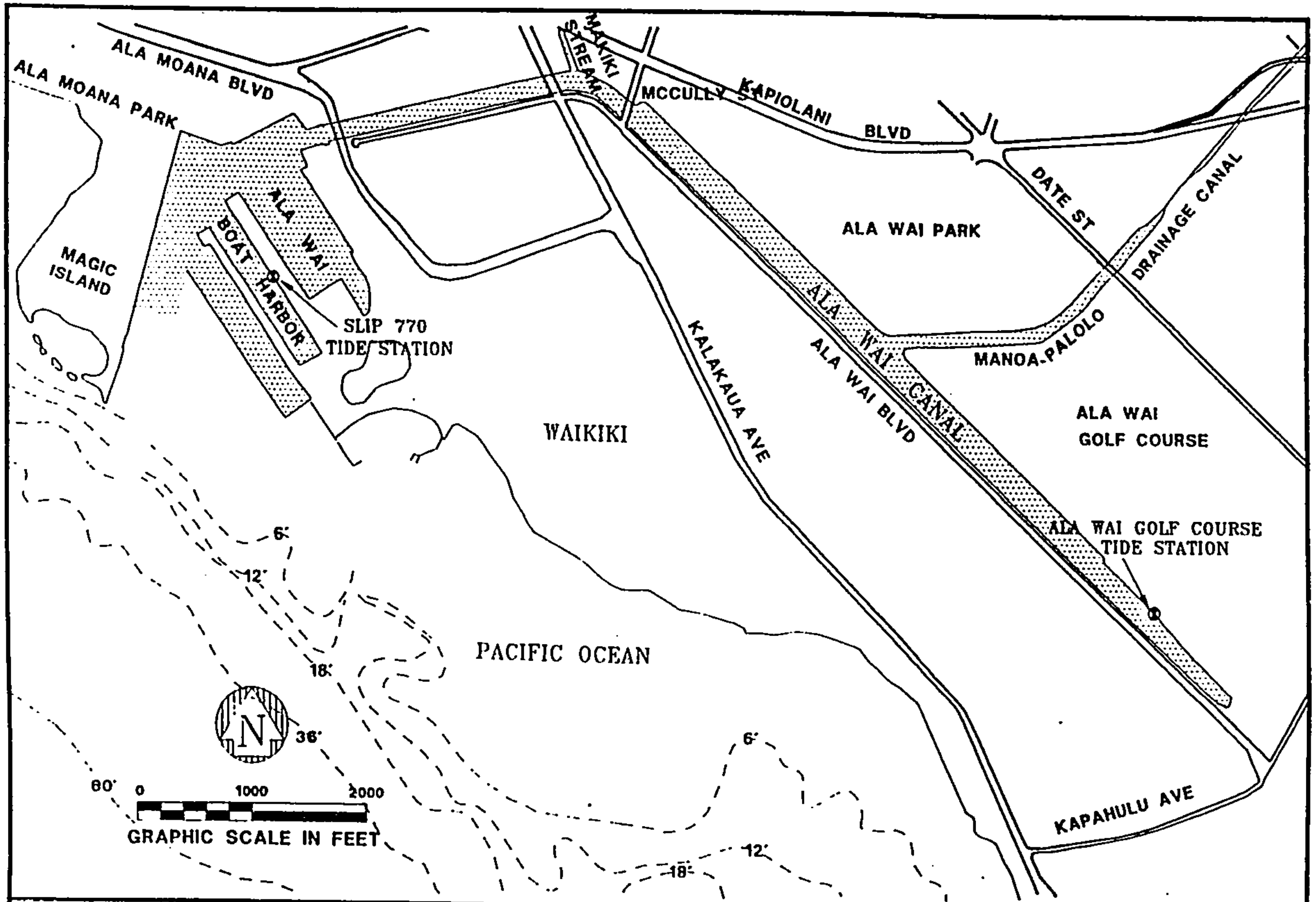
ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	Ala Wai Canal 1978 Dredging Plan	FIGURE 2-2



ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	Ala Wai Canal CROSS-SECTION NUMBERS	FIGURE 2-3



ALA-WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	Ala-Wai Canal Profile Sections	FIGURE 2-4



ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	Ala Wai Canal Tide Measuring Stations	FIGURE 2-5

24

Ala Wai Current and Circulation

Previous studies have indicated that the tidal flow in the deep layer of the canal is strongly influenced by the landward drift, which decreases the flow during the ebb tide, and intensifies the flow during the flooding tide. The magnitude of the surface current velocity is influenced by the magnitude of the fresh water runoff, the size of the tidal range, and the speed and direction of the wind.

In order to quantify water current flow in the Ala Wai Canal, two types of current methodologies were used. To obtain a long term representation of current vectors at given locations, three current meters were located in the canal. In addition to current meter measurements, the current flow circulation in the canal was measured using current drogues. Current drogues are almost neutrally buoyant objects which freely move with the current flow and provide a track of the marked parcel of water as it is driven by the tides, winds and stormwater inflow. The current drogues provide additional information on the water flow patterns at locations different from the deployed current meters.

Within the Ala Wai Canal, 53 individual current drogue deployments were performed under varying wind conditions (Kona winds, light & variable, and typical tradewind conditions), varying tidal conditions (flood and ebb tide), varying surface water runoff conditions, and with drogues set a different depths below the surface. Due to the shallow water conditions in the Ala Wai Canal, many of the deployments were "surface" drogues which consisted of 1-gallon plastic containers partially filled with water such that 90 percent of the container was below water level. In order to evaluate nearbottom circulation, "bottom" drogues were also deployed.

Within the Ala Wai Canal, the current measurements display very complicated variations with water depth, wind conditions, tidal phase and rainfall-runoff discharges. In particular, a two-layer and at times multi-layer circulation flow regime exist within the canal, primarily associated with distinct salinity variations between the surface layer (brackish water) and the underlying layers (seawater). With significant rainfall-runoff discharges into the canal, the surface layer will flow towards the ocean regardless of the tidal phase. With strong tradewind conditions, the surface layer will also tend to flow towards the ocean regardless of tidal phase. The lower layers of the canal waters are more strongly influenced by the tide, usually distinguished by inflow to the canal during flood tide and outflow during the ebb tide. For very large rainfall-runoff events, the discharge into the canal overcomes the tidal forces and the entire water column flows seaward independent of tidal phase. This very complicated, vertical flow variation characteristic of the canal required that a two-dimensional (2-D) hydrodynamic and water quality model of the canal be developed, which would be laterally averaged but would describe variation along the canal axis and in the vertical dimension between the surface and the bottom. The model is described in more detail in their project feasibility report.

Coastal Current and Circulation Measurements

In order to quantify ocean currents in the nearshore coastal waters, both current meter and drogue measurements were obtained. One current meter was centered at the Ala Wai Boat Harbor entrance channel and the other two located about 3,000 feet ewa and Diamond Head of this center station, at bottom water depths of about 60 feet.

The measured current data shows a strong correlation with tidal processes, with the currents primarily oriented along the bathymetry contours. There is a preference for current flow towards the southeast, which is parallel to the bathymetry contours, both in terms of the frequency of occurrence and the magnitude of the current speed. This occurs primarily during the ebb flow part of the tidal cycle.

In addition to the current meter measurements, current circulation in the nearshore coastal area was measured using current drogues. The current drogues utilized for this effort were essentially identical to the drogues used for current measurements in the Ala Wai Canal. For the nearshore coastal area, 40 individual current drogue deployments were performed under varying wind conditions (Kona winds, and light and typical tradewind conditions), varying tidal conditions (flood and ebb tide), varying surface runoff conditions, and variable depth drogue settings. The focus of the drogue deployments was in the area of the Ala Wai Boat Harbor entrance channel and the coastal waters in close proximity to the entrance channel.

The results indicate the similar two-layer characteristics of the discharged flow from the canal as was shown in Ala Wai Canal drogue measurements. During moderate and heavy surface runoff discharges into the canal, the surface layer drogues exhibit strong seaward velocities, while simultaneously released mid-depth and bottom drogues in the entrance channel area tend to flow parallel to the bottom depth contours. During heavy rainfall events, the surface layer plume discharged from the Ala Wai Boat Harbor entrance channel was clearly visible by the sharp boundary line between the silt-laden brown discharged waters and the clearer green ocean waters. The surface layer drogue velocities show strong offshore components, which dominated the tide-driven currents that tended to flow parallel to the bottom depth contours.

Dye Flushing Survey

A detailed dye flushing test was carried out involving the injection of Rhodamine WT dye into the entire Ala Wai Canal. Water samples were obtained daily for about 2 weeks, at 4 stations and at 4 locations in the water column (surface, 1/2 meter below the surface, mid-depth, and 1/2 meter off the bottom). The dye concentration data allowed a direct determination of the dye flushing time constant which is represented by the time that it takes for the dye concentration to fall to 50% of its initial value, T_{50}. Surprisingly consistent T_{50} time constants of the order of 40 to 60 hours were calculated for all 4 stations and the 4 different depth levels. These T_{50} flushing time constants were used in the calibration process for the 2-D hydrodynamic and water quality model. Conductivity-temperature-depth (CTD) profiles were also obtained during the dye flushing survey. Locations of the sampling stations are shown in Figure 2-6.

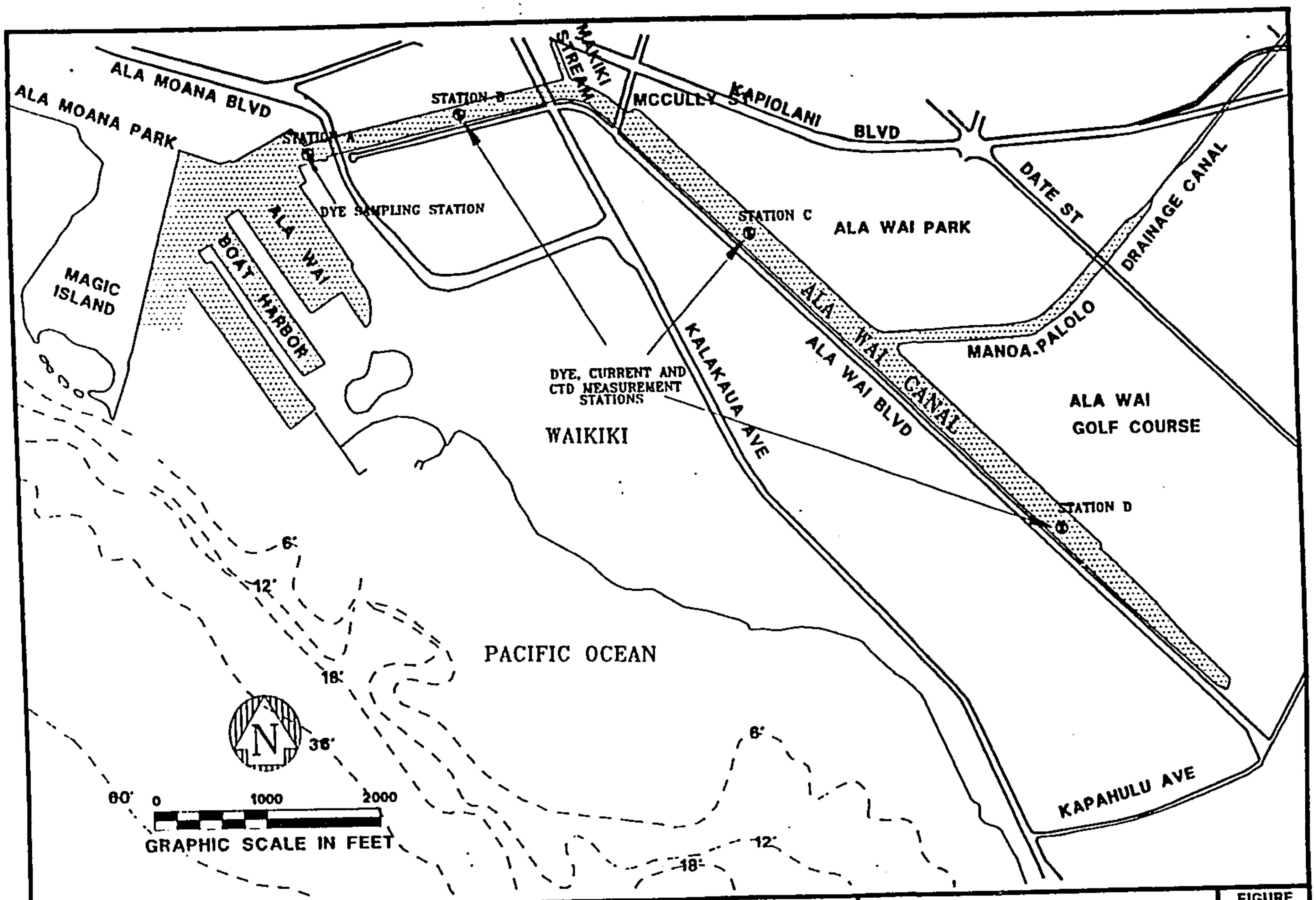
Water Quality

As the collecting point for the Makiki, Manoa, Palolo and Kapahulu watersheds (Figure 2-7), the canal accumulates sediments, nutrients, some heavy metal contamination, and solid waste trash. The results of these contaminations are reflected in discoloration of the water due to phytoplankton growth, suspended sediments, and visually objectionable trash. In addition, some incidence of bacterial infections has been reported.

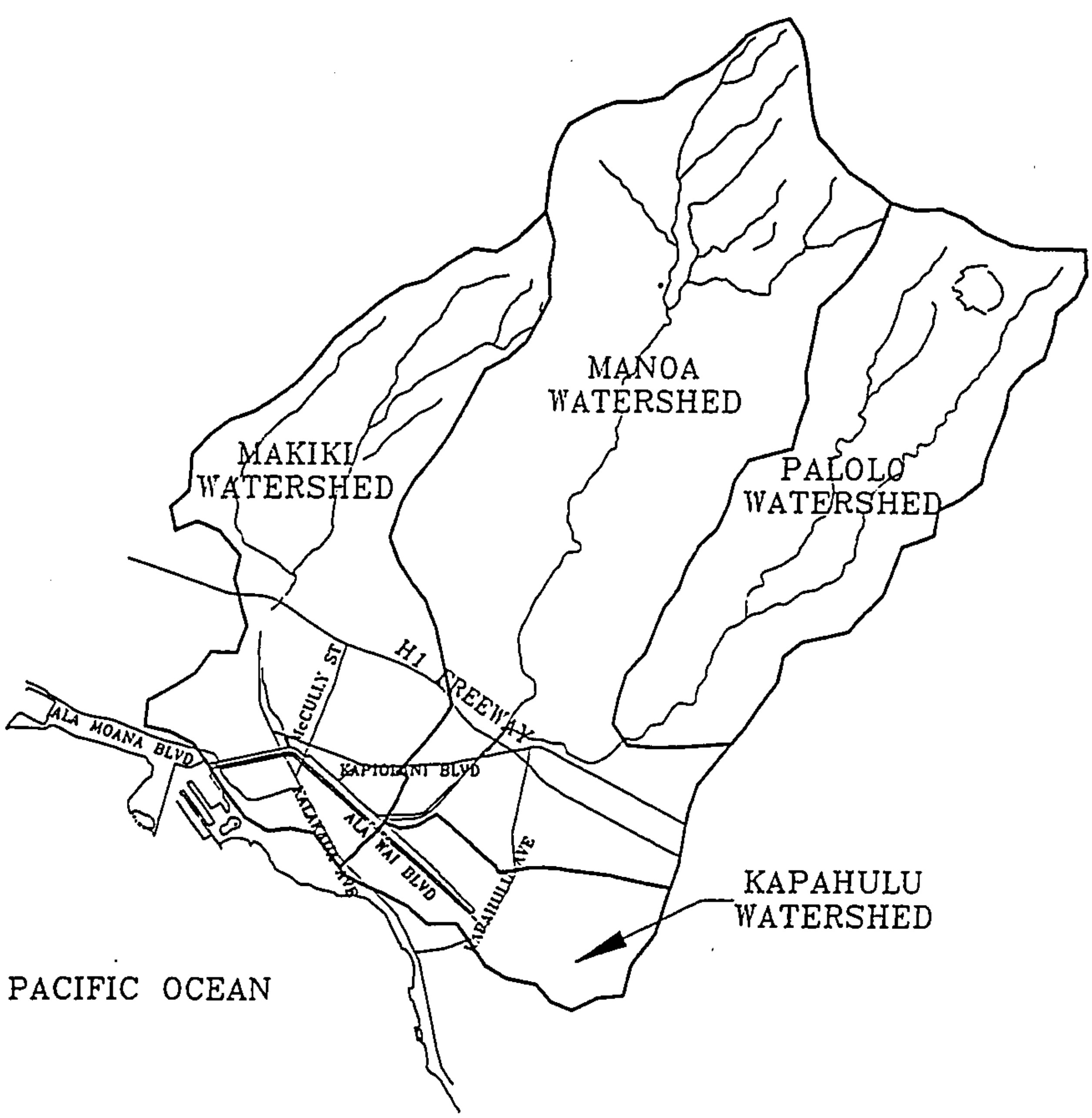
The two primary objectives of the water quality monitoring effort by OI Consultants, Inc. were to describe the existing environmental conditions within the canal and to provide input data for the computer model. This model helped identify pivotal parameters which affect water quality within the canal and establish targets which can be used to examine the effectiveness of different engineering alternatives such as routine maintenance measures (e.g., dredging), improved flushing rates, and water circulation in the canal. In order to choose the best of several engineering solutions to improve water quality, a series of water quality samples were collected to characterize conditions within the canal and within the source waters (streams, ground water, ocean water). These data were analyzed and compared with the available historical water quality data base for development of the canal model.

Water quality samples were collected at sixteen stations within and offshore the Ala Wai Canal, and in the major streams discharging into the canal (Figure 2-8). Samples were collected at or near high tide on six sampling days: October 3, November 1, December 3, 1991, January 7, February 8, and March 3, 1992. Samples were collected at three depths at most stations within the canal and nearshore marine waters: 0.5 m below the surface, 0.5 m above the bottom, and at mid-depth. Only surface or surface and bottom samples were taken at Station 8, the shallow mud flat at the confluence of the Manoa–Palolo Stream. Samples within the major streams feeding the canal were taken at mid-depth. Samples were collected with Niskin bottles closed at the target depth, or with 500 mL polyethylene bottles for the stream samples. Samples for bacteriological analysis were collected directly into 100 mL specimen cups and placed in a cooler at ambient temperature; all other samples were collected in 1 liter polyethylene bottles and placed over ice until processed in the lab. Continuous profiles of temperature and salinity were taken on several dates utilizing a conductivity/temperature/depth recorder with fine (10 cm) vertical resolution.

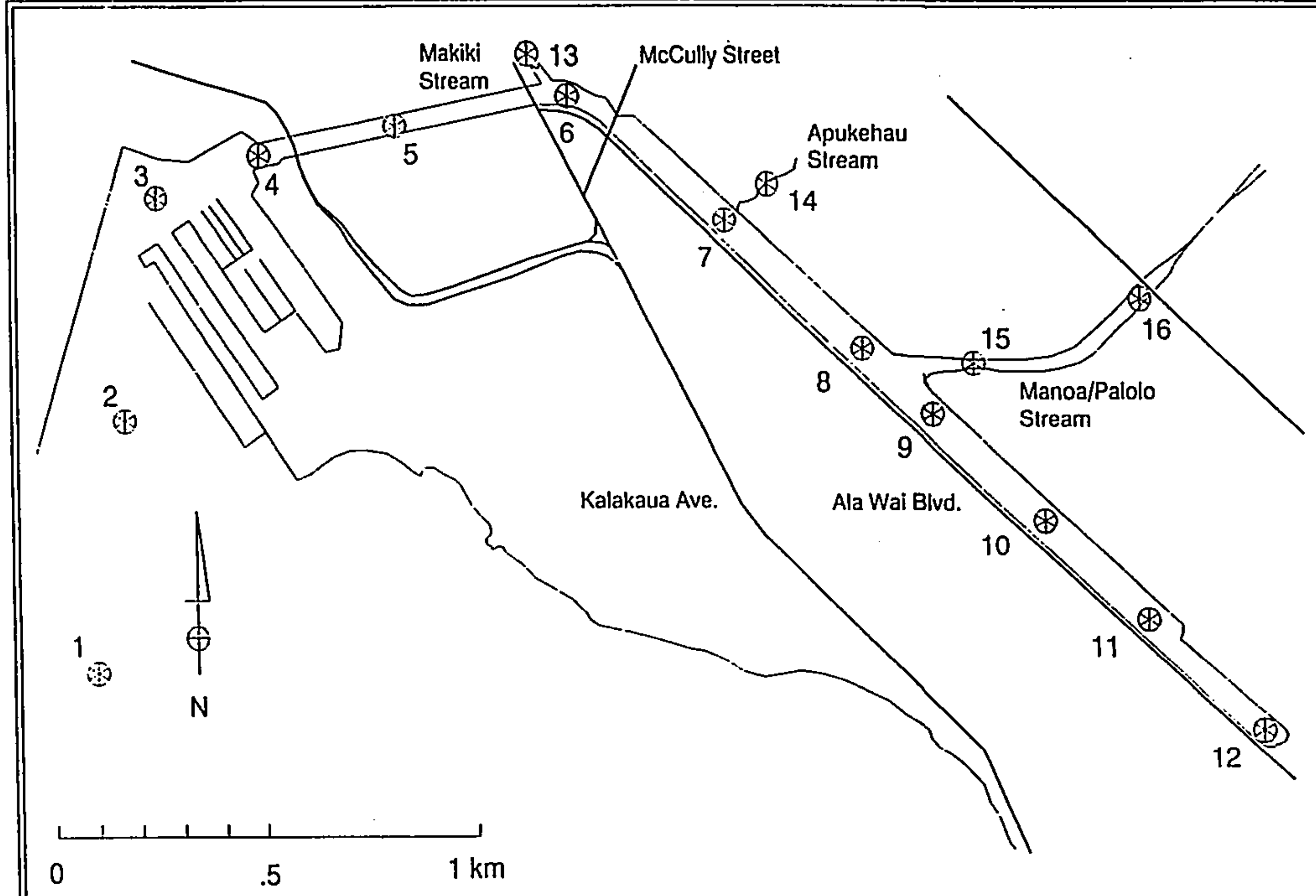
Water quality parameters measured included those listed in the State of Hawaii water quality standards for open coastal and estuarine waters and additional



ALÁ WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	Ala Wai Canal Dye, Current And CTD Sampling Stations	FIGURE 2-6



ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	WATERSHED LOCATIONS	FIGURE 2-7



OI Consultants, Inc.
Makapuu Point
Waimanalo, Hawaii 96795

ALA WAI CANAL ECOLOGICAL STUDY

WATER QUALITY STATIONS

Figure **2-8**

parameters which provide information on ground water sources and influence: temperature, salinity, total nitrogen, nitrate-nitrite, ammonium, total phosphorus, orthophosphate, reactive silicate, turbidity, suspended solids, particulate carbon and nitrogen, chlorophyll, dissolved oxygen, Ph, fecal coliforms and enterococci. The methods used for each analysis are presented in Table 2-1.

Table 2-1
Collection and Analysis Methods for the Ala Wai Canal Measured Water Quality Parameters

Water Quality Parameter	*Collection and Analysis Method*
Water Quality Samples	
Temperature	Precision thermometer
Salinity	Laboratory salinometer
Nutrients	
Total nitrogen	Technicon AutoAnalyzer II; D'Elia et al, 1977
NH4	Technicon AutoAnalyzer II; Solorzano, 1969
NO3/NO2	Technicon AutoAnalyzer II; Technicon Inc., 1977
Total Phosphorus	Technicon AutoAnalyzer II; Grasshoff et al, 1983
PO4	Technicon AutoAnalyzer II; Murphy and Riley, 1962
SiO4	Technicon AutoAnalyzer II; Strickland and Parsons, 1972
Particulate Carbon	Carbon-Nitrogen Analyzer; Grasshoff et al, 1983
Particulate Nitrogen	Carbon-Nitrogen Analyzer; Grasshoff et al, 1983
Chlorophyll	Turner Designs fluorometer; Strickland and Parsons, 1972
Turbidity	Turner Designs nephalometer; APHA, 1986
Suspended Solids	Filtration, electrobalance; APHA, 1986
Dissolved Oxygen	YSI laboratory oxygen meter
pH	Orion digital pH meter
Fecal Coliform	Filtration, incubation; APHA, 1986
Enterococcus	Filtration, incubation; APHA, 1986

Temperature/Salinity. Continuous profiles of temperature and salinity for selected stations in the nearshore marine environment and the Ala Wai Canal were developed from samples taken on January 7, 1992. Results are typical for the canal and adjacent waters under most tide and wind conditions. Nearshore waters

(Station 1) show patterns of generally vertically uniform temperature and salinity below about 1 m depth, with a low salinity, higher temperature layer overlying this. The upper layer is the relatively unmixed outflow of brackish water from the canal. The salinity profile at Station 3 reflects the greater influence of brackish water near the canal mouth, with the brackish layer extending to 2 m depth and surface salinity as low as 27 parts per thousand (ppt). The temperature profile appears to reflect some degree of solar heating of the upper layer, also seen at Station 1, with a cooler surface (<0.5 m depth) layer.

Groundwater Budget. The groundwater influx to the Ala Wai Canal was estimated from profiles of salinity taken at stations 3–12 in the canal on February 8, 1992. The data are presented in Table 2-2. The volume of fresh water (fw) was calculated as 111, 053 m^3 or 3.9 million ft^3.

TABLE 2-2
Calculation of Groundwater Influx into the Ala Wai Canal

Station	Channel Width (m)	Section Length (m)	Section Area (m^2)	Areal fw (m^3/m^2)	X-Section fw (m^3/m)	Section fw (m^3/section)
1	685	—	—	0.031	21	—
2	113	—	—	0.190	21	—
3	71	—	—	0.300	21	—
4	67	411	27,556	0.316	21	8,708
5	60	366	21,919	0.372	22	8,154
6	57	411	23,485	0.495	28	11,625
7	89	457	40,447	0.439	39	17,756
8	89	297	26,290	0.365	32	9,596
9	89	251	22,246	0.471	42	10,478
10	89	331	29,324	0.552	49	16,187
11	89	388	34,380	0.560	50	19,253
12	80	308	24,659	0.377	30	9,297
TOTAL		3,221	250,306			

Since salinity profiles from different sampling days were generally similar, it was assumed that the ground water influx is in a steady state with mixing and outflow. The dye studies described earlier provide estimates of the T_{50} (the time to decrease the concentration of a material by 50%) for the canal. For all shallow layers at

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stations within the canal, the T_{50} times were generally 40-45 hours. The daily turnover rate can be calculated from the T_{50} rate, and is estimated to be 33%; i.e., approximately 1/3 of the water in the canal is exchanged (removed) each day. Thus, at steady state, the volume of fresh water entering the canal is approximately 36,647 m^3 (1.3 million ft^3) per day. Assuming that the influx is relatively constant over the length of the canal (3,221 m), the calculated input per unit length is 11.4 $m^3/m/d$ (402.3 million ft3/m/d), or approximately 4.83 million gallons per day (mgd) per mile. This daily input rate is similar to that calculated for other islands (1 - 6 mgd per mile). The value is an estimate of the total freshwater inflow to the canal. It actually includes both groundwater and stream input, although no estimate of fresh water input by streams was included. However, stream flows during the period of salinity profiling were low, so the estimate of groundwater influx is probably not a large overestimation.

Other Water Quality Parameters. The data show that Makiki Stream is primarily a source of high-nutrient water with characteristics similar to groundwater (i. e., high silicate, nitrate and phosphate) In contrast, Manoa Stream shows the influence of surface runoff. Silicate levels are relatively low and constant throughout the Manoa-Palolo system (Manoa A-D, Palolo), indicating relatively low or no groundwater influx. Nutrient levels are very low at the head of Manoa Stream (Manoa A), and increase downstream. These stream water characteristics are reflected in the relationships between water quality parameters in the canal.

The correlation of nutrient ions with silicate varies strongly depending on their origin. Water from the Manoa and Palolo Streams tends to be lower in phosphate than groundwater seeping into the canal directly or via Makiki and Apukehau streams.

The composition of suspended matter varies. There is no consistent strong correlation between its components (chlorophyll, total suspended matter, turbidity, particulate carbon and nitrogen). Turbidity and total suspended solids are generally well correlated. Occasionally, high total suspended solids were not accompanied by high turbidity. Turbidity and chlorophyll are also well correlated. Total suspended solids tend to increase in bottom water from the mouth towards the end of the canal, but vary little in surface water throughout the study area. Turbidity also tends to increase in profiles towards the sediment. Chlorophyll levels are generally highest in mid-depth and bottom samples.

Fecal bacteria counts appear to be related to surface runoff and stream flow. Highest numbers were found after periods of rain and increased stream flow. However, the numbers decreased rapidly in samples with near-seawater salinity.

Visual Water Quality. The primary aspect of water quality in the canal which has been targeted for improvement is water clarity. Water clarity is a function of several components within the water column: dissolved material which colors the water; inorganic particulate material such as suspended sediments; and organic particulate material such as phytoplankton. Dissolved color and inorganic particulate material are input to the canal primarily in stream flows. The majority of these inputs occur during storm events and their impacts on water clarity are relatively transient. The majority of the inorganic sediments entering the canal via stream flow are discharged directly to the ocean during storm flows; some settle to the canal bottom and may be resuspended under strong winds and consequent vigorous vertical mixing.

The contribution of phytoplankton biomass to the total suspended solids load was estimated from relationships between phytoplankton chlorophyll, carbon and dry weight. Values derived from regression analyses were used to establish target chlorophyll levels for the physical-biological model of the flushed canal. A series of calculations were performed estimating the water clarity as a function of chlorophyll concentration. In addition, the water clarity was estimated utilizing the Secchi depth, a standard oceanographic measure of water clarity. It is defined as the depth to which a disk of solid white or alternating white and black quarters can just be seen. Thus it represents a measure of water clarity to which most people can relate.

Based upon these calculations, the target for maximum chlorophyll concentrations in the canal under active flushing has been set at 5 μg/l (micrograms per liter). Under the relatively conservative calculation of water quality, the water clarity at a chlorophyll concentration of 5 μg/l would be sufficient to see a light colored object on the bottom of the canal at a depth of 3.5 m (10–12 feet). The less conservative calculated water clarity may be more applicable since it reflects the dilution and flushing of colored dissolved material and/or inorganic particulates. Under this scenario, water clarity would be such that a light object would be seen at depths near 5.5 m (18 feet), and the water clarity in the shallower canal would be perceived to be significantly better than for the first case.

Some of the model runs resulted in chlorophyll levels higher than 5 μg/l but less than 10 μg/l. In those instances where the chlorophyll levels were within this range, water clarity would be decreased somewhat, but under the more likely chlorophyll-visibility scenario, a light-colored object would be visible on the bottom even at 10 μg l-1 chlorophyll.

Discussion and Conclusions. Water quality in the Ala Wai Canal is determined by its source waters (nearshore ocean water, groundwater, streams), mixing and tidal exchange, and input from the accumulated sediment via resuspension and regeneration. "New" nutrients (not recycled *in situ*) are derived from groundwater and the streams. Silicate concentrations, an indicator of groundwater, were usually higher in stream discharge than canal water, but occasionally, surface water in the canal contained concentrations exceeding the stream loads in the vicinity of discharge, and approached them on other occasions, despite higher salinity. Seawater dilution of the silicate input to the canal is conservative, with steepest gradients in the canal itself. Lesser gradients in the lowest reaches of the streams indicate lower silicate concentrations in the stream discharges than groundwater.

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Usually there is less silicate in water of the Manoa/Palolo Streams than in the Makiki Stream. However, the groundwater component in the streams varies, depending on the differences in rainfall in their respective water shed areas.

Phosphate ion concentrations are generally well correlated with silicate within the canal proper. The distribution of silicate and phosphate in different source waters is not proportional, however. The highest concentrations of both silicate and phosphate were observed at the mouth of Makiki Stream (Station 13). The source water for this stream is apparently undiluted groundwater, and the concentrations in Makiki Stream are assumed to represent groundwater conditions. Flow in Manoa and Palolo Streams is primarily surface runoff, and the lower nutrient levels reflect this different source. The lowest concentrations occurred in the confluence of Manoa and Palolo Streams, while dilution gradients were intermediate in the canal itself.

In the Ala Wai Canal, not all the phosphate followed the simple physical dilution model observed for silicate. At the Kapahulu end, high phosphate concentrations often occurred in bottom samples with high salinity and low silicate concentrations; high ammonium levels were noted in the same samples. The Kapahulu end of the canal serves as a trap for particulate materials. High organic matter and microbial activity cause oxygen deficiency in bottom water. Microbial activity releases regenerated nitrogen (as ammonium) and phosphate into the interstitial waters. Phosphate appears to be released from the sediment, like ammonium. Turbulence is not a likely physical mechanism for these releases. There are no waves and recreational activity (canoe racing) is infrequent. Rather, the release is likely through a process of simple diffusion from high concentrations in interstitial water to the overlying canal water. The high proportion of phosphate to silicate in the Makiki and Apukehau Streams probably reflects the groundwater ratio of these ions more closely, than that found in the canal.

Nitrate-nitrite concentrations follow the distribution pattern of phosphate in the streams, but not in the canal. Here, only low source concentrations of phosphate are correlated with low nitrate-nitrite concentrations. High source concentrations of nitrate-nitrite and phosphate occur independently of one another. The steepest nitrate-nitrite to silicate gradient (approximately 1/6, i.e., the highest apparent nitrate-nitrite concentration in groundwater) was observed commonly at the far end of the canal, where freshwater made up only 10% of the volume. Groundwater is not the only source of this nitrate. The nitrate-salinity plots show evidence of nitrate in addition to that provided by groundwater (i. e., data points above the conservative mixing line). Since these high nitrate values occur in surface water, while bottom water was shown to be increased in regenerated ammonium, a source other that the sediments is required. One possible source is percolation of nutrients added to the adjacent Ala Wai Golf Course.

Marine Biology

The marine biology of the canal was the subject of studies in 1970-71 by the State Fish and Game Division of the Department of Land and Natural Resources. Primary productivity was described by Carol Harris in 1975 and ecological studies of higher trophic level organisms (crustaceans and fish)were conducted by Jacqueline Miller, also in 1975.

The Miller study covered marine organisms of recreational value and their physical environment. Of the five species of crabs and 21 species of fish found in the canal, only two crab and six species of fish were reported in sufficient abundance to be of recreational importance. The two crab species are the Hawaiian swimming crab *(Podophthalmus vigil)* and the blur claw crab *(Thalamita crenata)*. The six fish species are awa *(Chanos chanos)*, awa awa *(Elops hawaiiensis)*, mullet *(Mugil cephalus)*, papio *(Scomberoides santi-petri)*, and kaku *(Sphyraena barracuda)* and *Tilapia mozambique*.

Three physical parameters were measured extensively throughout the canal as part of the Miller study, salinity, temperature, and dissolved oxygen. Of the three, dissolved oxygen was found to be the only parameter that affected the distribution of species. benthic fish and crab species were noticeably absent in areas of low oxygen concentrations.

Air Quality

Air quality in the vicinity of the canal is affected by vehicle emissions and natural sources. Ala Wai Boulevard is a major road transversing Waikiki, and emissions from vehicles would be likely to be blown across the canal. Natural sources of air pollution affecting air quality include ocean spray, plant pollens, and wind-blown dust.

The State Department of Health maintains a network of air quality monitoring stations located at various sites around Oahu. Based on data from these stations, it is likely that both the national and more stringent state standards are being met.

Noise

The existing noise environment is typical of an urban setting, especially on the makai side of the canal adjacent to Waikiki where there are many high rise buildings and heavy traffic on Ala Wai Boulevard. The larger amounts of open space on the mauka side of the canal result in a somewhat quieter environment.

Scenic and Visual Resources

As noted earlier, the water in the canal is not very clean. Achieving water clarity and improving the canal's appearance is a major project objective. However, the general setting of the Ala Wai Canal is beautiful, and from certain vantage points, stunning. The Description of the canal accompanying its nomination to Hawaii and National Registers of Historic Places notes that

> "The Ala Wai Canal provides an important aesthetic dimension to the Waikiki neighborhood with its open space and tranquil waters. While the land surrounding the Ala Wai has undergone incredible change in the last 71 years, the environment at the canal has remained relatively constant."

The Waikiki Master Plan describes the canal as an "important manmade landscape feature that serves today to physically and visually divide it [Waikiki] from the rest of Honolulu and create a distinctive attraction for both active and passive recreation."

Social and Economic Characteristics

Historic/Cultural Resources

The following information on the history of the Ala Wai Canal is taken from the document supporting the nomination of the canal to the Hawaii and National Registers of Historic Places, by the Hawaii Historic Places Review Board, because of its importance to the development of Waikiki and Honolulu generally. The Board approved the nomination and the Ala Wai Canal is now listed in the Hawaii Register of Historic Places. No decision has been made on whether the State Board will pursue nomination to the National Register.

Since the 1500's, "Waiatite" was the seat of government for Hawaiian royalty on the island of Oahu. From that time forward, Waikiki was also a documented rich and productive agricultural region until 1921 when construction of the Ala Wai Canal began.

Even after 1809, when Kamehameha I moved his court to Honolulu, Waikiki continued to be a favored haunt of Hawaiian royalty. The area was also increasingly popular with the growing number of *haole* (foreigners) living in Honolulu toward the turn of the century. As Waikiki's popularity began to grow, the value of the area increased and the community began to develop and change. The wetlands (referred to by many as "swamp lands" could, in the eyes of many in Honolulu, be put to better use than raising ducks and growing rice, but only if the land could be "reclaimed" (filled in).

Bath houses began to be established, the first in 1881. In 1903, the Honolulu Rapid Transit Company inaugurated a service between Honolulu and Waikiki, providing easier access to the area. By 1921, the year construction of the Ala Wai Canal began, five major hotels had been constructed in Waikiki. One project that had considerable influence was the reclamation of Fort DeRussy in the Waikiki area. In the first decade of the twentieth century, the U.S. Department of War acquired 73 acres of land in Waikiki; from 1909 to 1911 the Quartermaster Corps was assigned the task of filling "a portion of the fish ponds which covered most of the fort (Fort DeRussy)." This was the first reclamation of land in the area.

Increased public concern over the mosquito problem, and the potential spread of contagious and infectious diseases in Hawaii, was one of the most important factors leading to the construction of the Ala Wai and the Waikiki Reclamation Project. The mosquito was accidentally introduced to Hawaii in 1826, and the Waikiki wetlands provided an ideal breeding ground for these insects.

One final factor that led to the construction of the canal was the concern over the draining of wetlands onto the shores of Waikiki's beaches, at a time when bathing was becoming increasingly popular and there were a growing number of visitors to Hawaii's beaches. The proposed drainage canal would carry the runoff away from the Waikiki beaches.

The original proposal to build the Ala Wai Canal was put forward in 1906 by Lucius E. Pinkham, then president of the Board of Health of the Territory of Hawaii. In a report to the board, Pinkham recommended the reclamation of the Waikiki district of the city of Honolulu, proclaiming that the lands in Waikiki were in a deleterious and unsanitary condition. He proposed to fill in what he termed swamp lands to create an "attractive and charming" residential neighborhood. This reclamation of 625 acres would be accomplished by the construction of a "great lagoon" that would yield the necessary fill material and "create a quite marvelously beautiful, unique district, a Venice in the midst of the Pacific." He envisaged that the canal would be used for boating, providing an ideal course for racing. Thus, while the canal would serve a recreational purpose upon its completion, the primary reason for its construction was to provide the necessary fill for adjacent lands and to drain runoff from the Manoa, Makiki and Palolo valleys away from Waikiki's beaches. While the proposal was shelved for a number of years, upon his appointment as governor of the Territory by then-president Woodrow Wilson in 1913, Pinkham devoted much of the energy of his four-year term to the implementation of his Waikiki plan.

By 1920, 85 percent of the land required for the building of the canal had been acquired and bids to dredge the canal were solicited. In December 1920, the bids were opened and the contract for the project was awarded to the Hawaiian Dredging Company, owned by Walter F. Dillingham. Dillingham's bid was one of only two bids received by the Territory for the project.

Construction was begun in 1921 and by January of 1922, Hawaiian Dredging Company had completed the first phase of the project. The hydraulic dredge "Kewalo" was used by Hawaiian Dredging Company to dredge the canal. Because of the size of the dredge, it could not successfully operate in a width of 60 feet, so the canal had to be cut to an approximate width of 150 feet.

By mid-1923, the "Kewalo" had cut its way almost 6,500 feet towards Kapahulu Road, cutting a channel approximately 135 feet wide and 10-20 feet deep. Bigelow, reported that the canal "has now intercepted Apuakehau Stream which flowed by the Outrigger Club and all the filthy waters which previously flowed on to this fine swimming beach have been diverted and now flow out to the sea by way of the canal."

By mid-1924, the canal was 150 feet wide and had been dredged "its entire length" to Kapahulu Road. Due to a lack of funds, the Diamond Head end of the canal, called for in Lucius Pinkham's original proposal, was put on hold until "some later date, when funds are made available." Pinkham had recommended that the canal should exit back out to the ocean at Kapiolani Park, with tide gates at the both entrances to be closed at high tide and "the waters thus forced through the lagoon to exit at the Ala Moana bridge." This portion of the canal was never completed, though in 1967 the local Rotary club and other civic groups brought the idea up again with no success.

In order to provide the additional fill material necessary to bring the Waikiki Reclamation Project to completion, the canal was widened by 100 feet. By mid-1927, the filling of the McCully tract, a vast area of pondfields and fishponds, was completed and the canal was 250 feet wide almost to Kapahulu Road.

The canal acquired its name in 1925 when the City Planning Commission requested that citizens of Honolulu submit suitable names for the renaming of the Waikiki drainage canal. Jennie Wilson, wife of Mayor Wilson, suggested the name Ala Wai, Hawaiian for "waterway."

Population and Land Use

According to the 1990 census (DBED Data Book 1991), the resident population of Waikiki (Neighborhood Statistics Program Area #9, census tracts 18-20) was 19,000 as of July, 1989.[1] The population of the other districts adjacent to the canal were Diamond Head/Kapahulu (portion of Area #5 below the H-1 Freeway and Waialae Avenue, census tracts 15-17 and 21), 13,800; McCully/Moiliili (Area #8, census tracts 22-26), 28,500; and Ala Moana/Kakaako (Area #11, census tracts 36-38), 10, 650. The census tracts and Neighborhood Statistics Program Areas are shown in Figure 2-9 and 2-10.

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[1] All figures are rounded.

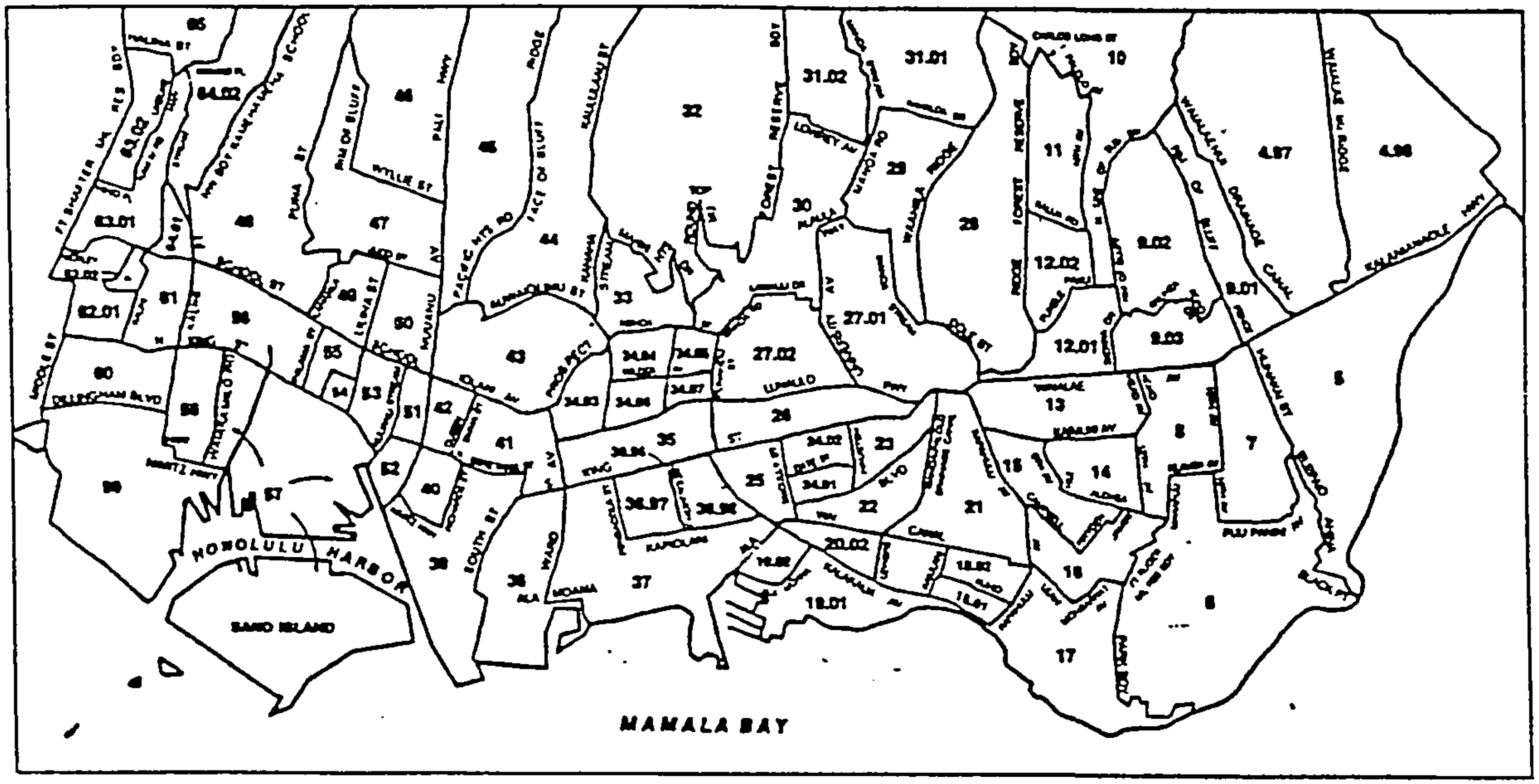


Figure 2-9 Project Area Census Tracts

Hawaii State Department of Business, Economic Development and Tourism, *The State of Hawaii Data Book 1991*

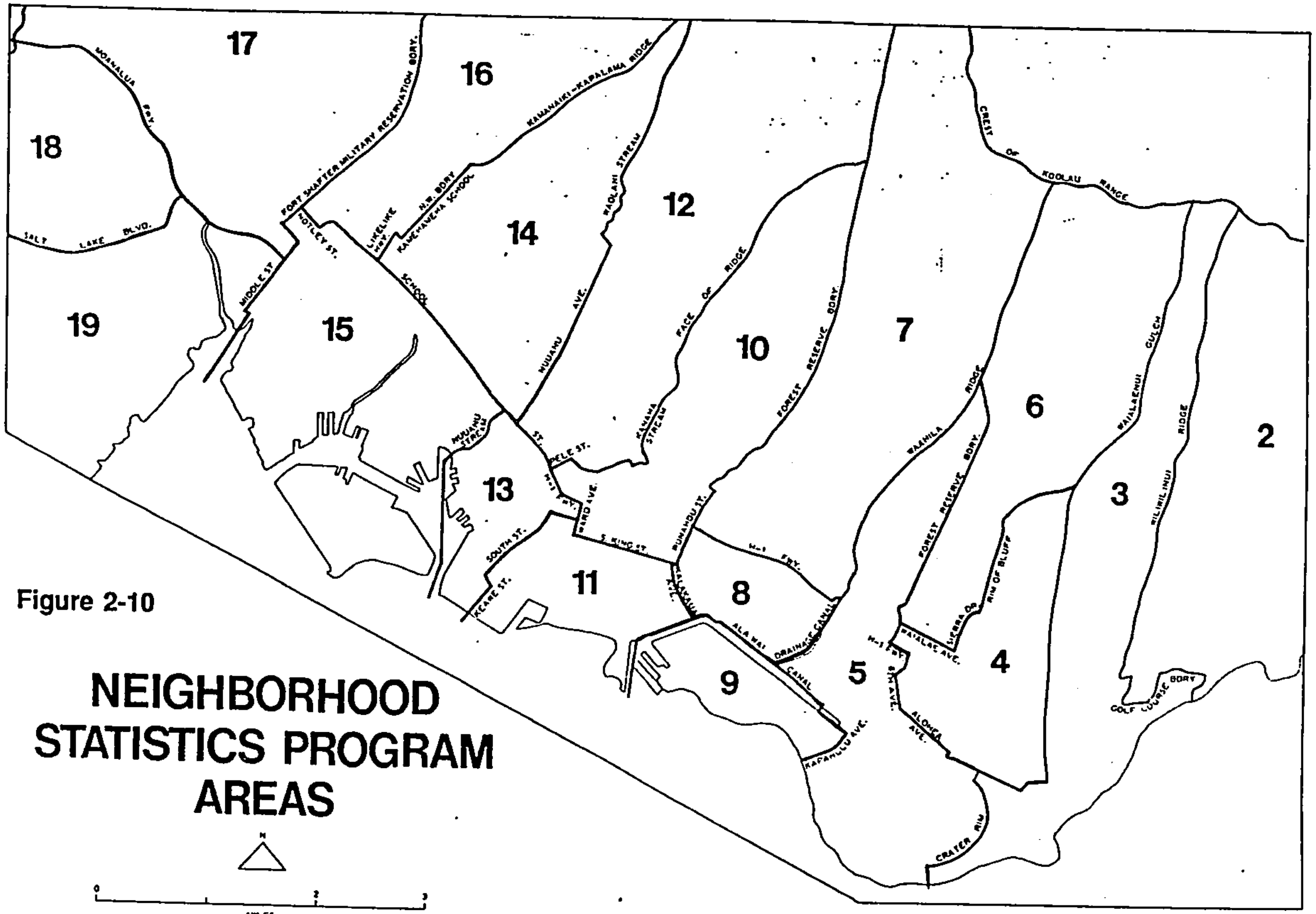


Figure 2-10

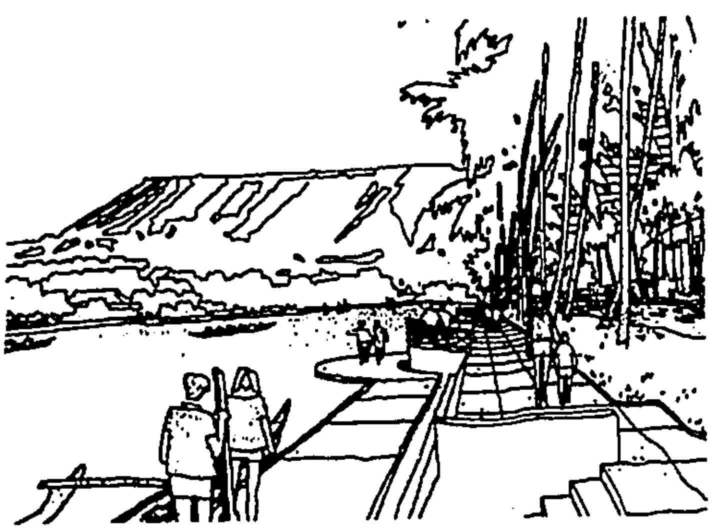
NEIGHBORHOOD STATISTICS PROGRAM AREAS

Hawaii State Department of Business, Economic Development and Tourism, *The State of Hawaii Data Book 1991*

The Waikiki Master Plan states that the current total inventory of visitor units in Waikiki—hotel and short-term condominium rentals—is 32,800. The plan notes that while resort use is predominant, Waikiki has retained a strong residential community which lends diversity and vitality to the district. Both the residential population and the housing stock occupied full-time have risen over the past two decades. However, the daily census of visitors and the visitor housing has risen substantially. Because of the strong demand for visitor units, over 11,000 apartment units are being used as visitor accommodations.

The Waikiki Master Plan examines several alternative growth scenarios. It recommends moderate growth, with some zoning modifications but no substantial increase in allowable densities, for a growth level of 3,000 to 5,000 additional visitor units. This scenario also envisions moderate growth in residential units, with a potential increase of 3,000 apartments, half of which would be moderately priced units on publicly owned sites.

The plan envisions a "grand Promenade" offering uninterrupted pedestrian access around the perimeter of Waikiki. The Ewa section of the canal is proposed to be enhanced as part of the Waikiki Promenade. The plan proposes that:



"A wide floating walkway would be created to permit additional pedestrian access for walking at the level of the water. The floating walkway may be used for small cafes; canoes and kayaks may tie off along its length. A pedestrian bridge to the ewa side of the canal would be provided at Lipeepee Street. Night lighting would be important in providing sparkle and life to the canal edge and highlighting the historic canal wall, which would be restored. Ala Wai Boulevard from the Ala Moana Bridge to Lipeepee would be closed. The right-of-way would be landscaped as a pedestrian promenade parallel to the canal.

Improvements to the Diamond Head side of Ala Wai Boulevard were intended to create opportunities for outdoor dining near the canal. A continuous planting strip to preserve the regular planting of trees would be required. Sidewalk cafes would be permitted.

The mauka section of the canal would be enhanced for recreational uses. A smaller floating walkway would provide access to the water's edge for pedestrians. The canal wall along this section of the canal is not historic and can be selectively rebuilt to provide wider steps to the floating walkway. Sidewalks and landscaping would be improved along Ala Wai Boulevard to enhance the street and provide shade and a suitable surface for walking or running. At intervals along the canal, overlooks would be created where pedestrians may sit and relax away from the main sidewalk."

The plan proposes to convert the golf course into a large landscaped park to "extend the feeling and uses found in Kapiolani Park to the mauka edge of Waikiki." A formal boat turning basin would be created at the Diamond Head end of the canal near the library. Facilities for competitive canoe and kayak racing and training would be developed around the turning basin. A pedestrian bridge would be constructed between the park and the makai side of the canal at the end of Nahua Street.

Employment

Waikiki and the Ala Moana Shopping Center across the Ala Wai Canal are major centers of employment and economic activity on Oahu. While the resident population of Waikiki was 19,800 in 1990, the de facto population was estimated as 95,800, based on an estimated 300 residents temporarily absent and an annual average daily visitor count of approximately 76,500 persons. The number of employed person in Waikiki for 1990 is not available. In 1980, there were 9,600 employed persons living in Waikiki and 30,000 working in Waikiki. Given the increase in visitors between 1980 and 1990, from 46,500 to 76,500, it would be expected that there would also be a similar increase in employment.

CHAPTER 3

PROBABLE IMPACTS AND MITIGATION MEASURES

Introduction

This chapter provides an evaluation of the environmental impacts associated with both the proposed deep groundwater well concept and a submerged pipeline system constructed in the Ala Wai Canal with an intake in the entrance channel to the Ala Wai Boat Harbor. The deep groundwater well system is the preferred alternative, primarily based on its low estimated construction cost versus the submerged pipeline system. Should this concept prove to be infeasible during a proposed prototype production well drilling and testing program, the alternate submerged pipeline system would then become the recommended alternative. The probable impacts common to both alternative concepts are discussed first, followed by discussions of impacts specific to each concept plan.

Environmental Impacts Common to Both Proposed Systems

Water Quality in the Canal

One of the necessary criteria for the deep groundwater well system is that the supply water should have the same general characteristics as coastal seawater. Based on this criterion, the water quality impacts due to both proposed flushing water systems for the Ala Wai Canal are identical.

Chlorophyll Concentrations. The existing chlorophyll concentrations in the canal, as generally represented by the Base Case 2-D model results, have maximum values that typically range to about 50 μg/l, with the worst concentrations existing at the Kapahulu end of the canal which range from 50 - 30 μg/l varying from the surface to the bottom respectively. Field measured dissolved oxygen concentrations are generally in the 5 mg/l range throughout most of canal waters except in the lower layers of the Inner Basin, the region between the confluence of the Manoa-Palolo Stream and the end of the canal, and at the Kapahulu end of the canal. In the bottom layer of the Inner Basin the dissolved oxygen concentration are about 1 mg/l.

The proposed injection of 20 cfs seawater into the Kapahulu end of the canal will decrease the chlorophyll concentrations from present conditions, to maximum concentrations ranging from 3.5 - 6.5 μg/l, with the Kapahulu end of the canal yielding chlorophyll concentrations between 6.5 to 0.2 varying from the surface to the bottom, respectively. If the maximum seawater inflow rate of 30 cfs is utilized, the maximum chlorophyll concentrations would typically range from 1 - 2 µg/l, with the Kapahulu end of the canal having chlorophyll concentrations between 2.0 to 0.2 µg/l varying from the surface to the bottom, respectively. This reduction in chlorophyll concentration will result in improved water quality and water clarity.

Dissolved Oxygen Concentrations. Dissolved oxygen concentrations will improve when 20 cfs of seawater is injected into the Kapahulu end of the canal. In the present situation, the dissolved oxygen concentrations in the canal are typically in the 5 mg/l range, except in the bottom layers of the Inner Basin with concentration of about 1 mg/l and at the Kapahulu end of the canal shows concentrations of 1-3 mg/l. When a 20 cfs seawater flushing water inflow is provided, the variations throughout most of the canal waters are relatively small when compared to the existing conditions (Base Case), but the improvement in the Inner Basin and at the Kapahulu end of the canal are more significant. In general, the dissolved oxygen concentrations in the Inner Basin and at the Kapahulu end of the canal typically range between 4 - 6 mg/l, with no significant decrease in the lower layers. The dissolved oxygen concentrations for a 30 cfs seawater inflow are very similar to the 20 cfs seawater inflow case. The more dense seawater effectively flushes the bottom layers, thereby improving its water quality characteristics.

Water Clarity. During typical conditions in the Ala Wai Canal, when no significant rainfall events occur, the water clarity in the canal waters is primarily determined by the water column chlorophyll concentrations. Under present conditions with typical maximum chlorophyll concentrations of 30 - 50 µg/l, the depth that a solid colored white object (Secchi Disk) can be visually seen is about 6 - 4 ft respectively. In the case of the Ala Wai Canal, since the bottom is dark in color, the ability to see the canal bottom is reduced from these standard Secchi Disk values.

With reduced chlorophyll concentrations of the order of 5 µg/l as are expected to be produced for a 20 cfs seawater injection rate, the depth at which the Secchi Disk can be visually seen are expected to be on the order of 11 - 12 ft, or about 2 to 3 times the water clarity that presently exists in the canal. For a 30 cfs seawater inflow rate, the expected chlorophyll concentrations of 1 - 2 µg/l convert to Secchi Disk distances of the order of 13 ft. Thus, it is expected that water clarity conditions will improve significantly.

Improvement in water clarity will provide a greater opportunity to see the bottom of the Ala Wai Canal. If canal dredging does not take place before the proposed improvements are implemented, the new view of the canal bottom will reveal debris and trash accumulated over decades. This unattractive view will likely prompt concerned citizens to complain about this situation. To remedy existing conditions and prevent future problems, an active maintenance program of bottom debris removal and dredging should be implemented as recommended in *A Maintenance Plan For The Ala Wai Canal.*

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Odor. The injection of flushing seawater will generally not have any immediate impact on odor from the Ala Wai Canal waters. The odor associated with the canal are primarily caused by hydrogen sulfide generated in the bottom sediments due to anoxic conditions. When these bottom sediments are disturbed during storm water discharges or during dredging operations, temporary odor problems may occur. On the other hand, to the extent the source of the odor come from suspended material in the water column, the reduced residence time of the canal waters associated with the proposed flushing seawater system will tend to mitigate this odor problem.

In the long term, the continuously operated seawater flushing system will provide an improvement to the general odor problems of the canal. With the expected significant reduction in phytoplankton growth, as evidenced by reduced chlorophyll concentrations, there would be less organic detritus materials which would settle on the bottom, thereby reducing the potential for hydrogen sulfide generation. When maintenance dredging of the canal is combined with the seawater flushing effects, the potential to significantly improve the odor problems of the canal are excellent.

Bacteria. In general, bacteria which enters the Ala Wai Canal does not grow within the canal waters, but instead undergoes dieoff. Bacteria dieoff is very sensitive to water salinity, because the dieoff rate is much higher in a seawater environment than in fresh water. Bacteria dieoff rates are usually described by the time that it takes for 90% of the bacteria to die from its initial value, designated T_{90}. For example, coliform bacteria dieoff rates, T_{90}, in seawater are of the order of 15 - 60 minutes. In fresh water, coliform dieoff rates are estimated to be of the order of 24 hours. Consequently, bacteria concentration measurements in the Ala Wai Canal consistently show a significant decrease with distance below the surface, particularly between the brackish surface layer and the lower near-seawater layers.

Bacteria concentrations in the Ala Wai Canal will improve from their present conditions when the 20 - 30 cfs seawater inflow is injected into the Kapahulu end of the canal. The injected seawater and its consequent circulation will induce vertical mixing, thereby increasing the salinity in the upper layers with its attendant biocidal effects. Moreover, the flushing seawater inflow will reduce the residence time of the waters in the entire canal, and more rapidly transport the upper layers into the ocean receiving waters where the high salinity concentrations will promote rapid dieoff.

Water Quality Impacts During Significant Rainfall-Discharge Events

While the circulation flow physical effects are minimal during a significant discharge flow event, the water quality consequences are more significant. Table 3-1 describes the chlorophyll concentrations for the Base Case (existing conditions) including a 2,150 cfs storm water discharge flow into the Ala Wai Canal, without and with the proposed 20 cfs seawater inflow at the Kapahulu end of the canal. The 2,150 cfs storm water discharge flow was arbitrarily selected as 1/2 of the one-year return period peak storm water discharge flow into the Ala Wai Canal.

For the BC plus 2,150 cfs storm water discharge, the chlorophyll concentrations are all very low throughout the canal except in the lower layers of the Inner Basin where they are very high, reaching levels of about 150 µg/l. In this situation the less dense fresh water flow layer isolates the lower layers of the Inner Basin, due both to the vertical cap and due to the inability of ocean waters to flow into the canal in the bottom layers. The result is an increase in the residence time of the waters in the lower layers of the Inner Basin, and consequent increase in chlorophyll concentrations and reduction in dissolved oxygen. When the 20 cfs seawater inflow is added to the BC plus 2,150 cfs storm water inflow, Table 6.1 indicates that the chlorophyll concentrations in the lower layers of the Inner Basin improve to 90 - 100 µg/l. These chlorophyll concentration results should be viewed as qualitative indications of the water quality effects since the 2-D model results are associated with steady-state, equilibrium conditions, and the 2,150 cfs storm water inflow rate is not expected to last for many days. In general, the flushing seawater inflow will have a small, beneficial water quality effect during significant storm water discharges into the Ala Wai Canal.

TABLE 3-1

Chlorophyll Concentrations (µg/l) for Base Case with 2,150 cfs Storm Discharge with and without 20 cfs Seawater Inflow Condition

Description	Station Number								
	4	5	6	7	9	10	11	12	Harbor
BC With Storm Discharge (Total 2,150 cfs)									
TOP	0.12	0.10	0.14	0.14	0.12	0.13	0.16	0.74	0.55
MIDDLE	0.27	0.19	0.26	0.23	0.21	0.17	0.15	0.80	1.07
BOTTOM	0.71	0.25	0.33	0.40	7.17	148.8	157.5	0.18	0.74
MAX	0.71	0.25	0.33	0.40	7.17	148.8	157.5	0.80	1.24
BC With Storm Discharge & 20 cfs Seawater Inflow									
TOP	0.11	0.10	0.13	0.13	0.12	0.13	0.14	0.32	0.60
MIDDLE	0.25	0.17	0.22	0.19	0.17	0.15	0.14	0.19	1.08
BOTTOM	0.71	0.22	0.28	0.33	4.40	91.53	101.9	0.16	0.74
MAX	0.71	0.22	0.28	0.33	4.40	91.53	101.9	0.33	1.30

Water Quality Impacts To The Boat Harbor And Ocean

While the 20 - 30 cfs seawater injection rates into the Kapahulu end of the Ala Wai Canal will improve the water quality conditions within the canal and in the main channel between the Ala Moana Bridge and the ocean entrance channel, there would be only small change in the water quality conditions in the Ala Wai Boat Harbor vessel mooring areas. For example, the existing chlorophyll concentrations at a representative harbor location vary from 5.5 - 0.9 µg/l from the top to bottom layers, respectively, and the 20 cfs seawater flushing water inflow rate will change these values to 3.5 - 0.9 µg/l from the top to bottom layers, respectively. In general, the water quality of the bottom layers of the Ala Wai Boat Harbor is controlled by the circulation of the more dense ocean water, while the surface layer is controlled by the less dense Ala Wai Canal waters. Consequently, improvements in the canal water quality only affects the upper layers of the Ala Wai Boat Harbor waters. In general, improvements in the Ala Wai Canal water quality improves the water quality in the upper layers of the waters in the Ala Wai Boat Harbor.

The discharge of the waters from the Ala Wai Canal into the nearshore ocean receiving waters through the entrance channel to the Ala Wai Boat Harbor will provide an improvement over existing conditions when flushing seawater is injected into the Kapahulu end of the canal. In the present situation as represented by the Base Case, the maximum chlorophyll concentration at the ocean end of the Ala Wai Canal near the Ala Moana Bridge is about 12 µg/l in the surface layer. When a 20 cfs seawater inflow rate is provided, the surface layer chlorophyll concentration is reduced to about 3.5 µg/l at this same location. Thus, the clarity of the discharging flow into the ocean receiving waters would be better when flushing water is provided. At the Ala Moana Bridge location, the 12 and 3.5 µg/l concentrations convert to Secchi Disk depths of approximately 9.4 and 11.8 ft respectively.

Under ordinary conditions, dissolved nutrient levels within the discharging waters will be higher than present conditions because less opportunity will be provided for phytoplankton growth to uptake the nutrients. No biological consequences due to this added nutrient discharge are anticipated because the large volume of ocean receiving waters is easily able to assimilate the additional nutrient load

During significant storm water discharge events, the flushing seawater inflow will have essentially no effect on the existing turbidity and water clarity of the discharges into the ocean receiving waters.

Hydrology/Hydraulics

Hydraulic Capacity. The existing bathymetry of the Ala Wai Canal has insufficient capacity to handle the 100-year peak discharge flow of about 28,900 cfs due to rainfall runoff. At present, without maintenance dredging of the sill area between the McCully Bridge and the confluence of the Manoa-Palolo Stream, the carrying capacity of the canal is about 12,700 cfs based on the average height of the makai bank of the canal. Even with the dredging of the sill area to –10 ft MLLW, the carrying capacity of the canal is not greatly improved since the flow capacity is restricted by the narrow width of the channel between the McCully Bridge and the Ala Moana Bridge. Preliminary analysis indicates that the Ala Wai Canal would need to be dredged to about –20 ft MLLW in order to handle the 100-year peak flow discharge.

The proposed flushing seawater systems will have minimal circulation flow influence during any significant rainfall runoff discharges into the Ala Wai Canal. The 20 - 30 cfs is an insignificant additional flow when compared to even small rainfall runoff events which vary annually from typically 100 cfs to 4,000 cfs. The present suspended solids material which inflows into the canal due to storm water runoff, and which does not deposit in the canal, produces significant turbidity and poor water clarity both in the canal and in the Ala Wai Boat Harbor, and in the nearshore receiving ocean waters. This situation would not be changed by the addition of the minuscule 20 - 30 cfs flushing seawater inflow.

Discharge Manifold Velocity. For either flushing systems, the discharge waters from the diffuser system across the Kapahulu end of the canal, would be designed to have a discharge exit flow velocity of about 4 ft/sec. This flow velocity would quickly dissipate (within about 25 - 50 ft from the diffuser) and the mean speed averaged across the cross-section would be imperceptible as described previously. The 4 ft/sec velocity is about equivalent to the discharge velocity from a typical 3/4 inch diameter water hose with the spigot fully opened, and consequently will not provide any danger to people or to vessel navigation.

Mean Water Velocity. The physical injection of 20 - 30 cfs seawater at the Kapahulu end of the canal will have an insignificant effect on the mean water velocities in the canal. In the area between the McCully Bridge and the Kapahulu end of the canal where most of the canoe racing is performed, typical mean water speeds due to the maximum 30 cfs seawater inflow, increases by only 0.016 - 0.046 ft/sec (0.011 - 0.032 miles/hour). The maximum speed increases are in the area of the Sill due to the reduced cross-sectional area. These water current speed changes would essentially be imperceptible to the recreational users of the canal. To place this current flow change in perspective, the maximum mean current flow speed increase of 0.032 miles per hour in the Sill area would be equivalent to the effects of a 1 mile per hour wind velocity blowing on the water surface.

Air Quality

Deep groundwater drawn from the test wells may produce unpleasant odors due to degassing of ammonia and sulfide. This would indicate that the water is unsuitable for use in the canal, and the testing would be terminated.

There will be unavoidable short term construction emissions from cranes and heavy equipment which will be mitigated to the extent possible. Suppression measures for fugitive dust will be employed for any surface earth-disturbing activities.

Energy Usage

The amount of electricity needed to operate the pump for the pipeline was calculated in preparing the cost estimates. For 20 cfs (9000 gpm), 36 kW is required, or 864 kW of electricity per day. 30 cfs would require an additional 50 percent or 54 kW (1296 kW per day). The amounts were not calculated for the deep groundwater well system but could be expected to be comparable.

Land Use and Visual Impacts

Improvements to water quality in the Ala Wai Canal are an essential component of the Waikiki Master Plan prepared by the Department of General Planning of the City and County of Honolulu. One recommendation is to create a boat turning basin at the Kapahulu end of the Ala Wai Canal by incorporating a semi-circular waterway extension on the mauka end of the canal. This Master Plan concept is compatible with the conceptual design of the diffuser discharge system. The discharge system can easily incorporate such changes in configuration of the canal end section, while still performing its technical function. In this situation, the diffuser system would extend into the semi-circular turning basin, but located along the Kapahulu edge to minimize interference with vessel navigation. It is also possible to incorporate water fountains into the discharge system, which would promote both mixing and aeration of the injected water.

Historic/Archaeological Resources

The Ala Wai Canal has been placed on the Hawaii Register of Historic Places and may be nominated to the National Register of Historic Places. Neither the proposed deep groundwater well supply system or the submerged pipeline laid in the canal to provide flushing waters at the Kapahulu end of the canal will significantly impact the structural characteristics and features of the canal, particularly the mauka and makai banks of the canal. At most, a small portion of the mauka bank would need to be excavated in order to construct the underwater diffuser system pipeline for the deep groundwater well system, or for the assembly and deployment of the discharge pipeline for the submerged pipeline system laid in the canal, and upon completion of this construction, the bank would be re-built to its original design. Thus, no impacts on the historic canal structure are envisioned.

Social Impacts

Social impacts from the proposed improvements should be generally beneficial. Both passive and active recreational activities will benefit from the improved clarity and odor of the canal waters. Those who enjoy canoeing, kayaking, and fishing will benefit directly from the improvements along with the walkers and joggers. There will be general benefit to residents of and visitors to Waikiki.

Well drilling may temporarily disturb activities at the Ala Wai Golf Course. Wells are proposed to be placed adjacent to the 18th fairway. The well housings are not large and should not interfere with golf course play. If there is a problem, one or two of the wells could be shifted to the parking lot.

If the pipeline alternative is chosen there will be temporary inconvenience to users of the park and/or the Ala Wai Golf Course on the mauka side of the canal. This is the logical area to store, assemble and deploy the pipeline. However, the high density of apartments, commercial and resort areas on the makai side would make the construction, deployment and maintenance operations more difficult and create an even greater nuisance.

Impacts Specific to the Deep Groundwater Well Supply System

Drilling Effects. As part of the feasibility evaluations of the deep groundwater well system to provide saline water for flushing of the Ala Wai Canal, the subsurface geologic strata on the mauka side at the east end of the canal was evaluated. The basis for an optimistic view of this concept is associated with the interpretation of the available deep drilled well data which show the potential for an impermeable layer (aquitard) to exist, which would restrict groundwater through-flow. The boring logs indicate this aquitard, comprised of a later-stage volcanic layer, underlies the entire east end of the canal and is located at depths of 80 to 120 ft below the ground surface with thicknesses of typically 50 to 80 ft. If this is the case, then the aquitard would provide effective vertical hydraulic separation between the pumped saline waters and the brackish groundwater. The saline in-flowing waters which make-up for the withdrawn waters would flow horizontally within the lower coral layers. The aquitard would also minimize dewatering of the surficial lagoonal deposits and thereby prevent any localized subsidence which could cause damage to structures and property.

The potential for subsidence due to dewatering and its effect on structures will also be minimized since the deep groundwater wells are proposed to be located on the Ala Wai Golf Course, and would be situated away from major building structures.

In addition, a calcareous mud layer also appears below the later-stage volcanic layer which could also function as an aquitard. On the Ewa Plain, a widespread calcareous mud layer at depth is currently being utilized as an aquitard, providing hydraulic separation of the overlying coral aquifer which is being used as a source of supply water, from an underlying coral aquifer which is used for disposal.

The proposed deep groundwater wells would be withdrawing water from an aquifer which is hardly used, and none of its uses occurs at the depth of pumpage proposed herein. Consequently, the proposed groundwater well supply system should not adversely affect any existing groundwater wells, whether potable or irrigation water.

The option to utilize a deep groundwater well system to supply flushing water for the Ala Wai Canal will need to be further evaluated through a Prototype Production Well Drilling And Evaluation Program. In addition to the drilling and testing of the prototype production well, four smaller diameter boreholes will also be drilled to depths of about 250 feet in order to confirm the subsurface geologic strata of the entire proposed groundwater source area at the Ala Wai Golf Course.

The objectives of this test program are to confirm the existence of the aquitard layer, test and insure that adequate flow rates can be produced without adverse effects, and verify the adequate water quality of the expected saline groundwater. Should any of the test results and evaluations indicate that this concept is not feasible based on the above-described criteria, then it is recommended that the alternate submerged pipeline system in the Ala Wai Canal be considered.

In addition, to confirm and ensure that the proposed groundwater sources have the necessary and required water quality to serve as flushing waters for the canal, both water quality and toxicity tests will be performed. Water quality monitoring for the test well will consist of the periodic collection and analysis of water samples for constituents which are included in Hawaii Water Quality Standards, other parameters of potential impact to biological responses, and potentially heavy toxic metals.

Noise. There would be some noise generated during the drilling of the deep groundwater wells, installation of the well casings and pumps, construction of the interconnecting underground pipelines, construction of the aeration system, and deployment of the diffuser system across the canal width. The construction generated noise would be temporary, and since the entire system is expected to be constructed in open area, away from building structures, the construction noise impacts are expected to be minimal.

During operations, some noise is expected from the well and aeration pumps, but these pump noise levels would be reduced by acoustic containment in order to meet Department of Health noise regulations.

Dredging. As part of the deep groundwater well supply system construction, the Kapahulu end of the Ala Wai Canal should be dredged to –6 ft MSL to provide a smooth transition for the discharging flushing waters. This dredging was a proposed option during the design of the 1977-1978 maintenance dredging project, but due to lack of funds was not implemented. It is recommended that during the next maintenance dredging of the Ala Wai Canal, the Kapahulu end of the canal also be dredged. If this is not performed as part of the maintenance dredging for the canal, then the dredging of the Kapahulu end of the canal would be performed during the construction of the deep groundwater well supply system.

It is estimated that about 5,000 yd^3 of material would be dredged from the last 400 ft of the canal. Due to the small volume of material, it is likely that land disposal of the dredged spoil would be more cost-effective than ocean disposal. The expected dredging activities would include the hydraulic dredging and pumping to a de-watering site either at the contractor's work area or in an isolated part of the canal. After sufficient de-watering to facilitate handling, the spoil would be loaded into trucks for transport to the landfill site. Potential environmental impacts include odor problems in the de-watering area, visual and noise effects, traffic interference due to truck traffic, and the use of landfill capacity which is a scarce commodity on Oahu. Between the end of the Ala Wai Canal and Kapahulu Avenue are located the Library for the Blind & Physically Handicapped and the Waikiki-Kapahulu Public Library. Noise levels in these areas will meet Department of Health noise regulations. The Thomas Jefferson Elementary School is located across the Ala Wai Boulevard and the Diamond Head School is located across Kapahulu Avenue. These two schools should not be affected by the dredging activities. The estimated time period for this dredging activity is about 2 weeks.

The construction of the diffuser discharge system across the Kapahulu end of the Ala Wai Canal will impact the existing benthic community structure. Since the Ala Wai Canal waters and bottom are already highly impacted by storm water discharges with their attendant sedimentary loads, debris, and trash which deposits on the entire canal bottom, the impact of the diffuser system construction will be insignificant.

Impacts Specific to the Submerged Pipeline System in the Ala Wai Canal

The proposed submerged pipeline system to discharge flushing seawater at the Kapahulu end of the Ala Wai Canal consists of an intake structure located at a bottom depth of about 40 ft; 4,000 ft of 40 inch diameter high density polyethylene (HDPE) suction pipeline laid on the ocean bottom; a submerged 3-pump station adjacent to Magic Island with the top of the station 2 ft below the water surface; a 12,500 ft long, 42 inch diameter HDPE discharge pipeline extending from the submerged pump station to the Kapahulu end of the canal, which is typically partially buried and routed on the mauka side of the canal near the mauka bank; and an 80 ft long, 28 inch diameter HDPE pipeline discharge manifold located laterally across the width at the Kapahulu end of the canal, placed on the bottom and secured with concrete collar weights.

Intake Structure And Pipeline. The intake structure will be placed on the west side of the Ala Wai Boat Harbor entrance channel. Two intake suction manifolds consisting of 36 inch diameter pipe sections will be elevated between 9 - 15 ft off the bottom in order to minimize the entrainment of bottom sand. A total of 360 3-inch diameter holes will be drilled into each suction manifold, yielding maximum (at 30 cfs inflow) intake velocities of less than 1 ft/sec. This maximum intake velocity together with the horizontal intake flow direction will minimize the suction of marine life and ensure that there would be no danger to divers. It is known that fish are sensitive to horizontal velocities and can sense and escape from this flow. But they are insensitive to vertical velocities and can easily be sucked into an intake if the intake flow was directed downward.

The highest point of the intake manifold structure would be about 25 ft below the surface, which is much deeper than the maximum draft of vessels that navigate in the area and into the Ala Wai Boat Harbor, and thus poses no danger to vessel navigation.

Both field measurements and analysis indicate that short-circuiting of the intake water with the exiting Ala Wai Canal and Boat Harbor waters would not be a problem. The flow layers are stratified in the area of the intake structure, with seawater comprising a major part of the lower water column and the less dense canal and harbor waters confined to the upper surface layers.

The intake manifold structure and the suction pipeline will be supported by hold down brackets which will elevate the bottom of the pipeline about 1 - 2 ft off the ocean bottom with a minimum clearance of 10 - 14 inches. The hold down brackets will be the only structure attached to the bottom, with 1-1/4 inch diameter holes drilled about 12 inches into the bottom and secured with 1 inch diameter grouted bolts (all thread rod) to firmly attach the hold down brackets to the ocean floor. A total of 360 hold down brackets will be used over the 4,000 ft of suction pipeline and it is estimated that 45 days of work by a two-man dive team will be required to install all the brackets. Thus, the impact to the marine benthic community will be minimal since the cumulative foot print of the hold down brackets on the ocean bottom is very small. Moreover, the navigation channel bottom area is a highly impacted zone, being originally constructed by dredging and influenced by significant vessel traffic. Thus, the impacts to both the benthic and reef fish community will be minimal.

The intake structure and suction pipeline system have been designed to withstand the 100-year design hurricane wave event. Consequently, it is expected that anchors deployed from the typical types of vessels that navigate in the area, should they snag onto the intake structure or pipeline, will not cause any damage to these systems.

Submerged Pump Station. The proposed location of the submerged pump station has been selected after a diving and nearshore reconnaissance survey. In order to decrease the installation costs and facilities maintenance operations, the selected site is close to the primary electrical power lines (located at Ala Moana Park, near the corner of Ala Moana Boulevard and Ala Moana Park Drive), with a consequent least cost for running the 3-phase power lines to the pumps. In addition, the predominant soil conditions at the proposed location are mainly coral and rubble which can be easily removed for installation of the pump station, instead of solid rock formations found towards the exit of the navigation channel, near the end of Magic Island. Moreover, access for cranes and heavy equipment to maintain and service the pumps becomes more available as the pump station is located closer to the main road.

The design of the subsurface pump station will minimize both the visual impacts to the Magic Island area and considerably reduce and minimize the noise associated with pump operations.

The submerged pump station has been designed to incorporate 3 identical pumps. One pump would supply the nominal 20 cfs flow rate and, if necessary, a second pump could be initiated which would provide a nominal 30 cfs of seawater inflow. The third pump has been provided as a backup pump and would also be used when other pumps are being maintained and serviced. This pump redundancy provides assurance that the flushing system will provide continuous service. It is expected that a once-per-year maintenance program will be required for each operating pump, and major overhaul is envisioned every 4 years of operation.

Discharge Pipeline. The 12,500 ft long discharge pipeline will convey water from the submerged pump station to the discharge manifold at the Kapahulu end of the canal. The proposed route of the pipeline is on the mauka side of the canal, located between 15 - 35 ft from the mauka bank, and will typically be partially buried or simply laid on the bottom in order to minimize the risk of undermining the existing mauka wall, and to reduce dredging costs.

The proposed discharge pipeline route will not interfere with the existing utility crossings that are buried in the canal (electric power conduits and sewer siphons). Moreover, the flushing water pipeline will not be affected by future maintenance dredging of the canal, which in the past has been confined to the central area starting at about 40 ft from either side walls. This dredging design was implemented to minimize the possibility of undermining the mauka and makai bank walls.

Concrete weights, 1 ton wet weight, typically spaced about 16 ft apart, are attached to the discharge pipeline to insure that the pipeline partially sinks into the bottom soil and to provide stability along the natural bottom slopes. In the areas where the pipeline is completely buried, the concrete anchor weights are spaced at 8 ft intervals. The design also provides for the future moving of sections of the pipeline, where flanged ends have been periodically incorporated. This allows pipe sections to be capped, floated by filling with air, and moved to a new location and submerged again. The concrete weights attached to the pipeline only represent about 20 - 25% of the total buoyancy of the pipe when filled with air.

To minimize the visual impacts, the discharge pipeline will be constructed so that the minimum depth from the water surface to the top of the pipeline is 3 ft, with a minimum clearance of 2.5 ft between the top of the concrete weights and the water surface. While the pipeline can probably be seen from the mauka bank, it would generally be unseen from other locations, particularly from the makai wall.

When the discharge pipeline crosses the Manoa–Palolo and Makiki Stream outlets, the pipeline will be buried such that the top of the pipeline is a minimum of –13 ft MLLW. This allows for maintenance dredging of these areas to depths of –10 ft MLLW. In the area between the Ala Moana Bridge and the submerged pump station, crossing the navigation channel, the discharge pipeline will be buried about 3 ft below the bottom.

Dredging for the Discharge Pipeline. Significant dredging will be required to partially and fully bury the discharge pipeline. It is estimated that about 50,000 yd^3 of sedimentary material would need to be removed. Based on this dredged spoil volume, the most likely scenario for disposal would be ocean disposal at the Environmental Protection Agency (EPA) designated site located about 5 miles from the Ala Wai Boat Harbor. The EPA disposal area is described by a circle, with a radius of 1,000 yds and a center point located at 21°14'19" North Latitude and 157°54'20" West Longitude.

The envisioned dredging operations would involve hydraulic suction dredging, where a rotating cutting head would dislodge the bottom sediments and create a water-sediment slurry which would be drawn into the suction line thereby reducing water turbidity impacts. Due to the low vertical clearances and small horizontal widths associated with the various bridge structures that cross the canal, it is not possible to use barges to transport the dredged spoil from the dredging site to the ocean disposal site. Thus, as performed during past maintenance dredging operations, a pump (8-10 inch) located on a floating barge would discharge the slurry through a long pressure pipe (10 - 12 inches diameter) into a hopper barge located at a temporary mooring in the Ala Wai Boat Harbor adjacent to Magic Island. Due to the length of this floating discharge pipeline, booster pumps may be required.

The slurry would be pumped directly into the hopper barge and silt curtains would be installed around the barge to mitigate and control any excessive spillage of slurry water into the Harbor. The dredged spoil loaded barges would be towed by tugboats to the designated EPA disposal site for disposal.

Based on past maintenance dredging projects, it is expected that large-size objects (car bodies, sofas, beds, refrigerators, trees, etc.) which are not able to pass through the slurry handling system would need to be removed by other means such as cranes. These large objects would need to be temporarily placed in the contractor's work area, de-watered if necessary, and transported to a landfill for disposal. There is the potential that odor problems would occur due to this temporary storage and de-watering of large objects, as well as visual impacts. The envisioned contractor's work area would be between Ala Wai Elementary School and the Ala Wai Canal and the Manoa-Palolo Stream. The contractor's work area will be fenced off during the construction period for security and safety reasons. Noise levels during the dredging operations will meet Department of Health noise regulations. The estimated dredging period is about 5 - 6 months.

Discharge Manifold. The discharge manifold located at the Kapahulu end of the canal will evenly distribute seawater across the canal width. The manifold has been designed as a simple L shape consisting of a 28-inch HDPE pipe sitting on or near the bottom. Concrete weights have been distributed along the discharge manifold to keep it in place. A total of 32 5.5-inch diameter holes, located 60° from the horizontal plane passing through the pipe centerline, are equally spaced along the manifold to evenly distribute flow and to reduce the flow velocity. The discharge manifold is made out of two 40-ft long sections of pipe flanged together to facilitate maintenance operations. The pipe and concrete weights will be placed in a water depth of 6 ft to provide minimum clearance between the pipe and water surface of 3 ft, and 2.5 ft clearance between the top of the concrete weights and the surface. These clearances will minimize interference with existing boat traffic, canoe racing, and kayaking activities.

Economic Impacts

The seawater well option and the use of a pipeline as a seawater source system have been standardized in order to provide a basis for cost comparison. The seawater well option has been evaluated based on five 200 foot deep wells (130 feet of 18-inch solid casing grouted in-place and 70 feet of open hole), each well delivering 2,500 gpm, spaced nominally 200 feet apart. The following describes the estimated construction and operation and maintenance costs for the proposed seawater supply wells where all costs are in 1992 dollars.

Groundwater Well System:

Engineering Design And Permitting Costs	$475,000
Construction Costs	$2,125,000
Subtotal	$2,770,000
Contingency 20%	$554,000
Total Estimated Engineering & Construction Cost	$3,324,000
Estimated Annual Operating & Maintenance Costs	$190,000

The capital and operational costs of the pipeline system are shown below where all costs are in 1992 dollars. The cost of dredging the estimated 5,000 yd^3 of bottom sediments from the Kapahulu end of the canal for the placement of the discharge manifold and to provide a smooth transition for the outflow waters is not included. It is recommended that this dredging of the Kapahulu end of the canal be performed as part of the next maintenance dredging project. Should this dredging not be performed, then the dredging costs must be added to the selected flushing system construction costs.

Pipeline System:

Engineering Design And Permitting Costs	$490,500
Construction Costs	$6,876,000
Less 5,000 yd^3 Of Dredging @ $34/$yd^3$	<$170,000>
Subtotal	$7,196,500
Contingency 15%	$1,079,500
Total Estimated Engineering & Construction Cost	$8,276,000
Estimated Annual Operating & Maintenance Costs	$71,500

Construction of either of the proposed systems will have a beneficial impact on construction employment. According to the Department of Business and Economic Development & Tourism, there was one direct construction job for each $115,000 worth of construction in place in 1992. The multiplier for construction is 1.4, that is, each new construction job is expected to result in 1.4 additional jobs. For example, $10 million in construction expenditures should result in approximately 87 additional construction jobs being created, plus 122 jobs in other fields for a total of 209 jobs. This projection is based on the annual level of construction expenditures, the percentage of labor content and the current hourly wage of a construction worker.

Using these assumptions, the expenditure of $3.3 million for the deep water wells would provide 29 construction jobs and 40 additional jobs. The expenditure of $8.3 million for the submerged pipeline would provide 72 construction jobs and 101 additional jobs. It should be noted that some of the jobs could be the result of employment shifts rather than new employment.

Relationship to EIS Significance Criteria

Chapter 200 (Environmental Impact Statement Rules) of Title 11 Administrative Rules of the State Department of Health specifies criteria for determining if an action may have a significant effect on the environment. The relationship of the proposed project to these criteria is as follows:

(1) *Involves an irrevocable commitment to loss or destruction of any natural or cultural resource;*

The project does not involve an irrevocable commitment of resources beyond the materials used in construction of the wells and/or pipeline. Pumping from the wells or through the pipeline can be stopped at any time.

(2) *Curtails the range of beneficial uses of the environment;*

The project as proposed will expand beneficial uses of the environment by creating a more pleasant area for recreation.

(3) *Conflicts with the state's long-term environmental policies or goals and guidelines as expressed in Chapter 344, Hawaii Revised Statutes, and any revisions thereof and amendments thereto, court decisions or executive orders;*

The project does not conflict with long-term state environmental policies or goals.

(4) *Substantially affects the economic or social welfare of the community or state;*

The project will support the improvements to Waikiki and adjacent areas proposed in the Waikiki Master Plan and enhance the economic and social welfare of the community.

(5) *Substantially affects public health;*

Improvements to water quality in the canal should be generally beneficially to public health.

(6) *Involves substantial secondary impacts, such as population changes or effects on public facilities;*

The project does not involve substantial secondary impacts such as population changes or effects on public facilities. Increased recreational use of the canal is anticipated, but there should be no significant impacts on water, sewer, transportation or other infrastructure systems.

(7) *Involves a substantial degradation of environmental quality;*

Adverse environmental impacts will be minor and limited to the construction phase. Overall environmental quality will improve.

(8) *Is individually limited but cumulatively has considerable effect upon the environment or involves a commitment for larger actions;*

The project will have a considerable effect on the environment of the Ala Wai Canal. Although the proposed projects to improve water quality in themselves do not result in a commitment to larger actions, it is expected that there will be a strong public demand for additional clean-up and continued maintenance measures to preserve water quality, once attained. Improved water quality will also provide an impetus for implementation of proposals in the Waikiki Master Plan such as the construction of a boat turning basin and floating walkways.

(9) *Substantially affects a rare, threatened or endangered species, or its habitat;*

No rare, threatened, or endangered species (plant or animal) will be affected by the project.

(10) *Detrimentally affects air or water quality or ambient noise levels;*

Noise and dust are unavoidable short-term consequences of construction but can be mitigated through strict adherence to public health regulations governing air pollution and noise. Impacts on air quality will be short-term and should not result in a violation of standards.

Dredging for construction will temporarily adversely impact water quality. In the long term water quality will improve.

(11) *Affects an environmentally sensitive area such as a flood plain, tsunami zone, erosion-prone area, geologically hazardous land, estuary, fresh water, or coastal waters.*

The Ala Wai Canal meets the definition of an environmentally sensitive area. The project is intended to improve water quality. It is consistent with existing and proposed land use regulations for the area.

CHAPTER 4

ALTERNATIVES TO THE PROPOSED ACTION

Project Alternatives

Once the 2-D model verification and calibration processes were completed, the model was used to evaluate design options to improve the water quality in the canal. The design options included injecting either flushing seawater or groundwater into the Kapahulu end of the canal; connecting the Kapahulu end of the canal to Waikiki Beach using a covered channel; and various dredging options to improve circulation in the existing canal. The criteria for evaluating the technical feasibility of any of the tested design options was whether the *chlorophyll* concentrations were about 5 µg/l with a maximum value of 10 µg/l. For any potentially feasible option, simulations were also run which included variation in wind speed and direction (tradewind and Kona wind), and tidal range variations. It was determined that the selecetd system would have to provide 20 cfs (9,000 gpm) to 30 cfs (13,500 gpm) seawater into the Kapahulu end of the Ala Wai Canal to meet the chlorophyll concentration objective.

Based on the results from the extensive computer model runs, the only options which proved to be technically feasible to warrant further feasibility analysis and conceptual design evaluations were the following:

◇ A submerged pipeline system which would intake ocean seawater in the entrance channel of the Ala Wai Boat Harbor in a water depth of about 40 feet with a submerged pump station located adjacent to Magic Island.

◇ A "non-trenched" buried pipeline which would be constructed using existing directional drilling technology to drill and install an underground pipe from the Kapahulu end of the canal to a location off Waikiki Beach, with the intake point located in a water depth of about 40 feet.

◇ A deep groundwater well system, located on the Ala Wai Golf Course, which would extract groundwater of approximately seawater salinity.

The deep groundwater well system and the submerged pipeline system have been described in Chapter 1. Makai Ocean Engineering, Inc. (MOE) provided the conceptual designs and costs estimates for both the submerged pipeline system with the intake in the entrance channel of the Ala Wai Boat Harbor and the directionally drilled underground pipeline system with an intake off Waikiki Beach. The "non-trenched" buried pipeline which would be constructed using existing directional drilling technology is decribed below.

The directional drilling pipeline alternative utilizes earth boring-trenchless technology to install an underground pipeline from a pump station at the Kapahulu end of the Ala Wai Canal to a location off Waikiki Beach, with the ground breaking point and intake located at a water depth of about 40 feet. The drilled hole would be about 7,000 feet long and the installed suction pipeline would be about 40 to 42 inches in diameter.

The earth-boring technology that offers the best opportunity to construct the trenchless underground pipeline is Directionally Controlled Horizontal Drilling (commonly referred to as directional slant drilling). This methodology is a two step process. The first part of the process consists of drilling a directionally controlled pilot hole, approximately 3 inches in diameter. The second phase involves the enlargement of the pilot hole to the desired diameter by reaming. The required pipeline is then installed in the hole using a "pull back" operation. Figure 4-1 schematically illustrates the directional drilling methodology.

Directionally controlled horizontal drilling uses slanted rigs with shafts which typically start at a depression angle of 10° to 20° from the horizontal. The shaft is guided in both azimuth and tilt angles, runs horizontally, and finally curves upward to break through the ground. The directional drilling method was originally developed in the U.S. in the early 1970s and uses mainly technology developed in the oil industry for vertical drills. This method is now commonly used for crossing under natural or manmade obstacles, especially river crossings. This method has revolutionized complicated river crossings for pipelines which were initially done by conventional dredging methods or were rerouted through long distances and crossed over at a bridge location.

The progress and location of the pilot hole is monitored by a specially designed sensor system. An instrumentation system located near the cutting head records the exact position, inclination and orientation of the drill head by measuring compass heading, tilt and relative rotational angle. This information is then transmitted through a wire to the surface where a computer collects and interprets the data. The direction of the cutting head can be continually adjusted to follow the designed underground route.

A total of 10 construction companies in the field of directional horizontal drilling were contacted to assess the feasibility of using slant drilling technology to construct a pipeline to flush the Ala Wai Canal. A brief summary of the information collected as well as advantages and disadvantages of using directional drilling methodology are provided below:

- ◇ All the companies but one agreed that a 6,000 to 7,000 foot long hole for a 42 inch pipe was beyond the current state-of-the-art. Currently, the longest hole ever drilled is 5,400 foot long, but this was done for a 16 inch pipeline. Recently, a 4,500 foot long hole for a 42 inch pipe was successfully completed.

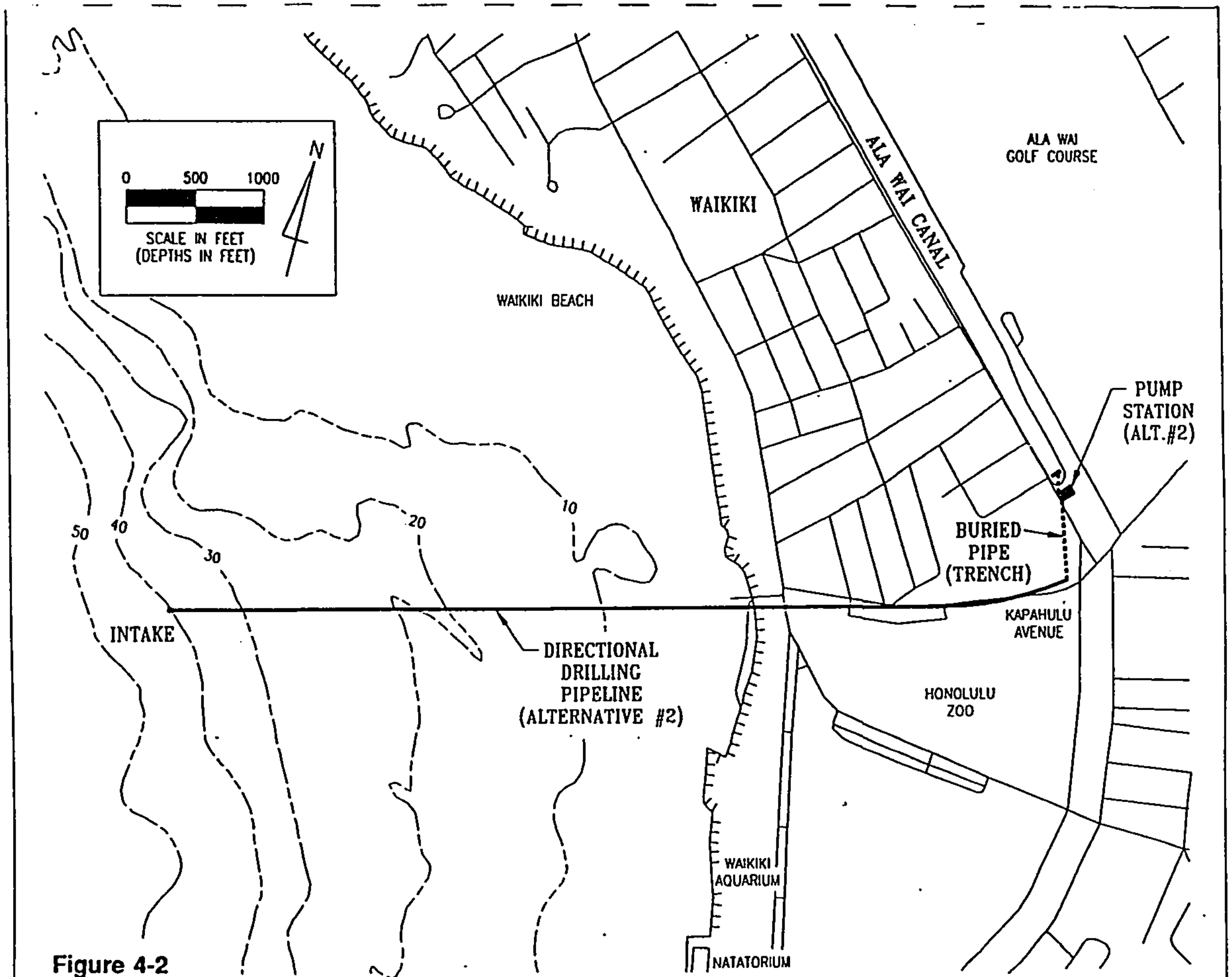


Figure 4-2

POTENTIAL LOCATION AND TRAJECTORY OF DRILLED HOLE UNDER WAIKIKI

◇ Due to the length of the pipeline proposed for the Ala Wai project, a heavy steel pipe is the most likely candidate to be used as the pipeline material. This pipe would have to be protected against corrosion to extend its life.

The following provides a summary of the capital and operational costs of the directionally drilled pipeline system based on 1992 dollars.

Engineering Design And Permitting Costs	$486,000
Construction Costs	$22,913,000
Subtotal	$23,399,000
Contingency 20%	$4,680,000
Total Estimated Engineering & Construction Cost	$28,079,000
Estimated Annual Operating & Maintenance Costs	$55,000

These estimated construction costs for the directionally drilled pipeline indicate that even under favorable soil conditions and assuming that bentonite can be used as a drilling fluid, this alternative is much more expensive than the alternative involving laying a pipe along the Ala Wai Canal. The following table provides a summary cost comparison of the three flushing seawater supply alternatives:

Alternative Description	Cost
Submerged Pipeline System Laid In The AWC	
Estimated Construction Cost	$ 8,471,500
Estimated Annual Operating & Maintenance Cost	$ 71,500
Directionally Drilled Pipeline System	
Estimated Construction Cost	$ 28,079,000
Estimated Annual Operating & Maintenance Cost	$ 55,000
Deep Groundwater Well Supply System	
Estimated Construction Cost	$ 3,324,000
Estimated Annual Operating & Maintenance Cost	$ 190,000

In addition to higher costs, the directionally drilled pipeline alternative has a high risk factor. The 7,000 ft long hole, which would be drilled to a large diameter for installation of a 40 to 42 inch diameter steel pipeline, is basically beyond the current state-of-the-art. If constructed, this pipeline would be the longest and largest diameter hole drilled in the world, using directional drilling technology.

There are two significant risks associated with the directionally drilled pipeline concept. These are:

◇ The quality of the subsurface soil along the drilling path is not known in detail. The presence of unconsolidated, non self-supporting soils along the drill route would considerably increase the risk and cost of the drilling operations.

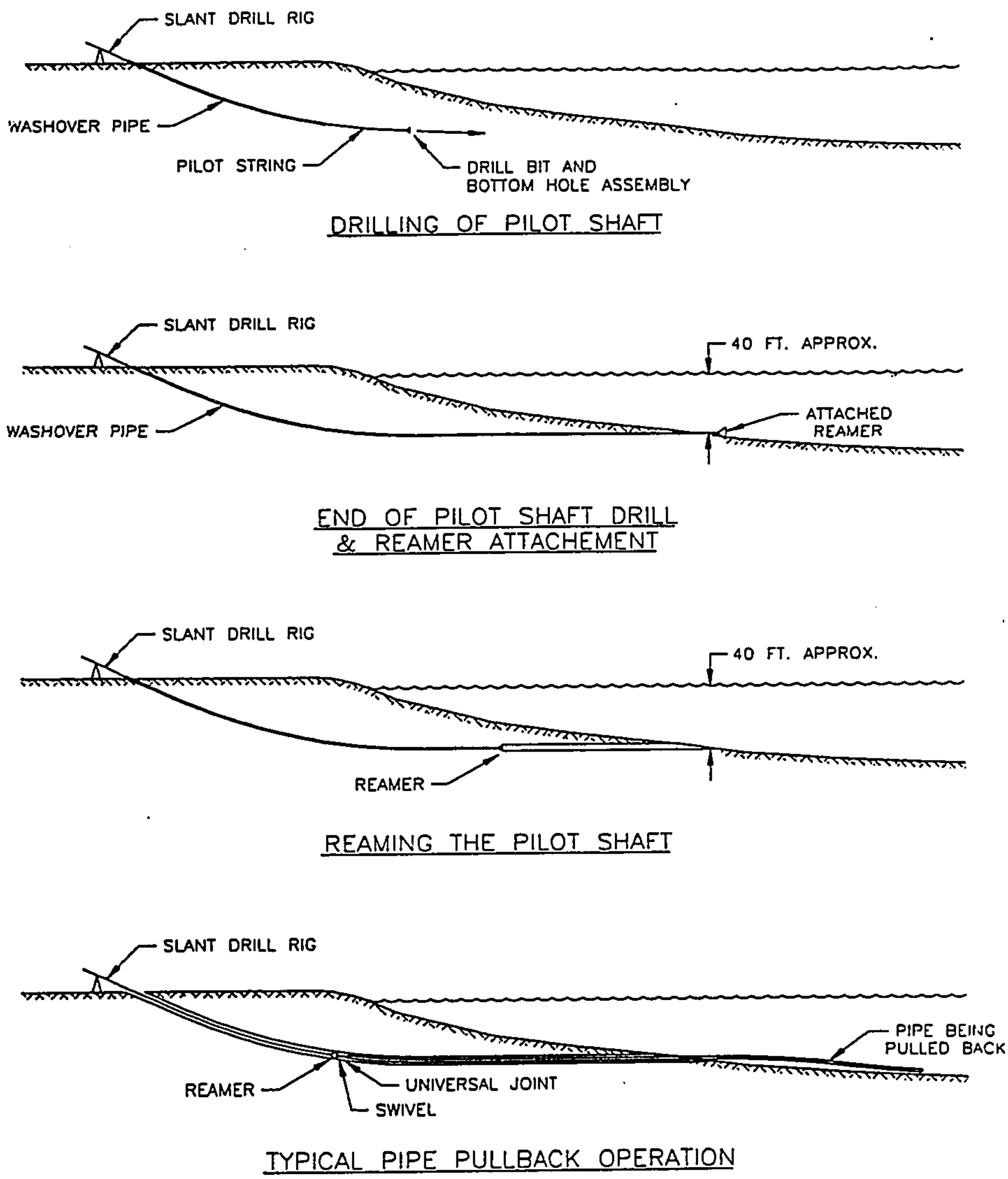

SLANT DRILL RIG
WASHOVER PIPE
PILOT STRING
DRILL BIT AND
BOTTOM HOLE ASSEMBLY
DRILLING OF PILOT SHAFT
SLANT DRILL RIG
40 FT. APPROX.
WASHOVER PIPE
ATTACHED
REAMER
END OF PILOT SHAFT DRILL
& REAMER ATTACHEMENT
SLANT DRILL RIG
40 FT. APPROX.
REAMER
REAMING THE PILOT SHAFT
SLANT DRILL RIG
PIPE BEING
PULLED BACK
REAMER
UNIVERSAL JOINT
SWIVEL
TYPICAL PIPE PULLBACK OPERATION

Figure 4-1

This job was completed in well consolidated and relatively soft soils (sand, silt and clay) which are optimum for slant drilling. The company which completed this job, Cherrington Corporation, was the only company who felt that they could drill up to a 7,000 foot long hole for a 42 inch pipe if the soil conditions were appropriate. Although information on the geology of the Waikiki area was provided to a total of five drilling companies that initially showed interest in drilling a 6,000 to 7,000 foot long hole, only Cherrington Corporation submitted a preliminary budget for the Ala Wai Project.

- All the companies agreed that the main risk associated with drilling a long hole is related to the quality of the subsurface soil along the drilling path. If pockets of unconsolidated materials are found along the drilled path, it is possible that soil may fall and clog the already drilled hole ("cave in" phenomenon). One solution to this problem is to pump concrete into these pockets of unconsolidated materials to minimize the risk of cave in. The presence of pockets of non self-supporting soils would increase substantially the cost of the operation. Given the geological data published for the area of Waikiki, it is not unreasonable to expect that some of these pockets would be encountered along the drilling path, and therefore increase the risk and price of the drilling operation.

- A second concern expressed by the drilling companies was the fact that bentonite drilling mud might not be allowed in this operation due to environmental concerns that the fluid may leak into the ocean waters. Recent experience with horizontal drilling at Keahole, Hawaii revealed that the use of bentonite was prohibited by the U.S. Army Corp of Engineers since the coastal waters at Keahole were classified as Class AA. Although the waters off Waikiki are classified as Class A, and therefore have less environmental restrictions than the waters off Keahole, it is not known at this point if the use of bentonite drilling mud would be allowed. If bentonite were not allowed in Waikiki, the risks and cost of the drilling project would increase even further since friction resistance would build up considerably faster with other drilling fluids than with the use of bentonite.

- The land area required for the drilling operation to take place varies with the type of rig and the size of the job. Land areas between 1/4 acre (for small rigs) up to 1 acre (for larger rigs) were requested by the contractor companies. For the length and size of the hole desired, an area close to one acre would be required. Currently, there is no such area available at the end of the Ala Wai Canal. An alternative would be to use part of the Jefferson School grounds or one end of the Honolulu Zoo (Figure 4-2) to set up the rig. Then an open trench excavation would be required to connect the drilled hole with the Ala Wai Canal. An additional constraint in the location of the drilling rig is that it is difficult to drill on a horizontal curve with this large diameter pipe, therefore, the drilling path must be as close as possible to a straight line.

- There is the potential that bentonite mud drilling fluid would not be allowed in the drilling operations due to environmental concerns and fear that the fluid may leak into the nearshore waters of Waikiki Beach. The use of a more "environmentally acceptable" drilling fluid would increase the risks and costs of the operations.

For these reasons, the drilling alternative was not pursued.

No Action Alternative

If the proposed project is not implemented, water quality in the Ala Wai Canal will continue to be poor. The planned dredging will enlarge the canal's capacity but it will not improve water quality. Because of the greater depths and less opportunity for tidal flushing, water quality may deteriorate further after dredging takes place.

CORRECTION

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

- There is the potential that bentonite mud drilling fluid would not be allowed in the drilling operations due to environmental concerns and fear that the fluid may leak into the nearshore waters of Waikiki Beach. The use of a more "environmentally acceptable" drilling fluid would increase the risks and costs of the operations.

For these reasons, the drilling alternative was not pursued.

No Action Alternative

If the proposed project is not implemented, water quality in the Ala Wai Canal will continue to be poor. The planned dredging will enlarge the canal's capacity but it will not improve water quality. Because of the greater depths and less opportunity for tidal flushing, water quality may deteriorate further after dredging takes place.

CHAPTER 5

AGENCIES, ORGANIZATIONS AND INDIVIDUALS CONSULTED

Consulted Parties

The following agencies and individuals have been consulted in the preparation of the feasibility study and the draft environmental assessment. Comments received during the review of the draft assessment will be addressed in the final document.

Member of the Ala Wai Cleanup Technical Committee:

Jacqueline Miller, Chair	UH Environmental Center
Representative Duke Bainum	State Legislature
Bruce Anderson	Deputy Director, Environmental Health Administration, Department of Health
Benjamin Lee	Chief Planning Officer, City & County of Honolulu
Maynard Hufschmidt	Environment & Policy Program, East-West Center
George Wilkins	UH Hawaii Institute of Geophysics
Hans Krock	UH Look Laboratory/OCEES Inc.
Eugene Dashiell	Eugene Dashiell Planning Services
Edward Lau	Department of Land and Natural Resources

State Officials

State Historic Preservation Office
Dave Parsons, Harbors Division, State Department of Transportation

City Officials

Councilman Andy Mirikitani
City and County of Honolulu
- Walter Ozawa, Department of Parks and Recreation
- Ken Radman , Honolulu Zoo
- Gary Okino, Department of General Planning
- Department of Public Works

Organizations and Individuals

Earl Hinz, Ala Wai Advisory Committee
Rick Scudder, Conservation Council for Hawaii
Patricia Tummons, Environment Hawaii
Gilbert Chu, Hawaii Visitor Bureau
Burn Russell, Hawaii Yacht Club
Douglas Muller, Life of the Land
Clyde Morrell, Natural Resources Defense Council
Oahu Hawaii Canoe Racing Association
Martha Black, People's Water Conference
Sierra Club Hawaii Chapter
Denise Antollina, Sierra Club Legal Defense Fund
Bill Hamm, TORCH
Christinna Krammer, Waikiki Improvement Association

Preparers

The following firms were involved in the preparation of this environmental assessment:

KRP Information Services
Edward K. Noda & Associates, Inc.
O. I. Consultants, Inc.

47a

CHAPTER 6

COMMENTS AND RESPONSES TO THE DRAFT ENVIRONMENTAL ASSESSMENT

The following agencies and individuals have submitted written comments. This is followed by the written comments received and responses.

City Officials

City and County of Honolulu
- Walter M. Ozawa, Director, Department of Parks and Recreation
- Roland D. Libby, Jr., Acting Chief Planning Officer, Department of General Planning

Organization and Individual

John Harrison, U.H. Environmental Center
David Kimo Frankel

DEPARTMENT OF PARKS AND RECREATION
CITY AND COUNTY OF HONOLULU
650 SOUTH KING STREET
HONOLULU, HAWAII 96813

92 DEC 31 P1:23

FRANK F. FASI
MAYOR

WALTER M. OZAWA
DIRECTOR

December 22, 1992

Mr. William W. Paty, Chairperson
Board of Land and Natural Resources
State of Hawaii
1151 Punchbowl Street
Honolulu, Hawaii 96813

Dear Mr. Paty:

We have received a copy of your Draft Environmental (DEA) Assessment for the Ala Wai Canal Improvement Project. If you prepare an Environmental Impact Statement, we would like to be listed as a consulted party.

While we support your Department's efforts to improve the water quality of the Ala Wai Canal, we have concerns about how this project may impact our parks in the area. These concerns are:

Impacts Generated by the Deep Groundwater Well System

We have serious concerns that the proposed well system may adversely impact our existing wells at the Ala Wai Golf Course and at the Honolulu Zoo. We are also concerned that the large amounts of water that you are planning to remove may cause subsidence at the golf course or in other parts of Waikiki.

The University of Hawaii's Environmental Center's letter of September 30, 1992 raised raise several significant questions that need to be completely addressed. Because of the complex technical issues associated with this alternative, the Board of Water Supply needs to be consulted prior to any declaration of negative impact.

Our Department also has several "non-technical" questions about the way this project might impact the golf course and other ongoing activities in the area. Will the new pump system require the displacement of any ongoing activities? What kind of aesthetic impacts will be associated with this project? Will the pumps or the pumping station generate noise or vibration?

Impacts Generated by the Submerged Pipeline System

Generally this alternative seems to involve less significant environmental concerns for our Department. Our recreational Canoe Council has expressed some concerns over the plans to lay piping in the canal. The Council has reviewed the drawings included in your EA and concluded that their canoeing and kayaking activity will not be impacted by the submerged piping alternative. However, we are concerned about the risks that the piping might pose to their escort boats and to their launching ramps.

In order to maximize the usable waters of the canal, the Canoe Council has asked that you consider relocating the submerged piping to the makai side of the canal. If this will not be possible, the Council has asked that you consider locating the submerged piping as close to the mauka bank as possible.

It is essential for the recreational users of the canal to be able to launch their kayaks and canoes from the storage areas on the mauka bank. Will the design and location of the submerged piping interfere with the existing ramps?

We understand that although you considered the possibility of laying a directionally drilled pipeline, that alternative is no longer under active consideration.

Finally, we also note that your Draft Maintenance Plan for the Ala Wai Canal was not extensively discussed in the EA. We assume that there will be a separate EA for the Maintenance portion of the project.

As we stated earlier, we support your efforts to improve the water quality in the Ala Wai Canal, however, we do need to be certain that any actions that may be undertaken will not have any serious unforseen negative environmental consequences.

Mr. William W. Paty
Page 2
December 22, 1992

If you have any questions about our concerns, please call John Morihara of our Advance Planning Branch at 523-4246.

Sincerely,

WALTER M. OZAWA, Director

WMO:ei

JOHN WAIHEE
GOVERNOR OF HAWAII

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

KEITH W. AHUE, Chairperson
BOARD OF LAND AND NATURAL RESOURCES

DEPUTIES
JOHN P. KEPPELER, II
DONA L. HANAIKE

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

REF:WL-LN

APR 15 1993

Mr. Walter M. Ozawa, Director
Department of Parks and Recreation
City & County of Honolulu
650 South King Street, 10th Floor
Honolulu, Hawaii 96813

Dear Mr. Ozawa:

Draft Environmental Assessment
For The Ala Wai Canal Improvement, Honolulu, Oahu, Hawaii

Thank you for your letter of December 22, 1992 regarding the subject project. Our response to your comments is as follows:

Impacts of Deep Groundwater Well System

We share your concerns that a deep groundwater well system to provide saline water for flushing of the Ala Wai Canal could adversely affect the existing wells at the Ala Wai Golf Course and the Honolulu Zoo and could cause subsidence at the golf course and other surrounding areas.

As part of the feasibility evaluations of the deep groundwater well system, the subsurface geologic strata on the mauka side at the east end of the canal was evaluated. Interpretation of the available deep drilled well data show the potential for an impermeable layer (aquitard) to exist, which would restrict groundwater through-flow. The boring logs indicate this aquitard is comprised of a later-stage volcanic layer and underlies the entire east end of the canal. It is located at depths of 80 to 120 ft below the ground surface with thicknesses of typically 50 to 80 ft. If this is the case, then the aquitard would provide effective vertical hydraulic separation between the deep pumped saline waters and the near-surface brackish groundwater. The saline in-flowing waters which make-up for the withdrawn waters would flow horizontally within the lower coral layers. The aquitard would thus minimize dewatering of the surficial lagoonal deposits and thereby prevent any localized subsidence which could cause damage to structures and property.

It is expected that pumping water from the deep aquifer at the 200 foot depth of plumage will have no adverse effects on either existing potable water supplies or the existing groundwater supply used for irrigation of the Ala Wai Golf Course. Because this layer is thought to be completely separate from the upper aquifer, it should not cause subsidence problems.

However, there is some uncertainty on the subject. This is why a prototype production well drilling and testing program will be undertaken to confirm the expected subsurface geologic strata and demonstrate that such high capacity pumping can be accomplished without adverse effect. It will also be used to develop other design parameters.

Once a prototype well has been drilled, full scale pumping tests will be conducted. Placement of sounding tubes to various depths in the annular space will enable the effects of pumping on overlying layers to be measured, thereby demonstrating that pumping could occur without de-watering the overlying surficial lagoonal deposits.

In addition to the drilling and testing of the prototype production well, four smaller diameter boreholes will also be drilled to depths of about 250 feet in order to confirm the subsurface geologic strata of the entire proposed groundwater source area at the Ala Wai Golf Course. The Board of Water Supply will be consulted before any test wells are drilled.

Should any of the test results and evaluations indicate that this concept is not feasible, the alternate submerged pipeline system in the Ala Wai Canal will be pursued.

If the project is feasible, the wells are proposed to be placed adjacent to the parking lot at the Ala Wai Golf Course Clubhouse (see attached Figure 5 from Appendix H of the Feasibility Report) alongside the 18th fairway. The cart path may have to be relocated a few feet mauka. This should not interfere with golf course activities except during the construction period.

In regards to aesthetics, detailed design of the structures has not been undertaken because the feasibility of using wells is still to be demonstrated. If the deep groundwater well system is proven feasible and funding is made available for implementation, the wells and pump structures will be designed to be compatible with City plans for the area.

There will be some noise generated during the drilling of the deep groundwater wells, installation of the well casings and pumps, construction of the interconnecting underground pipelines, construction of the aeration system, and deployment of the diffuser system across the canal width. The construction generated noise will be temporary, and since the entire system is expected to be constructed in an open area, away from building structures, the construction noise impacts are expected to be minimal.

During operations, some noise is expected from the well and aeration pumps. These pump noise levels would be reduced by acoustic containment in order to meet Department of Health noise regulations.

Impacts Generated By The Submerged Pipeline System

If the deep groundwater well system proves to be infeasible, the submerged pipeline system is recommended for implementation. A full design process would then be required, consisting of a preliminary and final engineering design phases. During the preliminary engineering phase, the relocation of the submerged pipeline to the makai side of the Canal would be re-evaluated. If the engineering decision continues to favor the mauka side of the Canal, the pipeline would be located as close to the mauka bank as is feasible.

One of the criteria used in the evaluation of the feasibility of the submerged pipeline system was that the recreational uses of the Canal were to be fully maintained. Thus, the submerged pipeline system will be designed and located in order not to interfere with the existing ramps used to launch kayaks and canoes from the mauka bank.

Draft Maintenance Plan

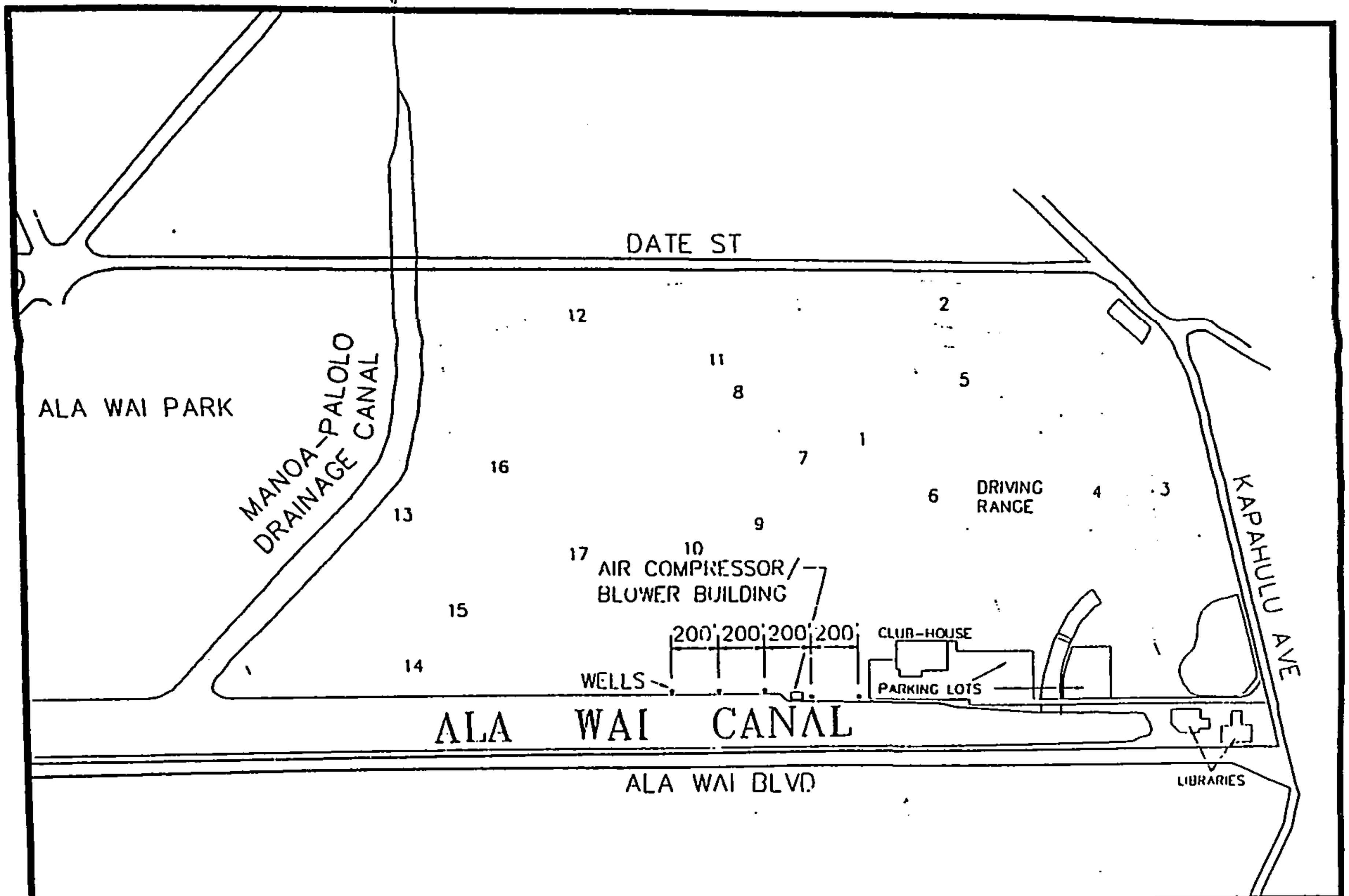
The maintenance plan, like any maintenance plan, does not require an environmental assessment in order to be implemented. However, the major dredging recommended in the maintenance plan will require a separate EA.

If you have any questions, please feel free to contact Mr. Manabu Tagomori of the Division of Water and Land Development at 587-0230.

Very truly yours

KEITH W. AHUE
Chairperson

c: Edward K. Noda & Associates, Inc.
KRP Information Services



ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	PROPOSED LOCATIONS OF THE FIVE 2500 GPM SALTWATER SUPPLY WELLS	FIGURE 5

DEPARTMENT OF GENERAL PLANNING
CITY AND COUNTY OF HONOLULU
650 SOUTH KING STREET
HONOLULU, HAWAII 96813

92 DEC 31 P1:23

GO 11/92-3536A

December 22, 1992

The Honorable William W. Paty, Chairperson
Board of Land and Natural Resources
Department of Land and Natural Resources
State of Hawaii
P.O. Box 621
Honolulu, Hawaii 96809

'92 DEC 23 A8:07

Dear Mr. Paty:

Draft Environmental Assessment for the
Ala Wai Canal Improvement, Honolulu, Oahu, Hawaii

In response to your letter of November 30, 1992 regarding the subject draft environmental assessment, we offer the following:

1. The visual impacts of the wells and pump structure should be addressed.

2. The draft EA adequately addresses the project's impacts in relation to the various proposals of the Waikiki Master Plan except the proposed pedestrian bridge which will link Waikiki with the Ala Wai Golf Course. This pedestrian bridge will be an extension of Nahua Street. Potential impacts on this proposal should also be addressed.

3. An amendment to the City's Development Plan Public Facilities Map is needed before the construction of either the submerged pipeline or well supply solutions can proceed.

Thank you for the opportunity to comment. Should you have any questions, please contact Gary Okino of our staff at 527-6067.

Sincerely,

ROLAND D. LIBBY, JR.
Acting Chief Planning Officer

RDL:js

JOHN WAIHEE
GOVERNOR OF HAWAII

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

KEITH W. AHUE, Chairperson
BOARD OF LAND AND NATURAL RESOURCES

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

APR 15 1993

Mr. Robin Foster
Chief Planning Officer
Department of General Planning
City & County of Honolulu
650 South King Street, 8th Floor
Honolulu, Hawaii 96813

Dear Mr. Foster:

Draft Environmental Assessment
<u>For Ala Wai Canal Improvement, Honolulu, Oahu, Hawaii</u>

Thank you for your letter of December 22, 1992 regarding the subject project. Our response to your comments is as follows:

Visual impact of the wells and pump structure.

Copies of schematic drawings of the proposed wells and pump structures (Figures 5-8 from Appendix H of the Feasibility Report) are attached. Detailed design of these structures has not been undertaken because the feasibility of using wells is still to be demonstrated. At this phase, it is envisioned that the individual well and pump structure would be about 4 ft square and about 1-2 ft high. If the deep groundwater well system is proven feasible and funding is made available for implementation, the wells and pump structures will be designed to be compatible with City plans for the area.

Impacts on proposed pedestrian bridge at Nahua Street.

There would be no impact on the proposed pedestrian bridge at Nahua Street under either the deep groundwater well system or the submerged pipeline system. The wells are proposed to be placed adjacent to the parking lot at the Ala Wai Golf Course Clubhouse (see Figure 5), a considerable distance from the proposed bridge. The pipeline would probably be visible from the pedestrian bridge but otherwise would have no impact.

Amendment to the City s Development Plan Public Facilities Map.

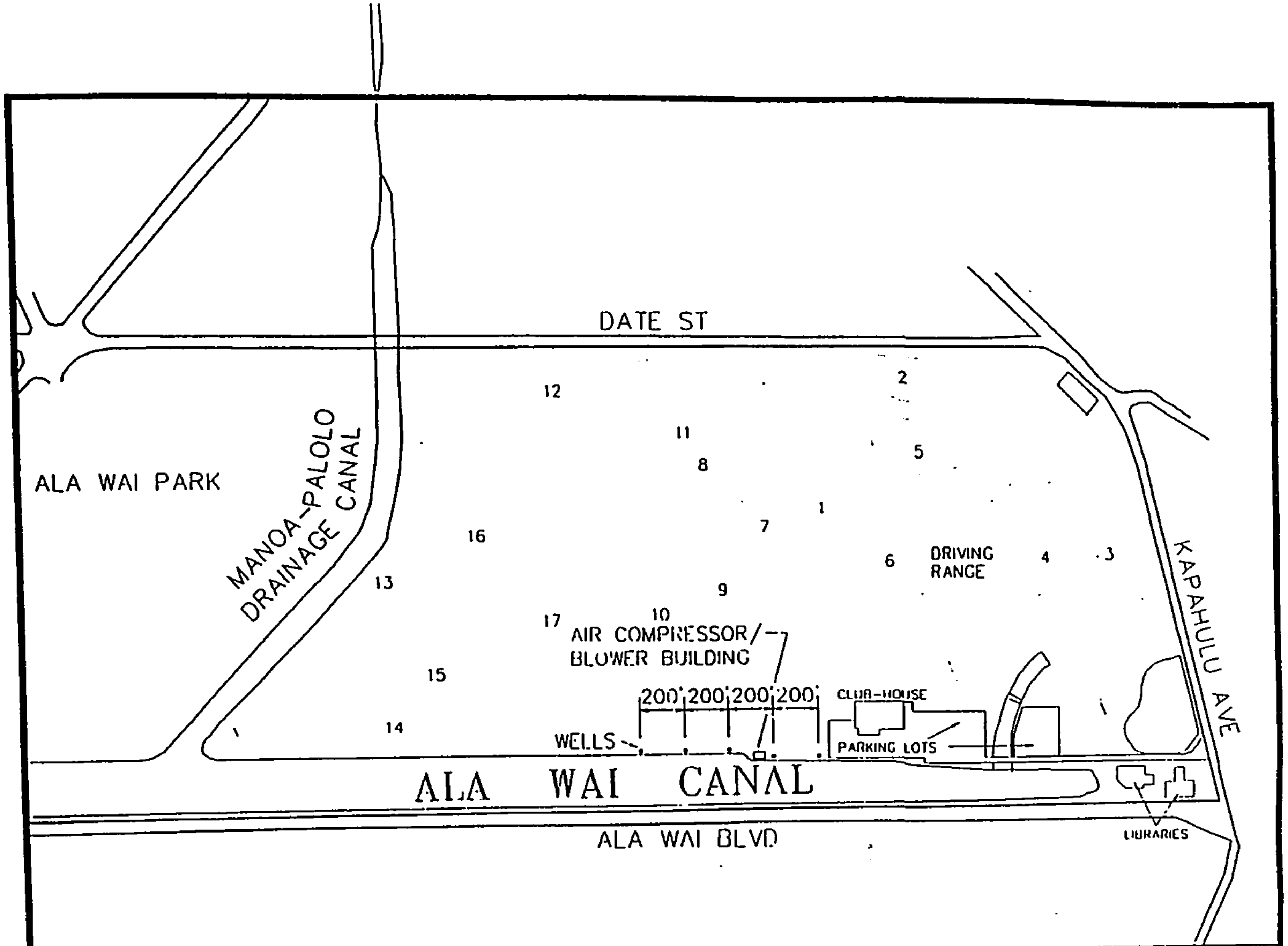
Thank you for letting us know that this is required. Once funding for the project is obtained, we will initiate an application for an amendment to the City's Development Plan Public Facilities Map.

If you have any questions, please feel free to contact Mr. Manabu Tagomori of the Division of Water and Land Development at 587-0230.

Very truly yours,

KEITH W. AHUE
Chairperson

c: Edward K. Noda & Associates, Inc.
KRP Information Services



ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	PROPOSED LOCATIONS OF THE FIVE 2500 GPM SALTWATER SUPPLY WELLS	FIGURE 5

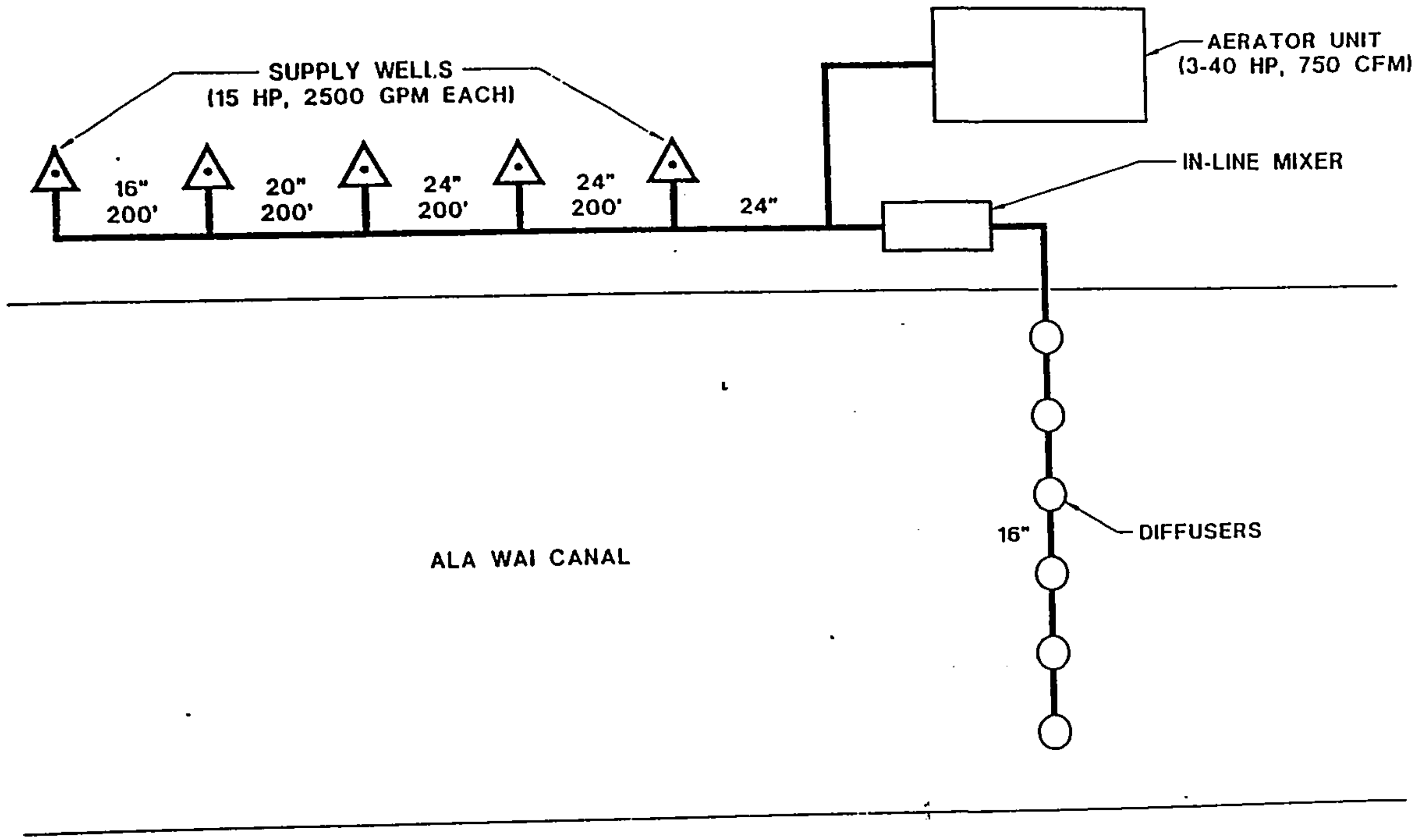


FIGURE 6
PROPELLER PUMPS, MECHANICAL AERATION,
AND DIFFUSER DISCHARGE

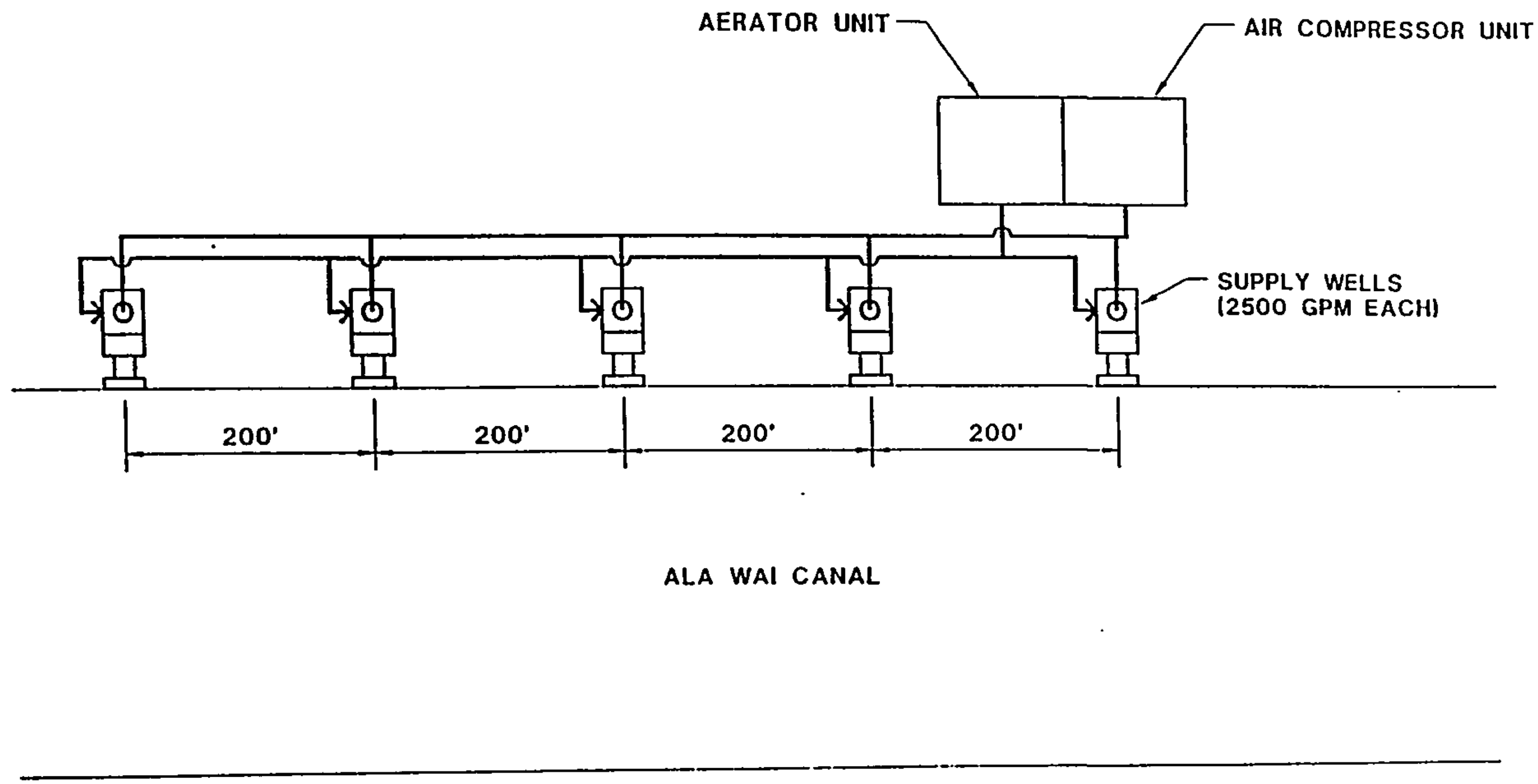


FIGURE 7
AIR LIFT PUMPING SCHEME

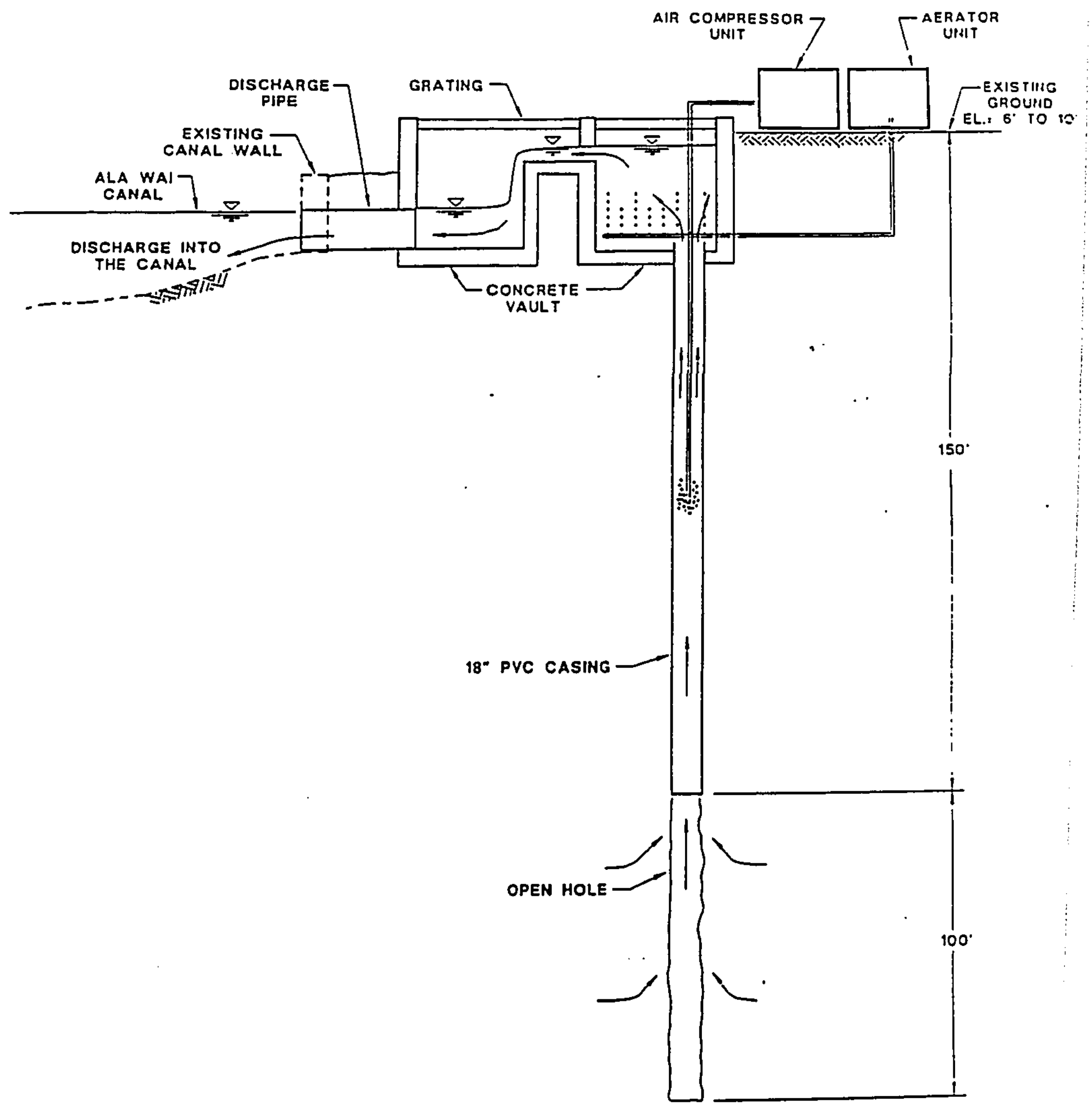


FIGURE 8
AIR LIFT PUMP AND
WELL SECTION SCHEMATIC
(NOT TO SCALE)

University of Hawaii at Manoa

Environmental Center
A Unit of Water Resources Research Center
Crawford 317 • 2550 Campus Road • Honolulu, Hawaii 96822
Telephone: (808) 956-7361

December 23, 1992
EA:00013

Mr. Edward Lau
Division of Water and Land Development
Department of Land and Natural Resources
P.O. Box 373
Honolulu, Hawaii 96809

Dear Mr. Lau:

Draft Environmental Assessment (EA)
Ala Wai Canal Improvements

The Department of Land and Natural Resources of the State of Hawaii proposes to improve water quality in the Ala Wai Canal (AWC) to standards acceptable for water-based recreational activities. The specific objectives of the project are to:

1) increase water flow and circulation in the canal while addressing environmental concerns;

2) decrease sources of pollutants through improved watershed management, and;

3) establish routine maintenance and management practices for the canal.

However, only proposed actions to increase water flow and circulation are assessed at this time. Implementation of the other objectives is not within the sole jurisdiction of the Department of Land and Natural Resources and requires cooperation with other departments, agencies, and the community.

Specifically, this project proposes to infuse 20 to 30 cubic feet per second (cfs) of seawater into the Kapahulu end of the AWC in order to improve water quality to within limits of state water quality standards for water-based recreational activities. Two alternative options for the project are discussed. The first is injection of 20 to 30 cfs of groundwater from 5 wells drilled on the premises of the Ala Wai Golf Course, to depths of 250 feet or greater, with the water discharged through a discharge manifold located across the AWC. This option would be pursued only after a prototype production well drilling and testing program has confirmed the expected subsurface geologic strata, water quality, and groundwater flow yield from coral layers at this depth and demonstrated that such high capacity pumping can be accomplished without adverse effects.

The second alternative is injection of 20 to 30 cfs of seawater delivered to the Kapahulu end of the AWC through a 12,500 foot long, 42 inch diameter submerged pipeline, laid and partially buried in the AWC. An intake structure located near the entrance to the Ala Wai Boat Harbor at a depth of about 40 feet would connect to a 4,000 foot long, 40 inch diameter suction pipeline leading to a submerged pump station located adjacent to Magic Island. The Environmental Center has reviewed the draft EA with the assistance of Edward Laws, Oceanography; Andrew Tomlinson, Environmental Center; and Elizabeth Gordon, Environmental Center.

General Comments

In general, we applaud the efforts of the Department of Land and Natural Resources to improve the water quality of the AWC and the overall environmental conditions of the Waikiki, McCully, and Kapahulu areas in the vicinity of the AWC. **However, we strongly** suggest that an environmental impact statement be prepared for the proposed project in order to augment certain sections of the draft EA and to address questions concerning the complexity, large scope, and cumulative impacts of the proposed action. These factors collectively trigger many of the significance criteria requiring preparation of an environmental impact statement as prescribed by Section 11-200-12, Hawaii Administrative Rules (HAR). Furthermore, significant impacts of a proposed action are not limited to negative effects, but also include impacts that may be beneficial. In addition, cumulative impacts of a proposed action must be addressed, as prescribed in Section 11-200-12, HAR. Consequently, we suggest that the draft EA be re-submitted as a Preparation Notice (PN) and that the body of the present document form the basis of a truly comprehensive environmental impact statement for the proposed AWC improvements.

Modelling and Data

Our reviewers have expressed concerns over the dynamic modelling for the AWC in the draft EA its feasibility report. First, although the draft EA refers in passing to the relative importance of individual rainfall/sedimentation events on the AWC, the intermittent nature of pulsed water/sediment inputs is not reflected in the model. Second, the 2-dimensional hydrodynamic model used for the AWC does not adequately address the thermally driven circulation in the AWC. Gonzalez (1971) noted that circulation in certain portions, particularly the rear or Kapahulu section, was more thermally influenced than tidally driven as stated in the draft EA. Would such a thermal structure in the AWC affect the proposed project to flush the canal with seawater? The model also fails to account for spatial variations in nutrient levels, particularly elevated nitrate levels at the Kapahulu end. However, our reviewers note that given its limitations, the model does provide substantial contributions to the remediation planning, and they further note that while refinement is certainly possible, it may be unnecessary for the present purposes.

Deep Groundwater Well System Alternative

Our reviewers expressed a number of serious concerns regarding the deep groundwater well alternative. First, what will be the chemical characteristics of the water drawn from deep aquifers? Is the water likely to be anoxic, and will there be concomitantly high levels of hydrogen sulfide? Are there any geological substrata having volcanic basalts or ash which might have reacted with the water being withdrawn? Are there other potential sources of toxic leachate which might compromise the biological integrity of the AWC? Water drawn from deep wells for support of marine biological applications in other areas has proven problematic (e.g., Anuenue Fisheries Lab, some of the UH facilities at Sand Island, and Coconut Island in Kaneohe Bay). Second, how will the pumping of large amounts of groundwater from the lower "aquitard" level affect the upper lagoonal layers of water? Will the possible draining of the groundwater from the lagoonal layers result in subsidence and possible structural damage to nearby buildings as documented in the case of the de-watering at the Duty Free Shopping Center.

Finally and most importantly, why was the prototype production well and test drilling program not conducted prior to issuance of the draft EA and included in the document? Data arising from the tests, including water quality, soils, geology, etc., are vital for comprehensive evaluation of the proposed action and selection of the most appropriate alternative. The intent of Section 343-6, Hawaii Revised Statues (HRS), is to provide for full disclosure of critical information concerning the proposed action, alternatives, potential impacts, existing conditions, mitigating measures, etc. Clearly, had the test drilling and prototype production program been conducted prior to release of this document, data would have been available to substantially address the above questions.

Pipeline Alternative

The description of this proposed alternative appears insufficiently comprehensive. First, there is only brief mention of dredging, (separate from maintenance dredging) which is to be conducted as part of the pipeline alternative. How will the dredging be conducted? Where will the dredge spoil be disposed? What are the existing conditions at the disposal site, and what are the potential impacts from the dredging and its disposal on the disposal area? Additional information would have been helpful concerning this alternative.

Second, the description of the existing environment is lacking in comprehensiveness. What are the existing conditions, including flora, fauna, geology, and water quality, of the coastal area near the Ala Wai Boat Harbor where the intake and outflow will be situated? What will be the impact on the existing conditions of the proposed pipeline? What are the soil types in which the pipeline will be partially buried?

Existing Conditions (general)

While the project is intended improve water quality and environmental conditions for recreational use of the AWC, the draft EA fails to provide an in-depth description of present recreational uses of the canal. How many people use the AWC and at what locations? (ie. How many canoe clubs actively paddle on the AWC?) What are the potential impacts of each alternative on recreational use during construction of the project and following its completion? Will present recreational uses of the area conflict with the construction phase of the two alternatives? How will the project enhance present recreational uses in the short and long-term?

In addition, there was no indication of any consultation with the Ala Wai Golf Course. How will the project affect the golf course during and following construction of the project? Will there be increased or decreased use of the golf course? Also, do operation and maintenance activities at the golf course affect the development of the proposed action? Do chemicals applied to the golf course contaminate the AWC? How will the groundwater well alternative affect the golf course?

The document also fails to describe potential traffic impacts resulting from the proposed project. Will traffic be affected, especially during construction of the pipeline alternative? Will noise be a factor for the adjacent community? How will the school be affected by construction of the proposed improvements? How often is the mauka side of the AWC, between the McCully Bridge and Kapahulu, used for recreational activities? How will the safety of pedestrians in this area, in particular children, be safeguarded during construction of the groundwater wells. What are the existing utilities in the area? Will the proposed alternatives have an impact on utilities in the AWC area?

Economic and Social Impacts

While the major rationale for the proposed project is the enhancement of water and environmental quality, there is no study or discussion of the long-term impacts of the proposed project on the area. Will the proposed project attract new business establishments and further improvements to the AWC area? The Waikiki Master Plan, which this draft EA and project refers to, includes definite plans for the AWC. The draft EA briefly mentions the enhanced opportunities for canal-side dining, etc. following the proposed improvements to the AWC. In what other contexts does this project intersect with the Waikiki Master Plan? Will there be enhanced revenues attributable to the proposed improvements? How will the project affect Waikiki and the social atmosphere of the McCully, Kapahulu, and Waikiki areas?

Significance Criteria

The draft EA states that the proposed alternatives do not invoke any of the triggers listed under Section 11-200-12, HAR, requiring preparation of an environmental impact statement. As noted earlier, we strongly disagree. From the information provided in the draft EA, we suggest that the proposed actions trigger at least seven of the prescribed triggers under Section 11-200-12, HAR. We reiterate that impacts, as defined under Section 11-200-12, HAR, are not limited to negative impacts but also include potential impacts from a proposed action that may have beneficial effects. As such, we suggest that the following criteria under Section 11-200-12, HAR, are invoked by the proposed project.

Section 11-200-12

"a) In considering the significance of potential environmental effects, agencies shall consider the sum effects on the quality of the environment, and shall evaluate the overall and cumulative effects of an action.

b) In determining whether an action may have a significant effect on the environment, the agency shall consider every phase of the proposed action, the expected consequences, both primary and secondary, and the cumulative as well as the short and long-term effects of the action. In most instances, an action shall be determined to have a significant effect on the environment if it:

4) Substantially affects the economic or social welfare of the community or State;"

According to the draft EA, "The project will support the improvements to Waikiki and adjacent areas proposed in the Waikiki Master Plan and enhance the economic and social welfare of the community." Waikiki constitutes the State's major tourist destination, and the Waikiki Master Plan is intended to be a major portion of the State's attempt to renovate the area and to revitalize the lagging tourist economy, thereby enhancing private and public revenues. Clearly, the stated intent of the proposed project, to enhance the environment of Waikiki, will affect the revenue generating capability of the State. Regardless of whether the project is successful, it will result in substantial effects to economic and social welfare.

Section 11-200-12b
"5) Substantially affects public health;"

Again, a central objective of the project, as outlined by the consultants and the Department of Land and Natural Resources in the draft EA, is to significantly enhance the public health of recreational users of the region by improving environmental conditions in the AWC and the adjacent areas.

Section 11-200-12b
"6) Involves substantial secondary impacts, such as population changes or effects on public facilities;"

On the basis of information provided by the draft EA, it is difficult to make a determination of significance under this criterion. However, the proposed project is intended to enhance the environment which could spur further uses of the AWC under the Waikiki Master Plan, including canal-side dining, recreational use, etc. It is very likely that with increased public utilization, there will be a need for a long-term increase in public services, including police patrols, restrooms, fire protection, electricity for lighting, waste water disposal, etc.

Section 11-200-12b
"7) Involves a substantial degradation of environmental quality:"

As noted above the draft EA fails to resolve many questions concerning potential environmental degradation resulting from the proposed action. It is not clear if the groundwater well alternative will further contaminate the AWC, drain lagoonal layers, and affect nearby structures. In addition, impacts associated with the pipeline alternative, including dredging and spoil disposal, coastal impacts at the Ala Wai Boat Harbor, traffic, and noise, may be significant.

Section 11-200-12b
"8) Is individually limited but cumulatively has considerable effect upon the environment or involves a commitment for larger actions;"

The very nature of the proposed project is to create a cleaner environment in the AWC and in the adjacent areas. The draft EA states, "The project will have a considerable effect on the environment of the Ala Wai Canal. Although the proposed projects to improve water quality in themselves do not result in a commitment to larger actions, it is expected that there will be a strong public demand for additional clean-up and continued maintenance measures to preserve water quality, once attained." Therefore, we suggest that the proposed project invokes this criterion.

Section 11-200-12b
"10) Detrimentally affects air or water quality or ambient noise levels;"

There is insufficient information in the draft EA to make a determination of significance under this criterion. Of primary concern is the information concerning pipeline dredging and water quality.

Section 11-200-12b
"11) Affects an environmentally sensitive area such as a flood plain, tsunami zone, erosion-prone area, geologically hazardous land, estuary, fresh water, or coastal waters."

The Ala Wai Canal meets the definition of an environmentally sensitive area and thus invokes the criterion for significance under this trigger.

Summary

While we applaud the Department of Land and Natural Resources' proposals to improve the water quality of the AWC and the surrounding area, we strongly recommend that an environmental impact statement be prepared for the proposed action. Clearly, the scope of the proposed action will have major long-term effects on the area and the State in general. The draft EA includes some excellent data and is formatted quite well, but in order to make sound decisions concerning the proposed project and the future of the AWC and the State in general, a more comprehensive compilation of data and a wider public review process such as would be attendant on preparation and consideration of an EIS is required.

Thank you for the opportunity to comment on this draft EA. We hope our comments are useful in the preparation of an environmental impact statement and please feel free to contact us at the Environmental Center if you have additional questions.

Sincerely,

John Harrison, PhD
Environmental Coordinator

cc: OEQC
Roger Fujioka
Edward Noda & Associates, Inc.
KRP Information Services
Elizabeth Gordon
Andrew Tomlinson
Ala Wai Cleanup Technical Group

JOHN WAIHEE
GOVERNOR OF HAWAII

STATE OF HAWAII
DEPARTMENT OF LAND AND NATURAL RESOURCES
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APR 14 1993

Dr. John Harrison, Director
Environmental Center
317 Crawford Hall
2550 Campus Rd
Honolulu, Hawaii 96822

Dear Dr. Harrison:

Draft Environmental Assessment
For The Ala Wai Canal Improvement, Honolulu, Oahu, Hawaii

Thank you for your letter of December 23, 1992 regarding the subject project. Our response to your comments follows:

General Comments

See comments under Significance Criteria below.

Modeling and Data

This model utilized for this project, like all models, has limitations. However, as you note, refinement of the model may be unnecessary for the present purpose. We do not think that the proposed action would be affected by additional research necessary to answer the questions you have posed.

Deep Groundwater Well Alternative

We share your concerns that a deep groundwater well system to provide saline water for flushing of the Ala Wai Canal could have adverse effects. The water pumped may not be of sufficient quality to be useable. This is why a prototype production well drilling and testing program will be undertaken to confirm the expected subsurface geologic strata, test the water for quality and toxicity, and demonstrate that such high capacity pumping can be accomplished without adverse effect on existing wells and buildings in the surrounding area.

Once a prototype well has been drilled, full scale pumping tests will be conducted. Placement of sounding tubes to various depths in the annular space will enable the effects of pumping on overlying layers to be measured, thereby demonstrating whether pumping can occur without de-watering the overlying surficial lagoonal deposits.

In addition to the drilling and testing of the prototype production well, four smaller diameter boreholes will also be drilled to depths of about 250 feet in order to confirm the subsurface geologic strata of the entire proposed groundwater source area at the Ala Wai Golf Course. Should any of the test results and evaluations indicate that this concept is not feasible, the alternate submerged pipeline system in the Ala Wai Canal will be considered.

It would not be logical or even possible to postpone an environmental assessment until after information was obtained from a prototype well because drilling the test well itself requires an environmental assessment. Also, no money has been appropriated for the prototype well testing program, estimated to cost $300,000. The agency believes that dissemination of the feasibility study and draft EA has enhanced the prospects of obtaining funds to proceed with the project. We disagree that environmental assessments should be delayed until all possible information on a project has been collected. One of the benefits of circulating environmental documents for review and comment is to obtain important information, especially "local knowledge" on the environmental setting, potential impacts, and public acceptance of the proposed project.

Pipeline Alternative

Dredging and disposal of dredge spoils is discussed on pages 3-9, 3-10, 3-14 and 3-15. Note that dredging of the Kapahulu end of the canal is recommended to be done as part of the next maintenance dredging project. Major dredging for the pipeline would also be done as part of maintenance dredging. This action will require a separate environmental assessment.

Existing Conditions (general)

The action proposed and assessed is very limited. It is to improve water clarity by improving water flow and circulation. While we agree that it might be interesting to have an in-depth description of present recreational uses of the canal and to know exactly how many people use the canal, we do not agree that this information is necessary to assess the impact of improving water clarity. We did contact every known recreational user group as well as the nearby Neighborhood Boards and various other Waikiki organizations to ask for their comments and invite them to the public meeting on the project. No written comments or objections of any kind have been received.

The City Department of Parks and Recreation has been consulted. They are principally concerned with the potentially adverse effects on their existing wells and subsidence. Golfers will be inconvenienced during construction and the cart path on the 18th fairway may have to be moved a few feet. This should not interfere with play. If there is a problem, one or two wells could be shifted to the parking lot.

Every construction project, no matter how small, results in some impact to traffic and creates some noise. Noise impacts are described in the EA. The project has been designed to cause the least inconvenience possible. Energy usage was calculated and is not sufficient to strain existing utilities. We feel that these impacts have been adequately discussed.

Economic and Social Impacts

As noted above, the action proposed and assessed is very limited. It will improve water clarity by improving water flow and circulation. It will not do anything to address nonpoint source pollution or the debris entering the canal. The canal will continue to be muddy after rainstorms. It is hard to believe that this modest improvement to water quality will have such far-reaching effects as attracting new business establishments to Waikiki.

If the improvements are made before the canal is dredged, there may be a very adverse public reaction when water clarity is improved and the detritus at the bottom of the canal becomes visible.

To use a mathematical analogy, the proposed project is necessary but not sufficient. A number of other steps are required before there would be any quantifiable economic and/or social impact on Waikiki. Even if a special study were undertaken, it would be purely speculative. The only certainty is that on a physical level, the proposed action generally supports and does not conflict with the Waikiki Master Plan. The proposed improvements will not conflict with the Plans recommended boat turning basin or pedestrian bridge. The pumps can be hidden by landscaping.

Significance Criteria

We note that under your General Comments at the beginning of your letter and again under Significance Criteria that the Environmental Center believes that an environmental impact statement should be prepared. The question of whether to prepare an EIS was discussed by the members of the Ala Wai Cleanup Technical Committee. The consultants stated that, in their professional opinion, the adverse environmental impacts of the project appeared to be so negligible that preparing an EIS would be a waste of time and money. It was the consensus of the group that the change in the law that allows for the review of a draft environmental assessment before making a decision to make a negative declaration or proceed with a full EIS was an excellent method to find out whether others agreed with the consultants' conclusions. The major concern expressed at the meeting where this was discussed was in relation to public reaction. Some committee members were concerned that certain environmental groups would object strongly and oppose the project. For this reason, the consultants made a point of contacting as many groups and individuals as possible and sending them copies of the DEA for review and comment. They were also invited to a public meeting at the Ala Wai Golf Course Clubhouse on December 7, 1992.

The meeting was well attended and provided an opportunity for many residents to understand the project and have their questions answered. It apparently was successful because only four letters have been received, from the City Departments of General Planning and Parks and Recreation, the Environmental Center and a private citizen. We have received no communications from any environmental groups, much less any challenging the proposed issuance of a negative declaration.

We respect your opinion on this matter but we have to disagree. It is the responsibility of the agency to make the determination of significant impact. We believe this project to be important but we do not believe it has significant environmental impacts within the intent of the law and regulations. We believe that the funds that would be spent on an EIS can be put to better use in furthering the implementation of the project.

If you have any questions, please feel free to contact Mr. Edward Lau of the Project Development Branch at 587-0227.

Sincerely,

MANABU TAGOMORI
Manager-Chief Engineer

c: Edward K. Noda & Associates, Inc.
KRP Information Services

1638-A Mikahala Way
Honolulu, HI 96816

November 25, 1992

Edward Lau
DLNR, DOWALD
P.O. Box 373
Honolulu, HI 96809

Dear Edward Lau,

I'm writing to request that you ensure that the proposal to flush the Ala Wai Canal fully discusses its environmental impacts. While we all look forward to the day that the Ala Wai is clean, I hope that its cleanliness does not come at others' expense.

Would you ensure that the environmental study considers whether the flushing will cause fewer heavy metals, pesticides etc. to settle out in the Ala Wai. If so, these substances will be transported to the near shore waters of Waikiki. What impact will these substances have on marine life in Waikiki, surfers' health and near shore users? While the flushing may reduce the Ala Wai's nutrient problems, I'm afraid it could increase the amount of toxics in our coastal waters. Jeff Fox and Will Freeman's proposals to reduce such toxics in the watershed are an essential component to cleaning up the Ala Wai. Simply flushing toxics out of the Ala Wai and into our ocean is no solution.

Also, I hope that the true impact of using brackish water has been thoroughly studied. These deep wells will undoubtedly have an affect on our aquifer even though they will only be pumping brackish water. Alternatively, if water is pumped from Magic Island, how much electricity will be required? What is the equivalent in terms of barrels of oil?

Sincerely,

David Kimo Frankel

JOHN WAIHEE
GOVERNOR OF HAWAII

STATE OF HAWAII
DEPARTMENT OF LAND AND NATURAL RESOURCES
DIVISION OF WATER AND LAND DEVELOPMENT
P. O. BOX 373
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APR 14 1993

Mr. David Kimo Frankel
1638-A Mikahala Way
Honolulu, Hawaii 96816

Dear Mr. Frankel:

Draft Environmental Assessment
for Ala Wai Canal Improvement, Honolulu, Oahu, Hawaii

Thank you for your letter of November 25, 1992 regarding the subject project. Our response to your comments follows:

Flushing Effects

Although the Ala Wai Canal clean-up project covers three separate studies – one for maintenance, one for control of nonpoint sources of pollution, and one for improving the flushing of the canal – the environmental assessment only adresses improvements to be made to water clarity by improving water flow and circulation. This will be accomplished by adding a relatively small flow of water to the canal, approximately 20 to 30 cubic feet per second. In relationship to the large volume of water in the canal the proposed flushing flow will produce an imperceptible velocity increase. Also, the flushing flow will have no effect on the transport of pesticides, heavy metals or any other nonpoint sources of pollution entering the canal.

The flushing will not do anything to reduce nutrients, either. What it will do is to prevent the growth and proliferation of the phytoplankton feeding on the nutrients due to reduced residence times. This will improve clarity.

Deep Groundwater Well Alternative

There are a number of uncertainties associated with a deep groundwater well system as a source of saline water for flushing of the Ala Wai Canal. This is why a prototype production well drilling and testing program is proposed. The prototype test well would be drilled to confirm the expected subsurface geologic strata, test the water for quality and toxicity, and demonstrate that such high capacity pumping can be accomplished without adverse effect on existing wells and buildings in the surrounding area. Should any of the test results and evaluations indicate that this concept is not feasible, the alternate submerged pipeline system in the Ala Wai Canal will be considered.

Energy Usage

The amount of electricity needed to operate the pump for the pipeline system was calculated in preparing the cost estimates. For 20 cfs (9000 gpm), 36 kW is required, or 864 kWh of electricity per day. 30 cfs would require an additional 50 percent or 54 kW (1296 kWh per day). Based on HECO's average heat rate, roughly 1.5 barrels of oil would be used to generate the electricity needed to pump 20 cfs of water 24 hours per day.

If you have any questions, please feel free to contact Mr. Edward Lau of the Project Development Branch at 587-0227.

Sincerely,

MANABU TAGOMORI
Manager-Chief Engineer

c: Edward K. Noda & Associates, Inc.
KRP Information Services

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Job No. 31-OL-I

ALA WAI CANAL IMPROVEMENT

Honolulu, Oahu, Hawaii

FEASIBILITY REPORT

Report R-89b

Prepared by:

Edward K. Noda and Associates, Inc.
615 Piikoi Street, Suite 1000
Honolulu, Hawaii 96814

State of Hawaii
DEPARTMENT OF LAND AND NATURAL RESOURCES
Division of Water and Land Development
Honolulu, Hawaii

OCTOBER 1992

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Governor

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ALA WAI CANAL IMPROVEMENT
FEASIBILITY REPORT

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EXECUTIVE SUMMARY

The Ala Wai Canal (AWC), a 2-mile long man-made waterway constructed between 1921 and 1928, is the major drainage system for the Waikiki District of Honolulu, and also conveys surface runoff from the watersheds directly mauka of the AWC, including the areas of Makiki, Manoa, St. Louis Heights, Palolo, Moiliili, Kapahulu, and parts of Kaimuki and Diamond Head.

Besides providing an important drainage conduit for surface water runoff, the Ala Wai Canal was designed to serve as a sediment deposition basin in order to minimize the discharge of sediments into the nearshore coastal waters through the Ala Wai Boat Harbor entrance channel. In many respects, the AWC has performed it's functions very well. Since the AWC is a dredged collection system, it also collects nutrients from surface runoff waters and from other non-point sources such as groundwater. The murky green discoloration of the canal waters result from excessive phytoplankton growth, due to significant incident sunlight, and long residence times within the canal system. During and immediately after periods of heavy rain, the AWC waters display a distinct brown discoloration due to the suspended sediments which are entrained in the surface runoff, and possible re-suspended bottom sediments.

The State of Hawaii desires to improve the water quality in the Ala Wai Canal (AWC) to standards acceptable for water-based recreational activities. The Ala Wai Canal is used for a number of recreational purposes including canoeing, kayaking, fishing and some motor boating. In order to meet this goal, the following are the specific objectives of the present study:

- o Increase water flow and circulation in the canals while addressing environmental concerns.
- o Decrease sources of pollutants through improved watershed management.
- o Establish routine maintenance and management practices for the canal.

The herein described Feasibility Report responds to the first objective listed above. A separate report entitled "Management Plan for the Ala Wai Canal Watershed" prepared by Jefferson Fox and William Freemen, East-West Center, Environment and Policy Institute, dated October 1992, responds to the second objective. The third objective is addressed in another separate report entitled "Maintenance Plan for the Ala Wai Canal," developed by Edward K. Noda and Associates, Inc., dated October 1992.

The present Feasibility Study is primarily focused on the physical, biological and water quality conditions in the Ala Wai Canal. The initial task efforts of this study involved extensive field measurement programs including a bathymetry survey, current measurements within the Canal and in the nearshore coastal areas, a dye flushing test, tidal measurements, and biological and water quality surveys.

A bathymetry survey was performed to accurately map the existing bottom depths within the entire AWC in order to provide input data to a numerical hydrodynamic and water quality model of the Canal. When the present bathymetry data is compared to the last 1978 dredging design, the rate of sediment deposition in the Ala Wai Canal is calculated to be 10,300 yd^3/year. This sedimentation rate generally agrees with previous calculations and indicates a relatively consistent rate over the last 25 years.

High resolution tide measurements at the entrance channel to the Ala Wai Boat Harbor and at the Kapahulu end of the Canal were obtained for a one-month period. For comparison purposes, the actual tide measurements obtained by the National Oceanic and Atmospheric Administration (NOAA) at the Honolulu Harbor tide reference station were also acquired for the one-month measurement period. All three tide data sets, when superimposed, show very little amplitude and phase differences. Computer analysis of the tidal time-histories between the entrance and end of the AWC indicates that about a 73 second time delay exists. Analytical analysis confirms that a standing tide-wave system exists, and that the small time delay is due to friction. This result was then used to calibrate the hydrodynamic model by adjusting the bottom friction factor to obtain the required time delay.

Extensive current meter and current drogue measurements were obtained both within the Canal and in the nearshore coastal waters adjacent to the Ala Wai Boat Harbor entrance channel. In the nearshore waters, the velocity of the water column below the surface layer is strongly influenced by tidal forces, with the current flow generally oriented parallel to the depth contours. In nearshore waters in close proximity to the entrance channel, the surface layer during significant rainfall events is strongly affected by discharges from the Ala Wai Canal, where the outflowing water continues seaward until the plume momentum dissipates, whereby tidal forces again dominate.

Within the Ala Wai Canal, the current measurements display very complicated variations with water depth, wind conditions, tidal phase and rainfall-runoff discharges. In

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particular, a two-layer and at times multi-layer circulation flow regimes exist within the Canal, primarily associated with distinct salinity variations between the surface layer (brackish water) and the underlying layers (seawater). With significant rainfall-runoff discharges into the Canal, the surface layer will flow towards the ocean regardless of the tidal phase. With strong tradewind conditions, the surface layer will also tend to flow towards the ocean regardless of tidal phase. The lower layers of the Canal waters are more strongly influenced by the tide, usually distinguished by inflow into the Canal during flood tide and outflow during the ebb tide. For very large rainfall-runoff events, the discharge into the Canal overcomes the tidal forces and the entire water column flows seaward independent of tidal phase. This very complicated, vertical flow variation characteristic of the AWC required that a two-dimensional (2-D) hydrodynamic and water quality model of the Canal be developed, which would be laterally averaged but would describe variation along the canal axis and in the vertical dimension between the surface and the bottom.

A detailed dye flushing test was carried out involving the injection of Rhodamine WT dye into the entire Ala Wai Canal. Water samples were obtained daily for about 2 weeks, at 4 stations and at 4 depths in the water column (surface, 1/2 meter below the surface, mid-depth, and 1/2 meter off the bottom). The dye concentration data allowed a direct determination of the dye flushing time constant which is represented by the time it takes for the dye concentration to fall to 50% of its initial value, T_{50}. Surprisingly consistent T_{50} time constants of the order of 40 to 60 hours were obtained for all 4 stations and the 4 different depth levels. These T_{50} flushing time constants were used in the calibration process for the 2-D hydrodynamic and water quality model. Conductivity-temperature-depth (CTD) profiles were also obtained during the dye flushing survey.

Six monthly biological and water quality surveys were performed for the Ala Wai Canal Improvement Project. Water quality samples were collected at sixteen stations within and offshore the Ala Wai Canal, and in the major streams discharging into the Canal. Samples were collected at three depths at most stations within the Canal and nearshore marine waters: 1/2 meter below the surface, 1/2 meter above the bottom, and at mid-depth. Water quality parameters measured included those listed in the State of Hawaii water quality standards for open coastal and estuarine waters, plus additional parameters which provide information on ground water sources and influence: temperature, salinity, total nitrogen, nitrate-nitrite, ammonium, total phosphorus, orthophosphate, reactive silicate, turbidity, suspended solids, particulate carbon and nitrogen, chlorophyll, dissolved oxygen, Ph, fecal coliform and enterococci.

Water quality in the Ala Wai Canal is determined by its source waters (nearshore ocean water, groundwater, streams), mixing and tidal exchange, and input from the accumulated sediment via resuspension and regeneration. "New" nutrients (not recycled *in situ*) are derived from groundwater and the streams. The data acquired from the water quality surveys were extensively used in the calibration and verification of the 2-D hydrodynamic and water quality model.

One of the most important water quality criteria and which was used to evaluate the performance of alternative water quality improvement designs for the Canal, was water clarity. For the worst case situation when very little rainfall-runoff flows into AWC, the combination of high nutrients, strong and consistent sunlight, and long water residence times, promotes active phytoplankton growth which results in high chlorophyll concentrations and organic turbidity, producing poor water clarity. Thus, the key parameter to increasing water clarity is to reduce the chlorophyll concentrations in the water column. Based on water clarity analysis, a target chlorophyll concentration of 5 μg/l was selected, with a maximum concentration of 10 μg/l imposed as a not-to-exceed criteria for selection of the proposed design flushing alternatives.

The selected hydrodynamic and water quality model selected for this project was the two-dimensional, laterally averaged CE-QUAL-W2 model developed by the U.S. Army Corps of Engineers. Besides the hydrodynamic parameters of flow velocity and water surface elevation, the CE-QUAL-W2 model also simulates 20 water quality parameters and water temperature. A hydrodynamic verification process was first used to confirm the proper performance of the 2-D model. In this verification phase, current, dye concentrations, salinity concentrations, and water temperature outputs from the 2-D model were compared to field measurements, and excellent comparisons were obtained. The next phase involved an extensive water quality calibration process where phytoplankton chlorophyll concentrations, nutrients, and dissolved oxygen concentrations from the 2-D model results were compared with the field measured data. After extensive runs, a reliable set of rate process coefficients, and input flows and constituent concentrations were developed which produced good correlation between the 2-D model-predicted and field-measured data.

Once the 2-D model verification and calibration processes were completed, the model was used to evaluate design options to improve the water quality in the AWC. The design options included injecting either flushing seawater or groundwater into the Kapahulu end of the Canal; connecting the Kapahulu end of the Canal to Waikiki Beach using a covered channel; and various dredging options to improve circulation in the existing Canal. The criteria for evaluating the technical feasibility of any of the tested design options, was whether the chlorophyll concentrations were about 5 μg/l with a maximum value of 10 μg/l. For any potentially feasible option, simulations were also run which included variation in wind speed and direction (tradewind and Kona wind), and tidal range variations.

Based on the results from the extensive computer model runs, the only options which proved to be technically feasible to warrant further feasibility analysis and conceptual design evaluations were the following:

1. Injection of 20 to 30 ft^3/sec (cfs) seawater into the Kapahulu end of the Ala Wai Canal. For this option, two design concepts are proposed:

   - A 12,500 foot long, 42 inch diameter submerged pipeline laid and partially buried in the Ala Wai Canal, with an intake structure located in the entrance channel to the Ala Wai Boat Harbor at a water depth of about 40 feet below the surface; a 4,000 foot long, 40 inch diameter suction pipeline; a submerged pump station located adjacent to Magic Island, and a discharge manifold located across the Canal at the Kapahulu end.

   - A 7,000 foot long, 40 to 42 inch diameter "non-trenched" underground pipeline constructed using directionally controlled drilling technology, extending from a pump station located at the Kapahulu end of the Canal, to an intake location offshore of Waikiki Beach in a water depth of about 40 feet. A discharge manifold would distribute seawater across the Canal.

2. Injection of 20 to 30 cfs of groundwater from 5 deep wells drilled to depths of 250 feet or greater, located at the Ala Wai Golf Course, with the water discharged through a discharge manifold located across the Canal. The deep groundwater wells must produce salinity and nutrient concentrations similar to coastal seawater.

For the three alternative concepts described above, conceptual designs, and construction and annual operating and maintenance (O&M) cost estimates were developed. The submerged pipeline laid in the AWC and the deep groundwater well supply options proved to be technically feasible. The directionally drilled pipeline construction option was considered to be beyond the present state-of-the-art, with significant risks associated with this methodology. Moreover, the construction cost estimate for the directionally drilled pipeline option was over $28 million, which is considerably larger than the other two feasible options.

The construction cost estimate for the submerged pipeline laid in the Ala Wai Canal is about $8.5 million with an annual O&M cost of about $72,000. The construction cost estimate for the deep groundwater well supply system is about $3.3 million with an annual O&M cost of about $190,000.

Based on the limited available historic geologic strata data, the technical feasibility of drawing the required 20 to 30 cfs of deep groundwater appears promising. Since the construction cost of this option is significantly less than the submerged pipeline concept, it is recommended that the deep groundwater well supply system be selected for further feasibility evaluations. To proceed with this concept evaluation, a prototype production well drilling and testing program is proposed in order to: (1) confirm the expected subsurface geologic strata in the Ala Wai Course area; (2) test and confirm the groundwater source water quality and potential toxicity; (3) estimate the potential groundwater flow yield from coral layers at depth; (4) demonstrate that such high capacity pumping can be accomplished without adverse effects; (5) and to develop other design parameters. Besides the single prototype well, 4 additional smaller diameter wells will be drilled too confirm the subsurface geologic strata. The estimated cost for this well test program is approximately $300,000.

If the prototype production well test program confirms the technical and environmental feasibility of the deep groundwater well supply concept, it is recommended that an update and revision of the present conceptual design and construction cost estimate for the saltwater well supply system be performed. This new construction cost estimate would then be evaluated for implementation.

If the prototype production well test program indicates that the deep groundwater well supply concept is not feasible, then it is recommended that the submerged pipeline system laid in the Ala Wai Canal be considered for implementation.

The environmental impacts associated with both the deep groundwater well supply system and the submerged pipeline laid in the AWC have been evaluated. The assessments indicate that while there would be some temporary impacts (noise, visual, odor, turbidity) during construction, the overall environmental impacts after the completion of construction are very minimal, and in fact, there would be a measurable water clarity and quality improvement to the Ala Wai Canal waters.

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LIST OF FIGURES

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CHAPTER 1.0

INTRODUCTION AND OBJECTIVES

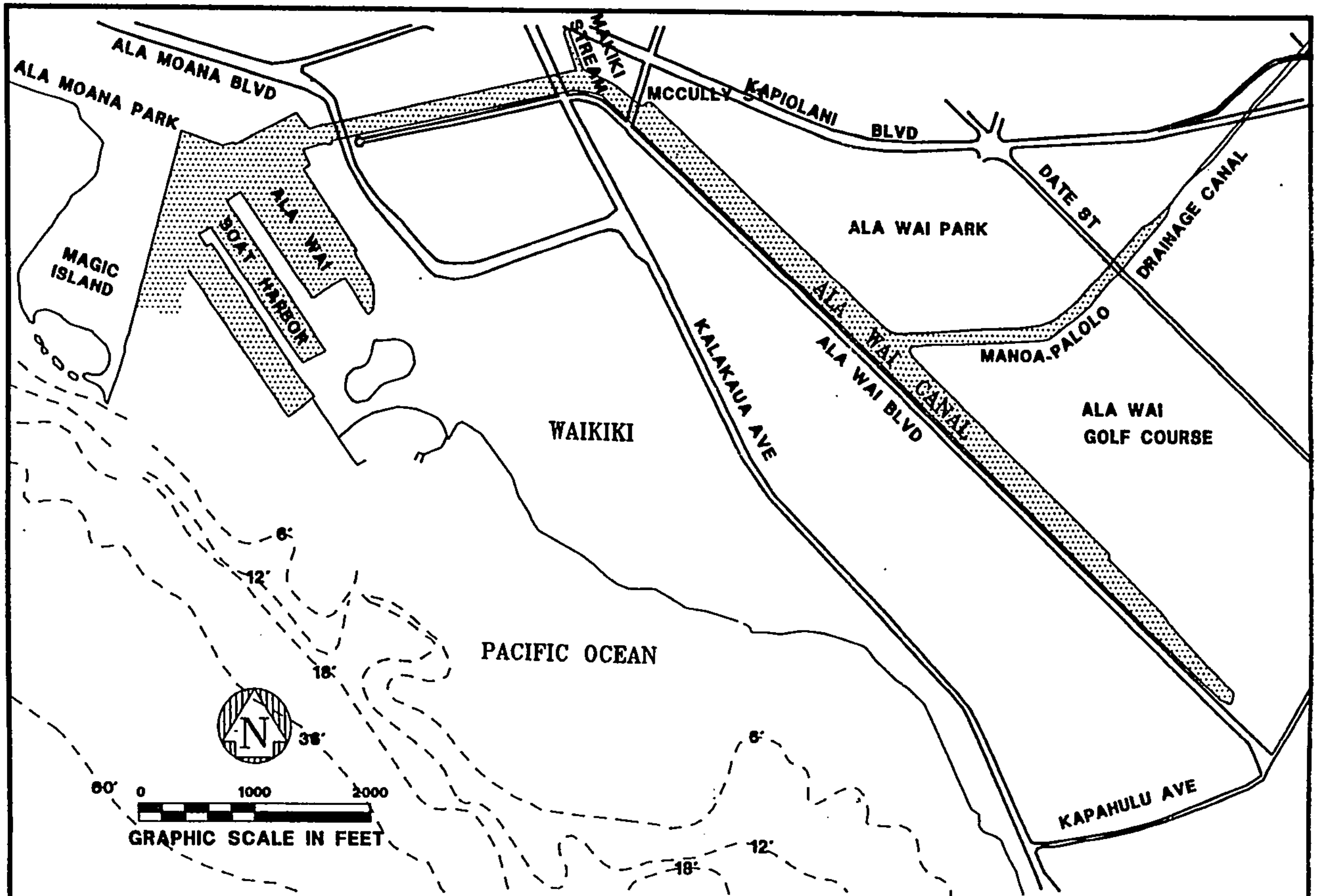
CHAPTER 1.0
INTRODUCTION AND OBJECTIVES

The Ala Wai Canal shown in Figure 1-1, constructed between 1921 and 1928, is a 2-mile long man-made waterway with widths ranging from 200 to 250 feet and average cross-sectional depths ranging from 3 to 8 feet, with spot depths ranging from 1 to 12 feet. The Ala Wai Canal (AWC) is the major drainage system for the Waikiki District of Honolulu, and also conveys surface runoff from the watersheds directly mauka of the AWC, including the areas of Makiki, Manoa, St. Louis Heights, Palolo, Moiliili, Kapahulu, and parts of Kaimuki and Diamond Head.

Besides providing an important drainage conduit for surface water runoff, the Ala Wai Canal was designed to serve as a sediment deposition basin in order to minimize the discharge of sediments into the nearshore coastal waters through the Ala Wai Boat Harbor entrance channel. In many respects, the AWC has performed its functions very well. Since the AWC is a collection system, besides satisfying its drainage functions, it also collects nutrients, suspended and dissolved in the surface runoff waters and from other non-point sources such as groundwater. While the waters within the AWC are ultimately discharged to the ocean receiving waters, high nutrient concentrations, significant incident sunlight, and long residence times within the canal system produce excessive phytoplankton growth, which is reflected in a murky green discoloration of the canal waters. During and immediately after periods of heavy rain, the AWC waters display a distinct brown discoloration due to the suspended sediments which are entrained in the in-coming surface runoff and possible re-suspension of bottom deposited sediments.

Besides its primary drainage functions, the State of Hawaii desires to improve the water quality in the Ala Wai Canal (AWC) to standards acceptable for water-based recreational activities. The Ala Wai Canal is used for a number of recreational purposes including canoeing, kayaking, fishing and some motor boating. In order to meet this goal, the following are the specific objectives of the present study:

- Increase water flow and circulation in the canals while addressing environmental concerns.
- Decrease sources of pollutants through improved watershed management.
- Establish routine maintenance and management practices for the canal.



ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	ALA WAI CANAL SYSTEM	FIGURE 1-1

The herein described Feasibility Report responds primarily to the first objective listed above. The results associated with the second objectives are provided in a separate report entitled "Watershed Management Plan" developed by the East-West Center, Environment and Policy Institute (Fox et al., 1992). The third objective results are provided in another separate report entitled "Maintenance Plan For The Ala Wai Canal", developed by Edward K. Noda and Associates, Inc. (1992).

The present Feasibility Study is primarily focused on the physical, biological and water quality conditions in the Ala Wai Canal. Chapters 2.0 and 3.0 of the report describe an extensive field measurement program to obtain detailed information on the existing conditions within the Canal itself, as well as oceanographic data in the coastal waters surrounding the entrance channel to the Ala Wai Boat Harbor. In parallel with the field data acquisition program, a hydrodynamic and water quality computer model evaluation and development program was carried out. This task effort initially focused on a one-dimensional (1-D) hydrodynamic and water quality model, but after an evaluation of the field measurements, which describe complex vertical variations in flow speed and directions as well as the other important mixing and water quality parameter variations, a two-dimensional (2-D) laterally averaged hydrodynamic and water quality model designated as CE-QUAL-W2 was selected.

Chapter 4.0 describes the CE-QUAL-W2 model characteristics and the verification and calibration processes using the field measured data to insure that the 2-D model reasonably represented the proper dynamic conditions of the waters in the Ala Wai Canal. Following the calibration process, the 2-D model was used to evaluate physical options which have been proposed to improve the water quality in the Canal.

Chapter 5.0 describes conceptual engineering designs for those options that would provide satisfactory water quality conditions in the Ala Wai Canal based on the results from the 2-D model (Chapter 4.0). Cost estimates for the various conceptual design options including operating and maintenance costs are also provided.

Chapter 6.0 describes the environmental impacts associated with the various conceptual engineering designs proposed in Chapter 5.0.

CHAPTER 2.0

PHYSICAL OCEANOGRAPHIC ENVIRONMENT

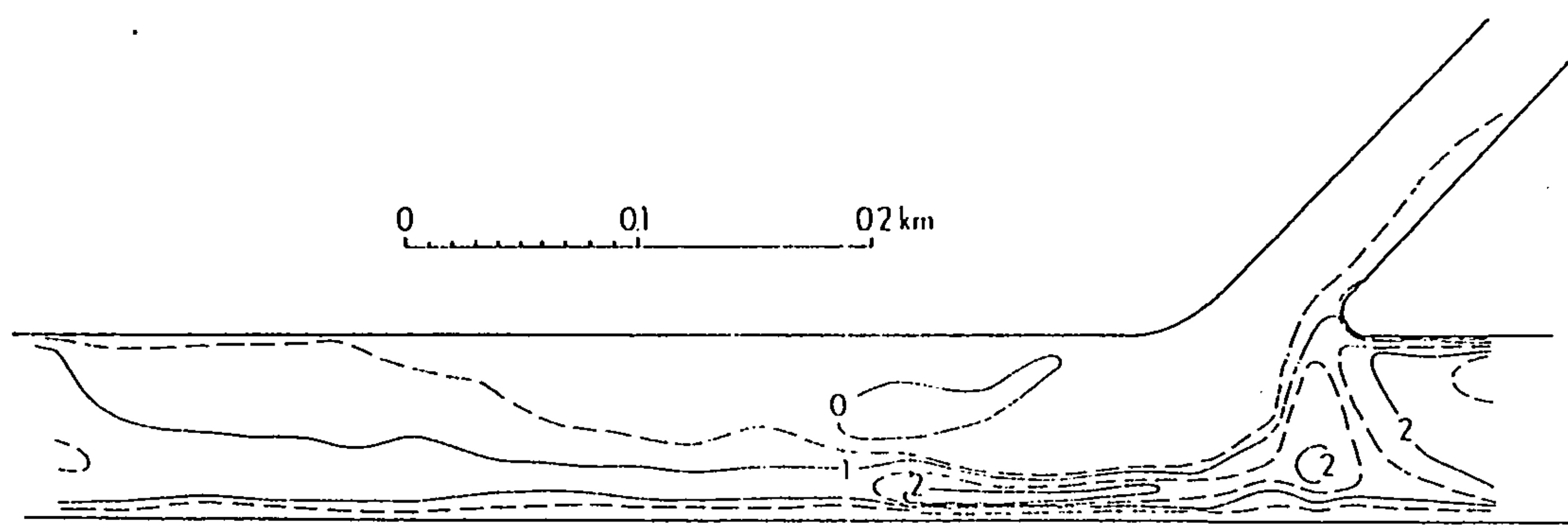
CHAPTER 2.0
PHYSICAL OCEANOGRAPHIC ENVIRONMENT

2.1. BATHYMETRY

The Ala Wai Canal was originally dredged in sections. A seaward section extending from the Ala Moana Bridge seaward about 500 feet was dredged to a depth of about 25 feet. The section from the Ala Moana Bridge to the 45° bend at the Makiki Stream confluence was dredged to depths between 10 to 13 feet, while the landward section between the Makiki Stream and the Kapahulu end of the channel was dredged to depths between 10 to 20 feet. Since the completion of construction in 1928, sediment deposition has significantly altered bathymetry in most of the channel sections. The Ala Wai Canal has been dredged twice since its construction, the initial dredging in 1966 and the second dredging in 1978.

In May 1965 the City & County of Honolulu carried out a bathymetry survey of a portion of the AWC, in preparation for the first maintenance dredging of the canal. Gonzalez (1971) utilized this data to construct a bathymetry map of the surveyed section between the McCully Bridge and the confluence of the Manoa-Palolo Stream which is shown in Figure 2-1. Sunn, Low, Tom & Hara, Inc. (SLTH) in 1977 developed a Preliminary Engineering Report for the second maintenance dredging of the AWC, which include a bathymetry survey of the canal. While the data is not provided in the form of a bathymetry map, the cross-section drawings of the existing canal bottom shows very similar patterns to the results shown in Figure 2-1.

The results shown in the 1965 and 1977 bathymetry surveys indicate that most sections of the AWC exhibit a relatively slow bottom sediment deposition rate. The area of the AWC which is most affected by sediment deposition is between the McCully Bridge and the Manoa-Palolo Stream confluence. The Manoa-Palolo Stream drains the Manoa and Palolo watersheds, which represents an area of about 7,200 acres and is the largest watershed area which drains into the AWC. Moreover, the Manoa-Palolo watersheds include part of the Honolulu Watershed Forest Reserve area, which is an area of steeply sloped, undeveloped forests which generate significant sediment loads during typical and major rainfall runoff events. The sediment laden flow enters the AWC at a 45° angle towards the ocean and flows seaward. Since the width and average depth of the AWC is significantly larger than the Manoa-Palolo Stream counterparts, continuity requirements dictate that there must be a substantial decrease in the mean velocity of the entering flow. This velocity reduction allows much of the larger size suspended sediment to fall out of the fluid and to deposit on the seaward side of the stream confluence forming a



DEPTH CONTOURS IN METERS, MLLW

ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	BATHYMETRY OF A SECTION OF THE ALA WAI CANAL, MAY 1965, FROM GONZALEZ (1971).	FIGURE 2-1

64

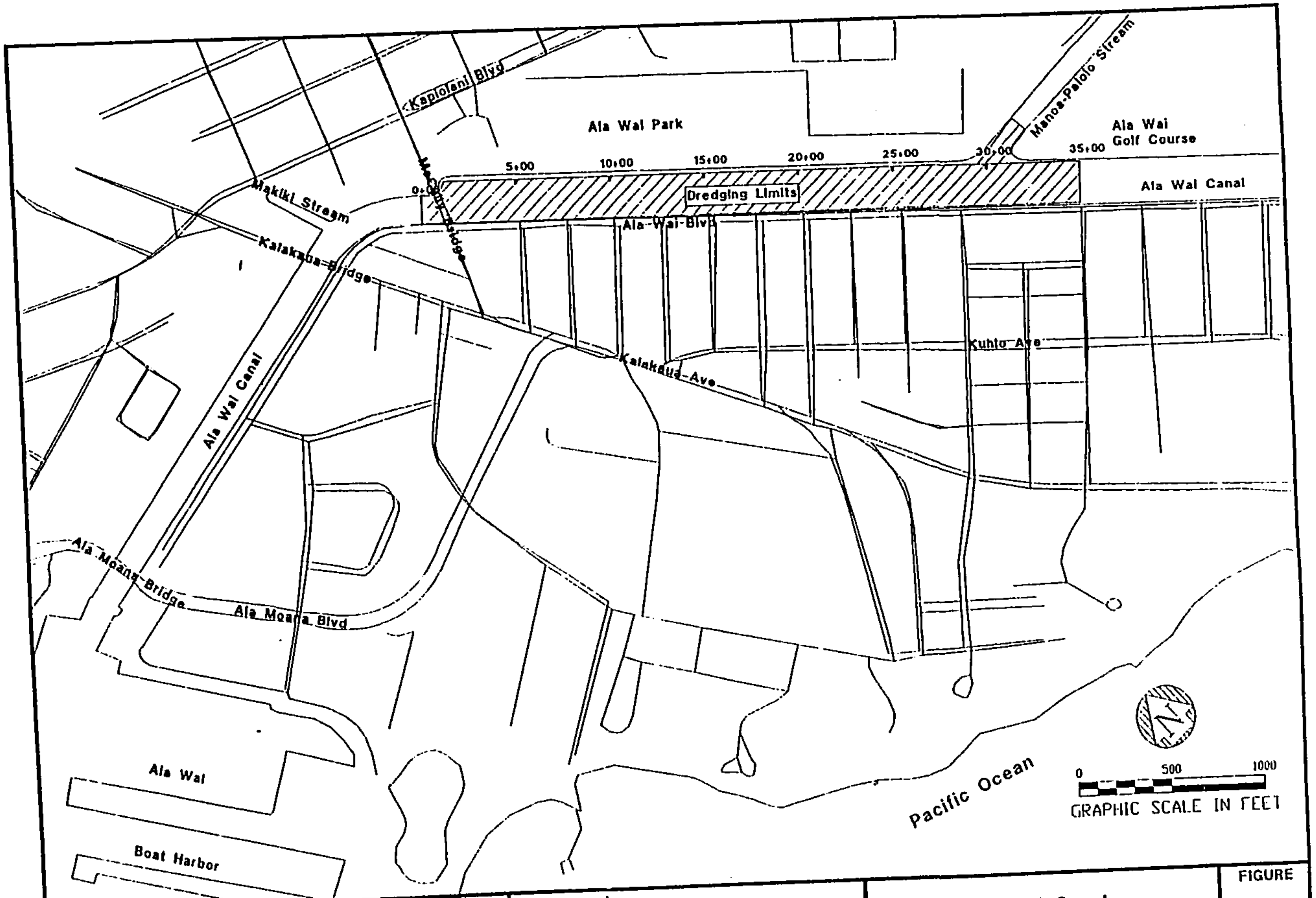
"sill". In both the 1966 and 1978 maintenance dredging programs, this sill area was the only section of the AWC that was dredged.

The 1966 maintenance dredging operations encompassed, a 1,750 feet section of the AWC, starting from the Kapahulu side of the Manoa-Palolo Stream confluence and extending 1,750 feet towards the ocean entrance. In addition, the Manoa-Palolo Stream was dredged to a distance of 500 feet upstream from the AWC confluence. The required dredge depth was -6 feet mean sea level (MSL). Based on the design requirements for the 1966 dredging operations, and comparing with bathymetry data obtained 40 months after the completion of dredging in mid-1966, Gonzalez (1971) estimated that the rate of sediment deposition in the AWC was 8,240 yd^3/year and 940 yd^3/year in the Manoa-Palolo Stream for a total sedimentation rate of about 9,180 yd^3/year (7,000 m^3/year). Gonzalez also calculated average silting rates of 0.65 feet/year (20 cm/year) and 0.39 feet/year (12 cm/year) for the sill and Manoa-Palolo Stream areas respectively. The silting rate in the sill area varied as a function of distance from the Manoa-Palolo Stream confluence, reaching a maximum rate of 0.92 feet/year (28 cm/year) about 600 feet seaward to less than 0.33 feet/year (10 cm/year) about 1,200 feet seaward from the confluence.

During the 1978 maintenance dredging program, a 3,500 feet section of the AWC was dredged to a depth of -10 feet mean sea level (MSL), beginning about 100 feet seaward of the McCully Bridge and extending up the canal to a location about 400 feet past the Manoa-Palolo Stream confluence as shown in Figure 2-2. To provide a smooth transition with the Manoa-Palolo Stream, the invert depth was varied from - 10 feet MSL at the confluence, to daylight at the existing stream bottom depth at about 200 feet upstream from the confluence. The initial plans provided an option to dredge the last 400 feet of the AWC at the Kapahulu end to a depth of -5 feet MSL. Due to budget limitations, this option was not exercised.

During the summer of 1991, studies of trophic conditions in the Ala Wai Canal were carried out by Laws et al. (1992). As part of this project, a bathymetry survey was performed. Assuming that the 1978 maintenance dredging was performed to -10 feet MLLW (3 meters) between the McCully Bridge and the Manoa-Palolo confluence, the sedimentation rate was calculated to be about 10,500 yd^3/year (8,000 m^3/year).

In order to accurately define the existing bathymetry features of the Ala Wai Canal for the present project, a hydrographic survey of the bottom depths in the canal was performed. The survey extended from the Ala Moana Bridge to the Kapahulu end of the AWC. To efficiently perform this survey, an automated bathymetry survey system was



ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	Ala Wai Canal 1978 Dredging Plan	FIGURE 2-2

utilized as shown in Figure 2-3. The bathymetry survey system consisted of the following components:

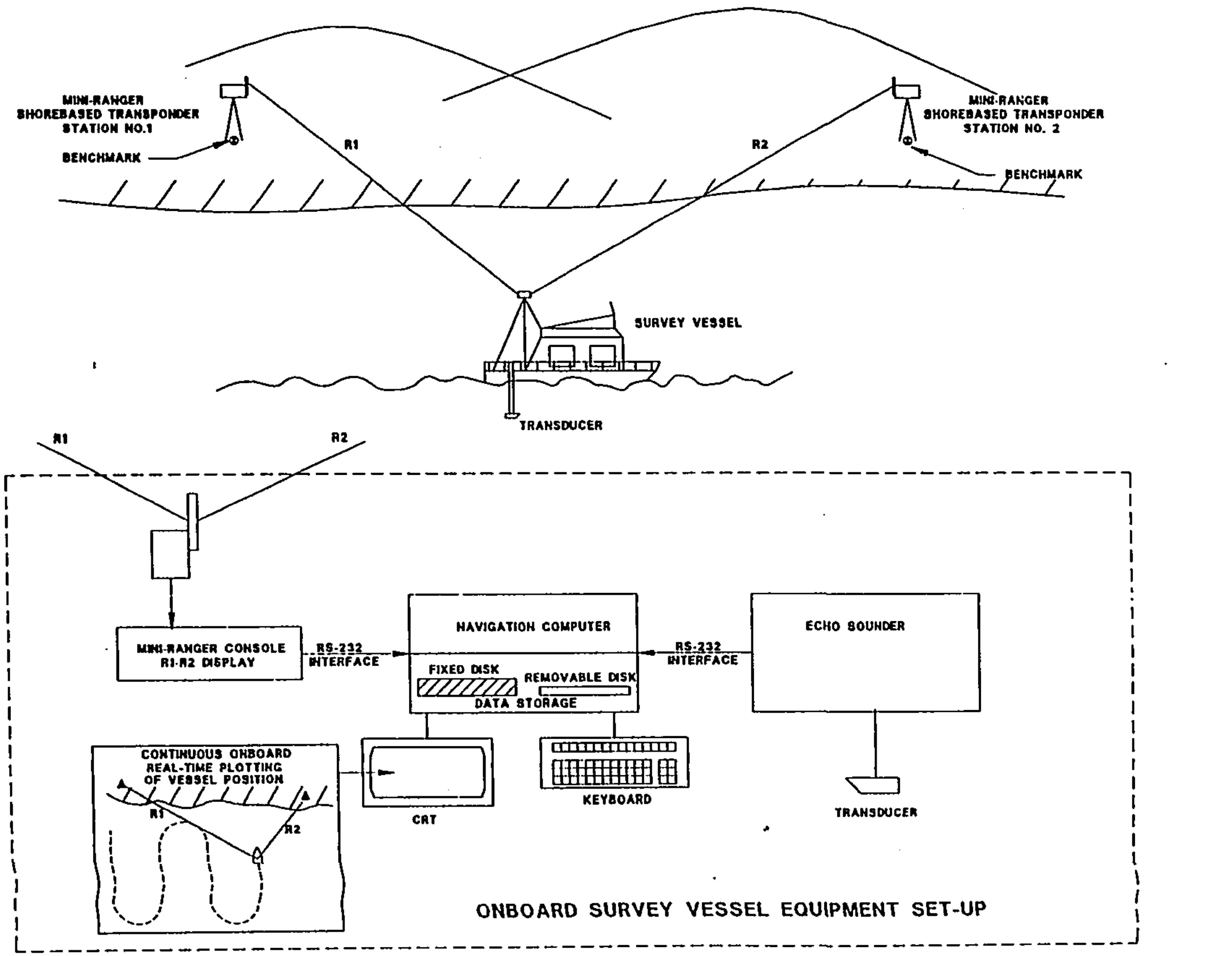
- An Ulvertech Model 205 echo sounder which operates at 500 Khz and provides an accuracy of ±2 cm for a range up to 100 meters (330 feet). The output from the echo sounder was interfaced to an onboard data acquisition system (DAS).

- In order to provide accurate and continuous positioning data for the survey vessel, a Motorola Mini-Ranger III System (MRS), which is a range-range electronic positioning system, was used. The MRS instantaneously measures the ranges to two or more shorebased transponders, which have been located over known geographic points. The MRS has a maximum range of about 40 nautical miles with a range accuracy of ±3 meters. The MRS is a line-of-sight system, and can operate in rain or at night. The MRS outputs the positioning data to the DAS using an RS-232C interface.

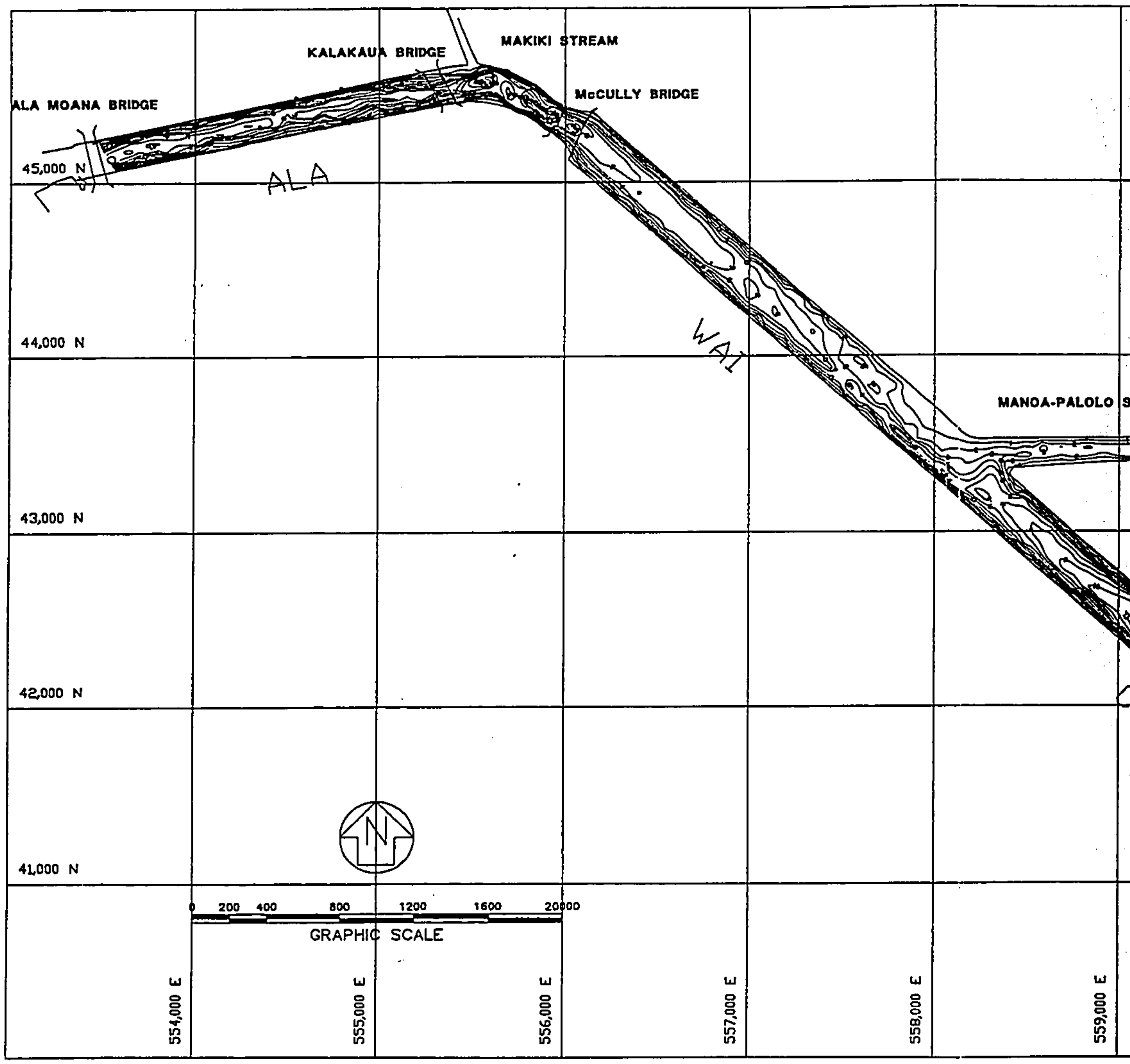
  The shorebased transponder stations were located on the roof tops of tall buildings surrounding the AWC. The exact locations of these transponder stations were determined by a Geodetic Positioning System (GPS).

- The bathymetry DAS recorded the instantaneous output from the echo sounder and the MRS, at one second intervals and simultaneously displayed the real-time vessel location and its past track on a CRT in order to guide the vessel pilot. The DAS recorded the data on hard disk and on a floppy disk for backup.

The raw data from the bathymetry survey was computer processed using EKNA's in-house software, where adjustments for the speed of sound in seawater, transducer depth and tidal phase were performed. The range-range vessel navigation data was transformed to x,y data and referenced to the Hawaii State Plane Coordinate System, Zone 3, Oahu. The x,y data and the adjusted water depth data were computer processed to develop the bathymetry map of the Ala Wai Canal. Figure 2-4 shows the final bathymetry map which has been referenced to the mean lower low water (MLLW) datum. Note that the MLLW datum is located 0.8 feet below the MSL datum. In general, hydrographic charts that are used for navigation purposes in Hawaiian waters are referenced to the MLLW datum, which is also the datum used to describe tidal variations. Thus, based on the MLLW datum being equal to zero (0), the MSL datum is located at +0.8 feet MLLW.



ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	SCHEMATIC REPRESENTATION OF THE BATHYMETRY DATA ACQUISITION SYSTEM	FIGURE 2-3



ALA MOANA BRIDGE
KALAKAUA BRIDGE
MAKIKI STREAM
McCULLY BRIDGE
ALA
WAI
MANOA-PALOLO ST
45,000 N
44,000 N
43,000 N
42,000 N
41,000 N
0 200 400 800 1200 1600 2000
GRAPHIC SCALE
554,000 E
555,000 E
556,000 E
557,000 E
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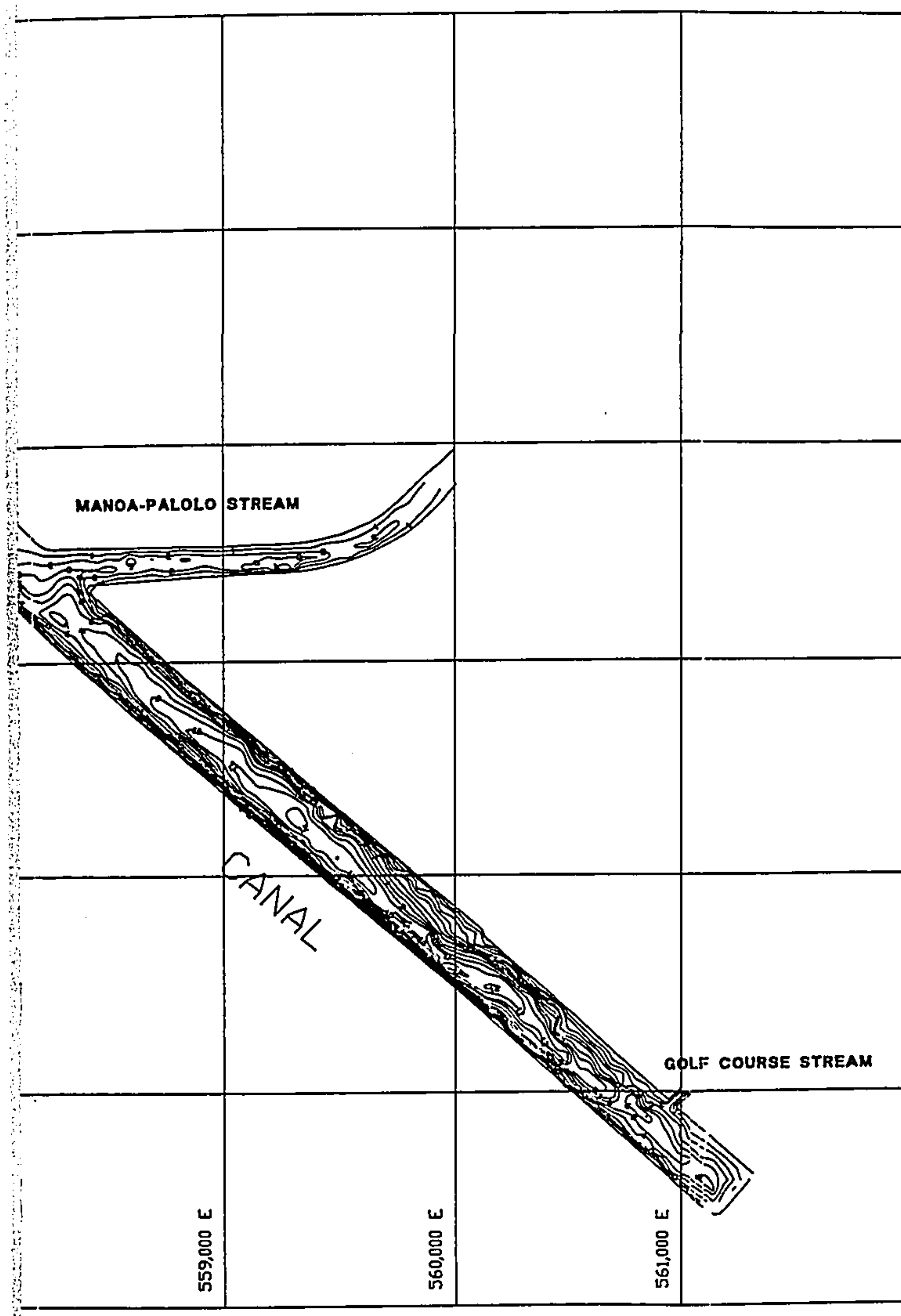
559,000 E



LOCATION PLAN

NOTES

1. DEPTHS IN FEET REFERENCED TO MLLW.
2. 1 FOOT DEPTH CONTOUR WAS INTERPOLATED BETWEEN THE ALA WAI CANAL EDGE AND THE MEASURED DEPTH DATA.
3. ALA WAI CANAL EDGE WAS DIGITIZED FROM AN AERIAL PHOTOGRAPH OF 1969
4. BATHYMETRY DATA OBTAINED ON SEPTEMBER 26-27, 1991

TRANSVERSE MERCATOR PROJECTION
X,Y COORDINATES IN THE HAWAII STATE PLANE COORDINATE SYSTEM, ZONE 3.

EDWARD K. NODA
& ASSOCIATES, INC.
615 Piikoi Street #1000
Honolulu, Hawaii 96814

ALA WAI CANAL
BATHYMETRY
SURVEY

FIGURE
2-4

SHEET 1 OF 1

DATE: OCTOBER 10, 1991

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

1" = 700 FEET

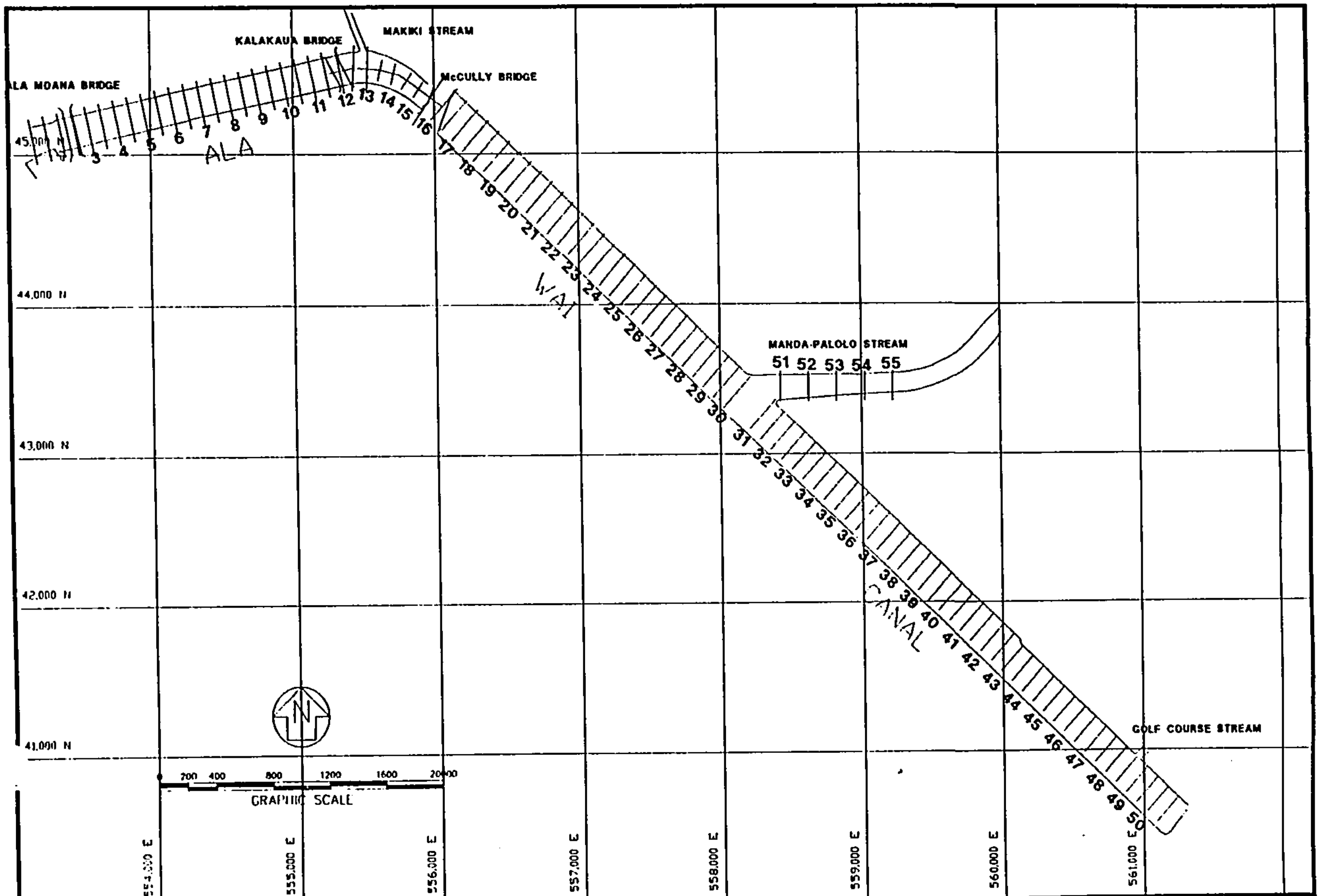
Comparison of Figures 2-1 and 2-4 shows that the accumulation of bottom sediments displays very similar hydrographic contour characteristics between these two survey maps.

Figure 2-5 shows cross-section station numbers beginning at the seaward end of the Ala Wai Canal and proceeding towards the Kapahulu end. The cross-sections are spaced at 200 feet intervals. Figure 2-6 shows bottom profile representation along the AWC referenced to MLLW, where the middle profile is along the center axis of the canal, the "upper quarter" represents a profile 1/4 width distance from the mauka bank, and the "lower quarter" represents a profile 1/4 width distance from the makai bank. Appendix A provides the existing canal bottom cross-sections at each of the stations shown in Figure 2-5. Note that cross-sections 51 - 55 are along the Manoa-Palolo Stream.

Based on the present bathymetry survey results as compared to the bottom profile design for the 1978 maintenance dredging program, Table 2.1 shows the accumulated volume of sediment material that has deposited during the intervening 13 years. Note that the station locations shown in Table 2.1 are identical to the stations used in the 1978 maintenance dredging plans and specifications.

The results in Table 2.1 for the average sediment deposition rate agree well with the results determined by Laws et al. (1992). While this sedimentation rate also agrees with the results of Gonzalez (1971) who calculated the annual sedimentation rate at 9,200 yd^3/year, Gonzalez's result was based on the dredging of 1,750 feet of the sill area beginning at the Manoa-Palolo Stream confluence and moving seaward. If the annual sedimentation rate is calculated from Table 2.1 between Stations 17+50 and 35+00, a distance of 1,750 feet, a value of 6,916 yd^3/year is calculated as compared to 8,240 yd^3/year from Gonzalez (1971). The rate of sediment accumulation calculated from Table 2.1 between Stations 17+00 and 35+00 is 0.53 feet/year versus 0.65 feet/year from Gonzalez.

It is well known that sediment concentration is approximately a linear function of the surface water runoff flow rate due to rainfall. Specifically, the larger rainfall/runoff events produce higher sediment yield concentrations (sediment weight/unit volume of flow) than their lower flow rate counterparts. Thus, a significant part of the deposited sediments in the AWC are due to the larger rainfall/runoff events. Consequently, a 13 year period of sediment accumulation provides a more stable representation than the 3.3 year (40 month) deposition period used by Gonzalez (1971). In general, considering the variability of rainfall/runoff events, the sediment deposition rates described by Gonzalez, Law et at. (1992) and calculated from the present study are all reasonably close, and

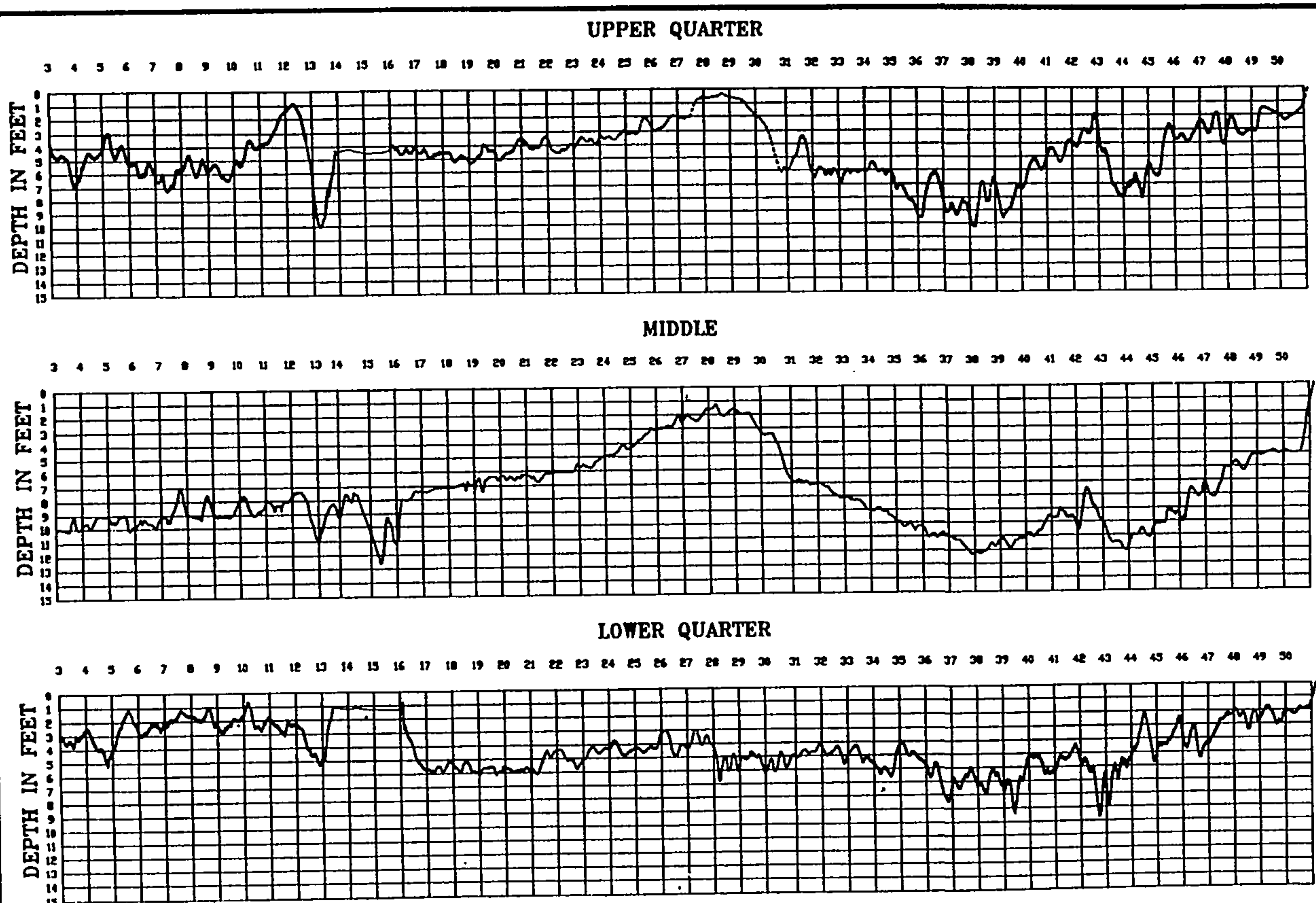


ALA WAI CANAL
IMPROVEMENT PROJECT

Edward K. Noda
and
Associates, Inc.

Ala Wai Canal
CROSS-SECTION NUMBERS

FIGURE
2-5



ALA-WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	Ala-Wai Canal Profile Sections	FIGURE 2-6

it is reasonable to assume that the sediment deposition rates in the AWC have not changed significantly in the past 25 years.

TABLE 2.1
Sediment Deposition Between 1978 and 1991 in a Section of the Ala Wai Canal

Station Locations	Sediment Deposition (yd^3)	Annual Rate of Sediment Deposition[1] (yd^3/yr)	Annual Rate of Sediment Accumulation[2] (ft/yr)
0+00 - 5+00	7,390	568	0.15
5+00 - 10+00	12,829	987	0.27
10+00 - 15+00	14,893	1,146	0.31
15+00 - 20+00	18,734	1,441	0.39
20+00 - 25+00	25,432	1,956	0.53
25+00 - 30+00	30,159	2,320	0.63
30+00 - 35+00	20,150	1,550	0.42
Manoa-Palolo St.	4,792	369	0.50
TOTAL	134,379	10,337	

Notes:

1. Based on an assumed 13 years of accumulation.
2. The canal and stream widths where dredging has been performed are assumed to be 80% of the width at the walls or bank tops.
3. Average annual rate of sediment accumulation between station locations 0+00 - 35+00 is 0.38 feet/year.

2.2. TIDES

The only previous record of tidal measurements in the Ala Wai Canal was obtained by Gonzalez (1971). Water surface elevation measurements were obtained at the seaward end of the AWC, at a location makai of the Ala Moana Bridge, and at the extreme landward end of the Canal. Thirteen days of record were obtained at the seaward station, but due to instrument failure only about 48 hours of data (July 3 to 5, 1969) were recorded at the landward station.

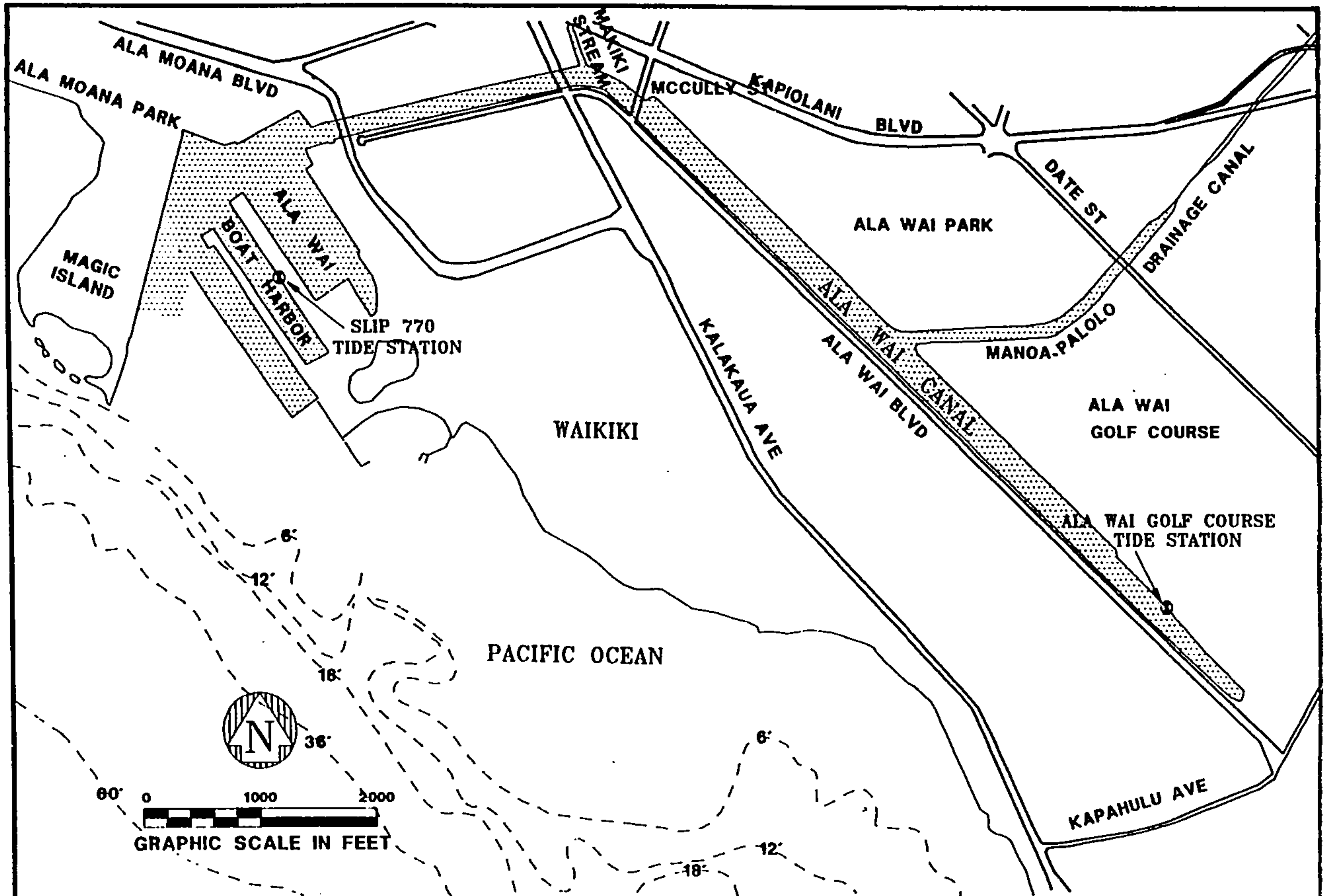
Gonzalez (1971) estimated that the time resolution of the tide measuring instruments provided an "uncertainty" of about ± 5 minutes. Within the limits of this time resolution and the length of the available data, no phase difference was observed between the two ends of the channel. Moreover, the tides in the AWC were noted to be of the same phase and amplitude as those predicted for Honolulu Harbor.

To more accurately quantify the tidal amplitude and phase relationships between the AWC and the ocean, a high-resolution tide measurement program was carried out. Two locations were selected to represent the Ala Wai Boat Harbor ocean entrance and the landward end of the Canal. The ocean entrance station was located at Slip 770, and the landward station was located near the Ala Wai Golf Course Clubhouse, both shown in Figure 2-7.

Water surface elevation measurements were made using Paroscientific, Inc. digiquartz pressure sensors, with a pressure range of 0 to 100 psia (0 to 60 meters). Instrument accuracy is ± 0.014 feet and the resolution is ± 0.0017 feet. The pressure sensors, housed in stainless steel pressure housings, were connected to Model 700 Pressure Computers which converted the data to engineering units using the individual and unique calibration coefficients. RS-232 output from the Model 700 instruments were input into IBM compatible portable computers (PCs) for data control. Specially designed field containments were fabricated to house the data acquisition system (DAS) consisting of a PC, Model 700 Pressure Computer and AC power supply connections, in order to minimize vandalism.

At the Slip 770 location, the pressure sensor was installed on a concrete piling, while the DAS in its containment housing was located on the vessel moored at the slip. At the Ala Wai Golf Course Clubhouse site, the pressure sensor was located on a pipe, which was part of the fence system surrounding the parking lot. The DAS/housing was located in the golf cart maintenance facility at the Clubhouse.

The PC controlled the rate of data acquisition. The program was set up to integrate the pressure data over a 3-minute interval, every three minutes. Pressure readings were obtained at an interval of 0.65 seconds. The computer clocks were accurately set to Hawaiian Standard Time (HST) just prior to the start of the program, and the clock times were carefully compared to HST at the end of the program. The entire data-time record was then adjusted due to differences in absolute time at the termination of the



ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	Ala Wai Canal Tide Measuring Stations	FIGURE 2-7

measurements. The time resolution is expected to be better than ± 1 second. The program was written to auto-start after a power failure, which occurred at the Slip 770 location.

The tide measuring sensors were deployed on November 7, 1991 and retrieved on December 6, 1991 for a one-month deployment period. Except for a few hours of data lost at the Slip 770 location due to a power failure, continuous pressure data was obtained at both locations. Figure 2-8 shows the mean-zero measured tide data from the Ala Wai Golf Course and Ala Wai Boat Harbor channel entrance locations, as well as the actual measured tide data at Honolulu Harbor. It is clear from Figure 2-8 that the tides at the AWC are very similar in amplitude and phase to the tides at Honolulu Harbor.

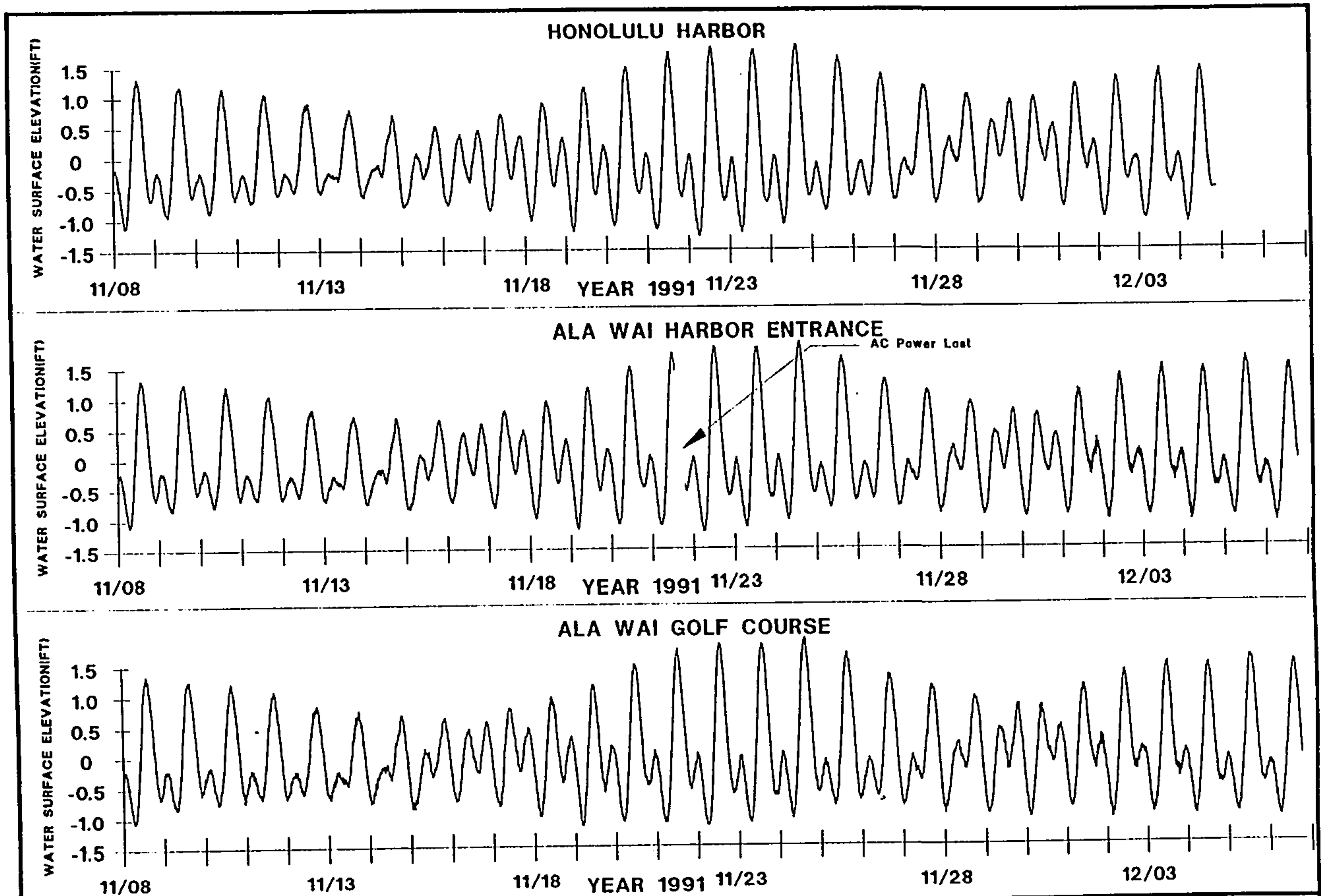
Figure 2-9 shows a superposition of the tides at the Ala Wai Golf Course, AWC ocean entrance and from Honolulu Harbor locations, and indicates the almost identical nature of the water levels at these three locations. At the scale shown in Figure 2-9, it is difficult to determine small tidal phase differences (seconds) between the ocean entrance and the end of the Canal. The phase relationships in a tidal driven system are very important drivers to hydraulic flow.

In order to determine accurate phase differences between the two water surface elevation time series records, the following analysis has been used. First, the data sets are processed to determine the maximum, minimum and mean elevations, designated y_{max}, y_{min} and y_{mean} respectively. An amplitude, a, is defined given by

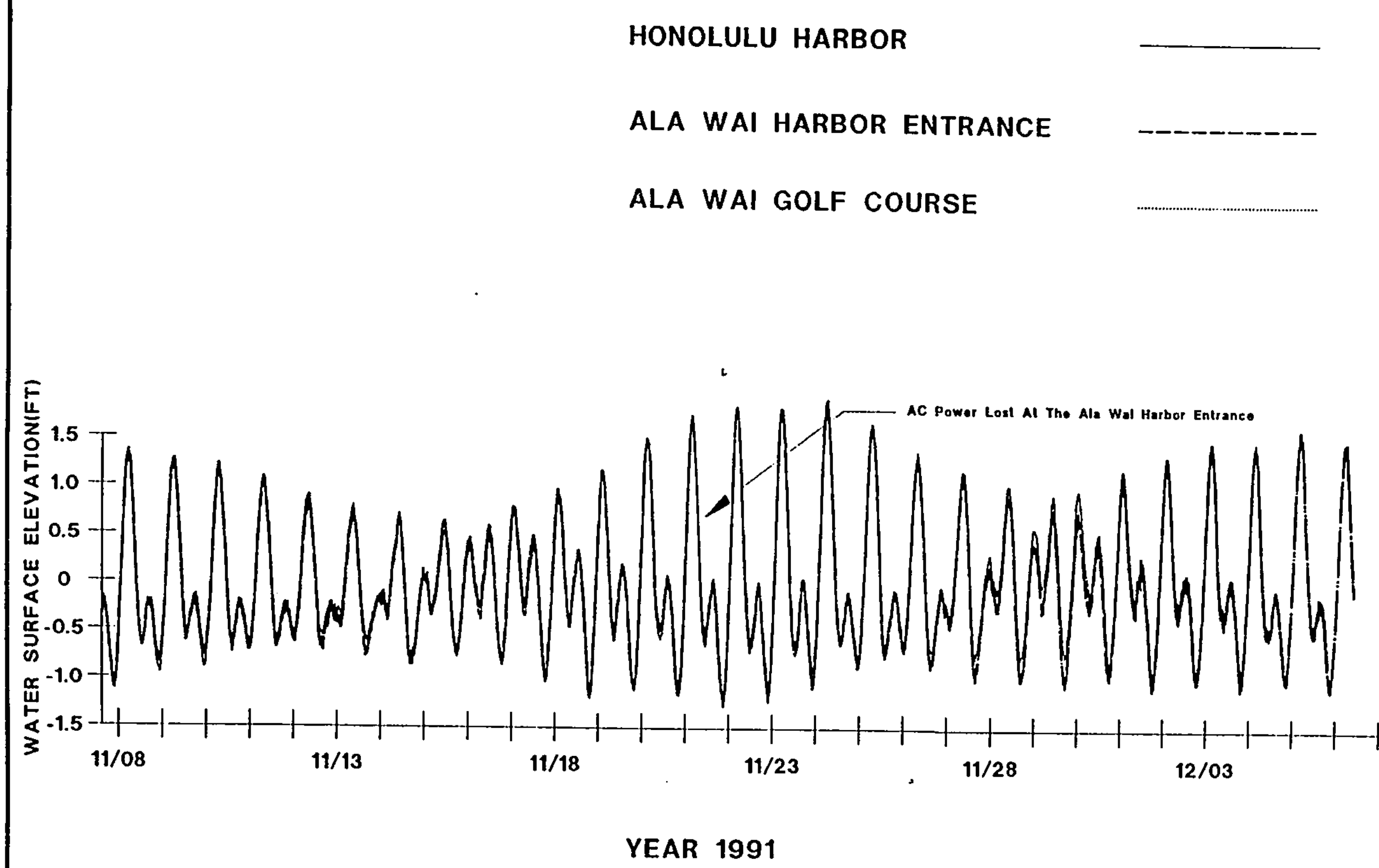
$$a = \frac{(y_{max} - y_{min})}{2} \qquad (1)$$

For each of the time series, a new time series is calculated by removing the mean and scaling the data by

$$Y_i = \frac{(y_i - y_{mean})}{a} \qquad (2)$$



ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	Ala Wai Canal Tide Measurements	FIGURE 2-8



ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	Ala Wai Canal Tide Measurements	FIGURE 2-9

where y_i = the original time series,
Y_i = the new time series,
i = the time index.

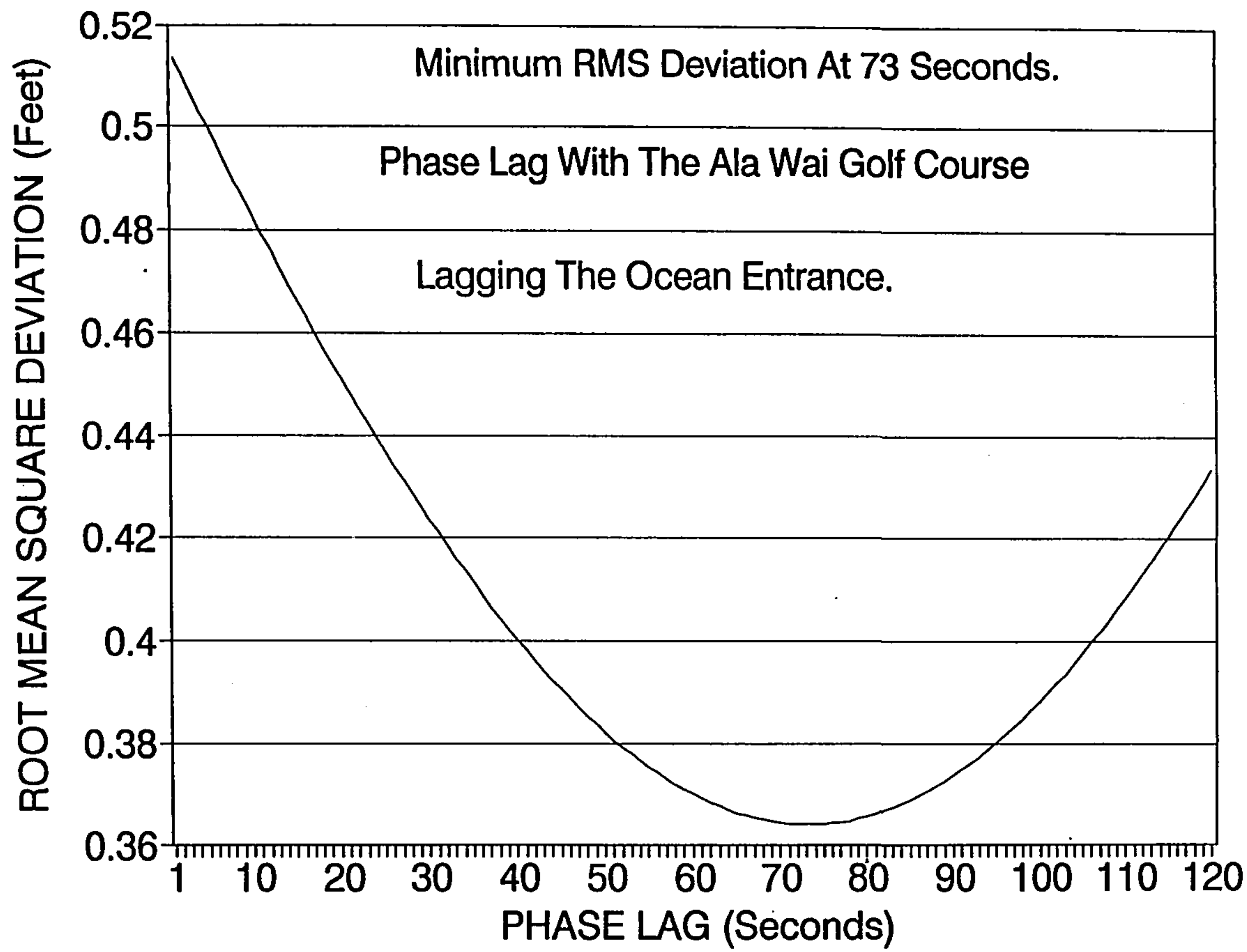
The procedure now is to slide the Ala Wai Golf Course record with respect to the ocean entrance record, and minimize the discrepancy between the two time series. A simple *difference* ϵ_i *is defined by*

$$\epsilon_i = E_i - \left[y_i + \frac{\Phi}{\Delta t}(y_{i+1} - y_i) \right] \tag{3}$$

where E_i is the ocean entrance data and y_i is the Ala Wai Golf Course data. The arbitrary phase shift is ϕ and Δt is the fixed data interval which is 180 seconds (3 minutes). For a fixed phase shift, the sum of the squares of the differences defined by Equation 3, divided by the number of points, and taking the square root, defines the Root Mean Square (RMS) deviation between the adjusted time series. The RMS deviation can be calculated as a function of phase lag ϕ. The phase difference between the two time series is the phase lag ϕ that yields a minimum value of the RMS deviation.

Figure 2-10 shows a plot of the RMS deviation as a function of the phase lag (seconds), and the minimum value is obtained at a phase lag of 73 seconds. In other words, the tide at the Ala Wai Golf Course lags the tide at the Ala Wai Boat Harbor entrance channel by 73 seconds.

The above analysis showing a very small phase lag relationship between the ocean entrance and inland terminus of the Ala Wai Canal is consistent with the behavior of a nearly pure standing wave. In the absence of friction, there should be no phase lag, and all points in the canal would move in identical phase. It can be shown analytically that with friction, the Ala Wai Golf Course tide data would lag the ocean entrance time series. This then allows the adjustment of bottom friction in the computer model to match the measured phase lag as shown in Figure 2-10.



ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	Tidal Phase Lag Analysis	FIGURE 2-10

2.3. WATER CURRENT FLOW AND CIRCULATION

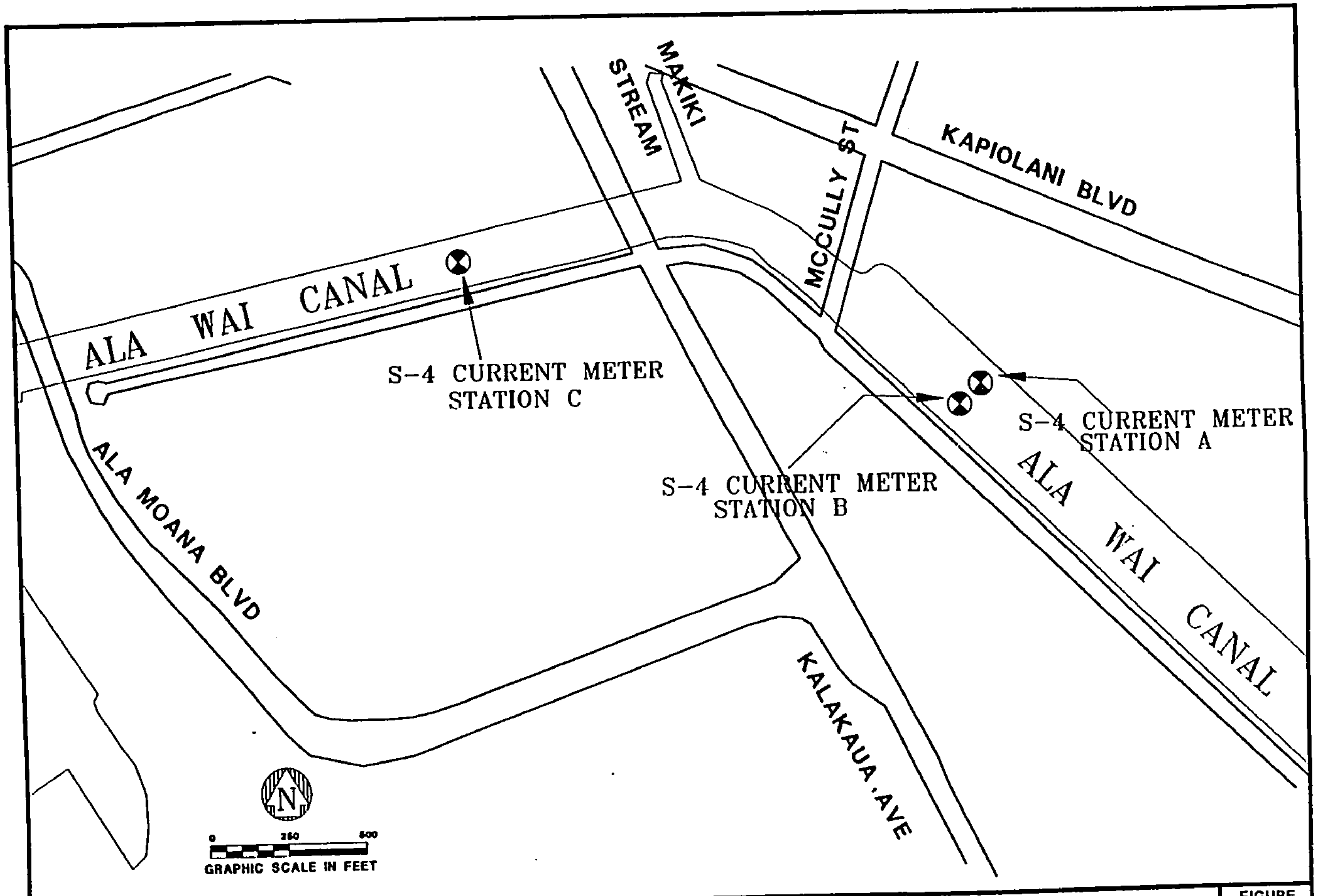
2.3.1. Ala Wai Canal Current and Circulation Measurements. Historically there have been very few water current flow measurements in the Ala Wai Canal. Gonzalez (1971) measured currents during a two day period (June 29 to 30, 1969) at various stations in the Canal. Current profiles were obtained along the axis of the Canal using Ekman-Merz current meters. The current measurements were made during the flood tide of June 29, 1969 and during the ebb tide of June 30, 1969. Water temperature and salinity as well as horizontal currents were measured as a function of water depth at each of the measurement stations.

The combination of data indicated alternating periods of two-layer and one-layer flows. During the two-layer flow, brackish water at the surface flows seaward and out of the AWC, entraining saline water from below and causing a compensating landward drift into the Canal in the deep layer. This flow process was primarily influenced by the magnitude of the fresh water runoff into the Canal, and by wind stresses. Superimposed on this two-layer system was the tidal flow process. The tidal flow velocity component was found to be approximately sinusoidal, leading the tidal phase by 90°, and directed into the Canal during flood tide and out of the Canal during ebb tide.

Gonzalez (1971) indicated that the tidal flow in the deep layer was strongly influenced by the landward drift, which decreased the flow during the ebb tide, and intensified the flow during the flooding tide. The magnitude of the surface current velocity was influenced by the magnitude of the fresh water runoff, the size of the tidal range and the speed and direction of the wind.

In order to quantify water current flow in the Ala Wai Canal, two types of current methodologies were used. To obtain a long term representation of current vectors at given locations, 3 current meters were located in the Canal as shown in Figure 2-11. Due to the very shallow water conditions, InterOcean Model S-4 current meters were used in order to avoid the influence of oscillatory currents due to wind generated waves. The S-4 current meters use electro-magnetic current sensors with no moving parts, and provide true vector-averaged data which is stored in computer memory.

Current meter stations A and B were deployed on March 2, 1992 about 400 feet landward of the McCully Bridge along cross-section number 18. The two current meter moorings were evenly spaced across the width, with Station A located about 1/3 the width from the makai side, and Station B located about 1/3 the width from the mauka side of the Canal. The current sensor was located about 2 to 3 feet off the bottom. On



ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	Ala Wai Canal Current Meter Stations	FIGURE 2-11

March 3, 1992, a single current sensor was deployed at Station C, cross-section number 9, in the center of the Canal. On March 20, 1992, all three S-4 current meters were retrieved. Figure 2-12 provides a schematic description of the current meter mooring design.

The current data was processed using a standard in-house format and the results are shown in Appendix B. The S-4 current data clearly show both the strong tidal phase dependency and the "landward" drift as noted by Gonzalez (1971). All three current meters display very similar patterns associated with the dominance of the inward or landward flows as provided by the percent frequency of occurrence versus direction and the progressive vector diagrams. Moreover, the velocity vector stick-plots show the strong tidal frequency signature, but the outgoing or seaward flow vectors tend to be much more attenuated than their landward flowing counterpart. During this time period, the wind conditions were in the light and variable range, with an average wind speed at Honolulu International Airport of about 5 knots from the east-northeast. Surface runoff was generally light during this period, with no significant rainfall events.

In addition to current meter measurements, the current flow circulation in the Ala Wai Canal was measured using current drogues. Current drogues are almost neutrally buoyant objects which freely move with the current flow, and provide a track of the marked parcel of water as it is driven by the tides, winds and stormwater inflow. The current drogues provide additional information on the water flow patterns at locations different from the deployed current meters.

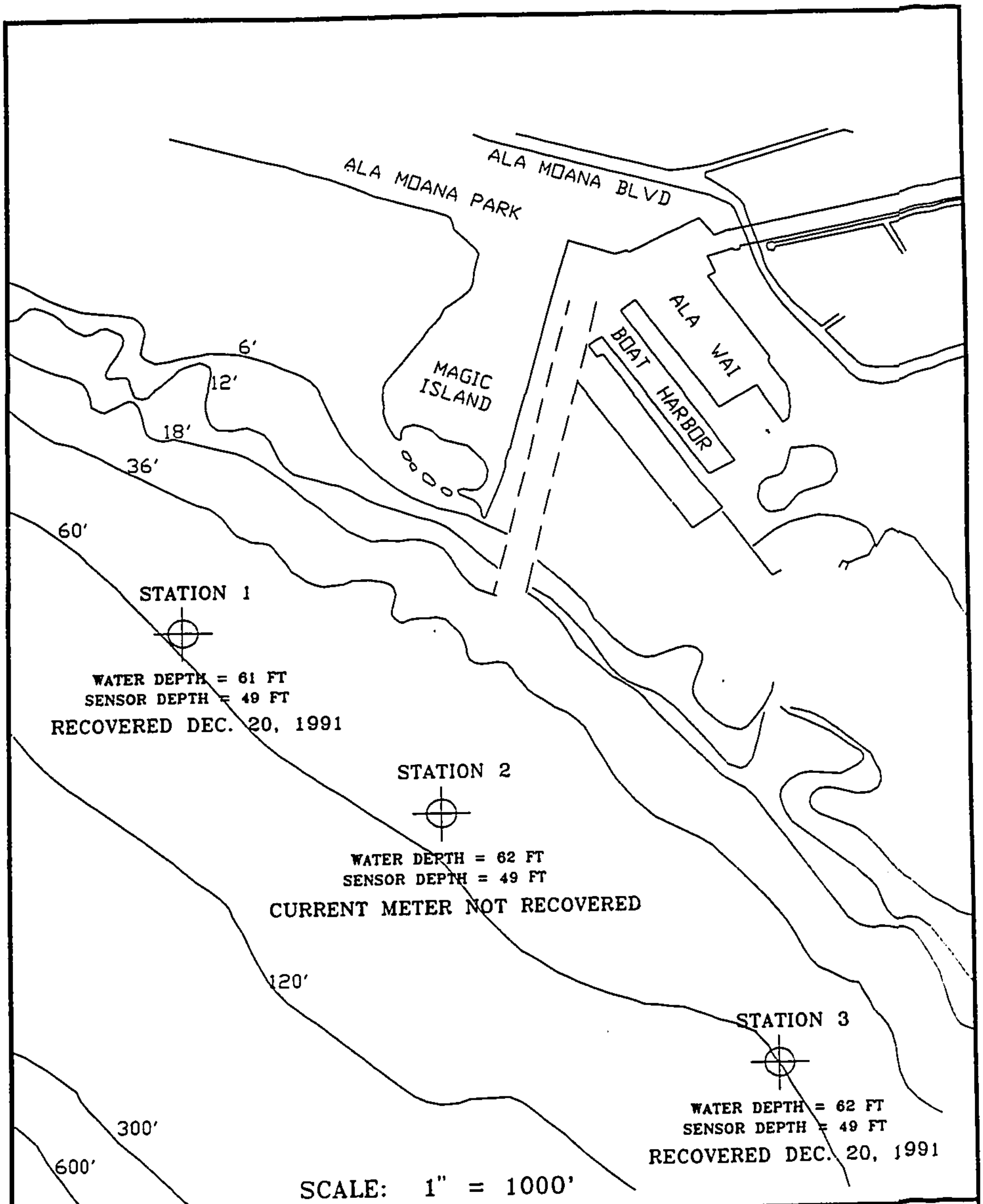
Within the Ala Wai Canal, 53 individual current drogue deployments were performed under varying wind conditions (Kona winds, light & variable, and typical tradewind conditions), varying tidal conditions (flood and ebb tide), varying surface water runoff conditions, and with drogues set at different depths below the surface. Due to the shallow water conditions in the Ala Wai Canal, many of the deployments were "surface" drogues which consisted of 1-gallon plastic containers partially filled with water such that 90% of the container was below water level. In order to evaluate nearbottom circulation, "bottom" drogues were also deployed with a schematic design shown in Figure 2-13. Due to the shallow bottom depths in the AWC, the vertical sail height shown in Figure 2-13 was reduced to 3 feet, with the distance from the surface float to the sail set at 2 to 4 feet, depending on the tidal elevation and the deployment location, which provided a maximum sail depth of 5 to 7 feet below the water surface.

The results of each individual current drogue deployment and discussions of the drogue results are shown in Appendix B. The current drogue results indicate that there is a very distinct and dominant two-layer flow in the Ala Wai Canal. The surface layer flow direction is strongly influenced by surface water runoff draining into the AWC and the magnitude and direction of the wind velocity. For example, for light and variable southerly wind conditions (Kona weather), with minimal rainfall events, the surface and bottom flows show similar patterns, with flow into the AWC during flood tide conditions and flow out of the Canal during ebb tide conditions. For conditions during tradewind events, even for light tradewind speeds, and with minimal rainfall events, the surface layer tends to flow seaward, independent of the tidal cycle, while the bottom layer continues to oscillate inconjunction with the tidal phase. For large rainfall events, the surface water runoff can dominate the surface flow direction, with flow seaward being the consequence, independent of wind conditions. If the surface water runoff flow is very substantial, this freshwater inflow could overcome the tidal forces, whereby a seaward flow would occur at all depths independent of the tidal conditions.

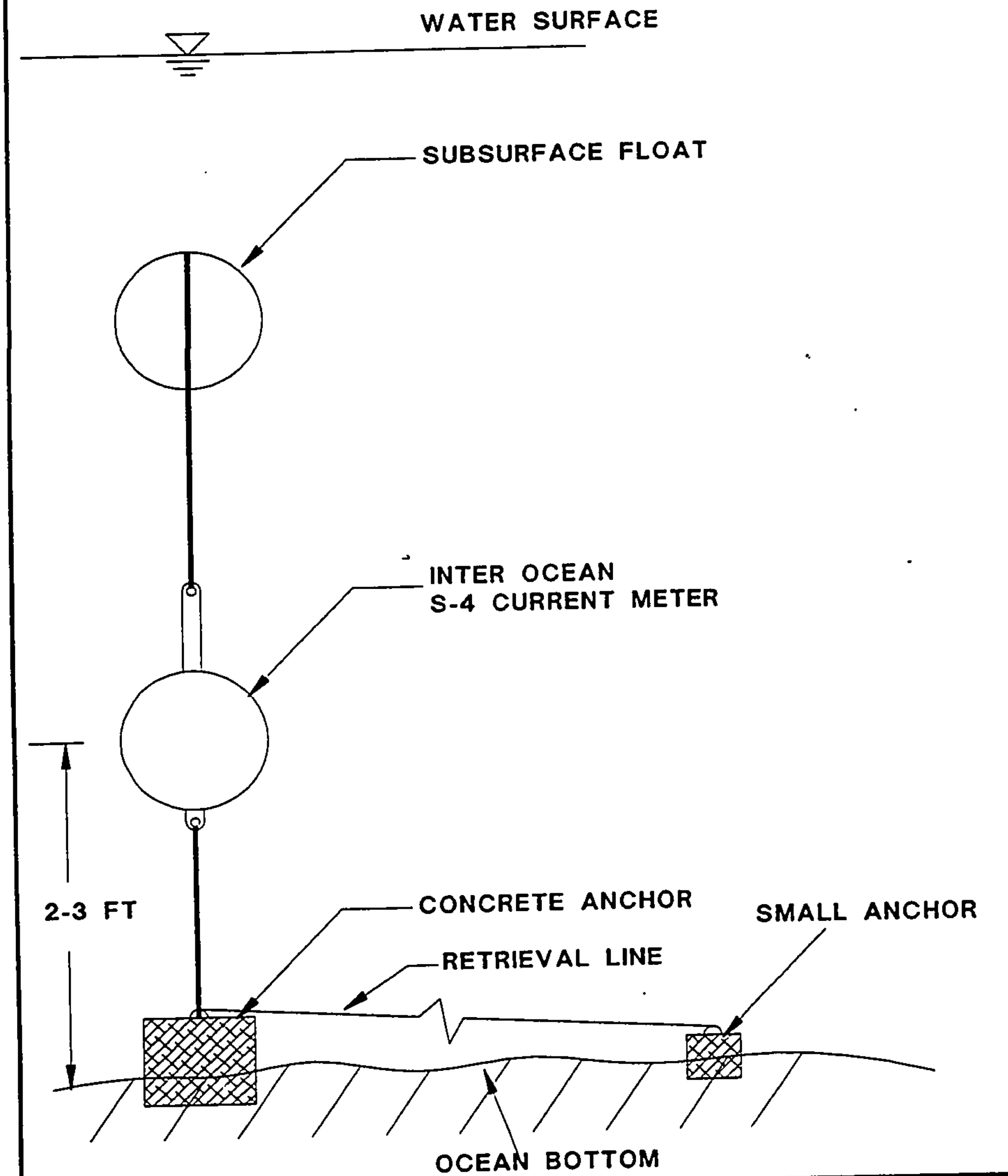
2.3.2. Coastal Current and Circulation Measurements. In order to quantify ocean currents in the nearshore coastal waters, both current meter and drogue measurements were obtained. Current meters were deployed at three nearshore coastal locations, one centered at the Ala Wai Boat Harbor entrance channel, with the other two meters located about 3,000 feet Ewa and Diamond Head of this center station, at bottom water depths of about 60 feet. The selected current sensor was the Aanderaa RCM-4 current meter, which records current speed and direction, water temperature and water pressure on magnetic tape at pre-set time intervals.

The three Aanderaa RCM-4 current meters were deployed on September 20, 1991 at the locations shown in Figure 2-14. Figure 2-15 shows the typical mooring array schematic design. The retrieval operations for the three nearshore coastal current meters were carried out on December 20, 1991. During the retrieval operations, only two current meters were recovered, which were Station 1 and 3 as shown in Figure 2-14. Station 2 located along the centerline of the entrance channel was not found. Divers did find the mooring anchor weights which restrained the mooring. It is suspected that vandalism was responsible for the loss of the current meter and its subsurface buoyancy spheres.

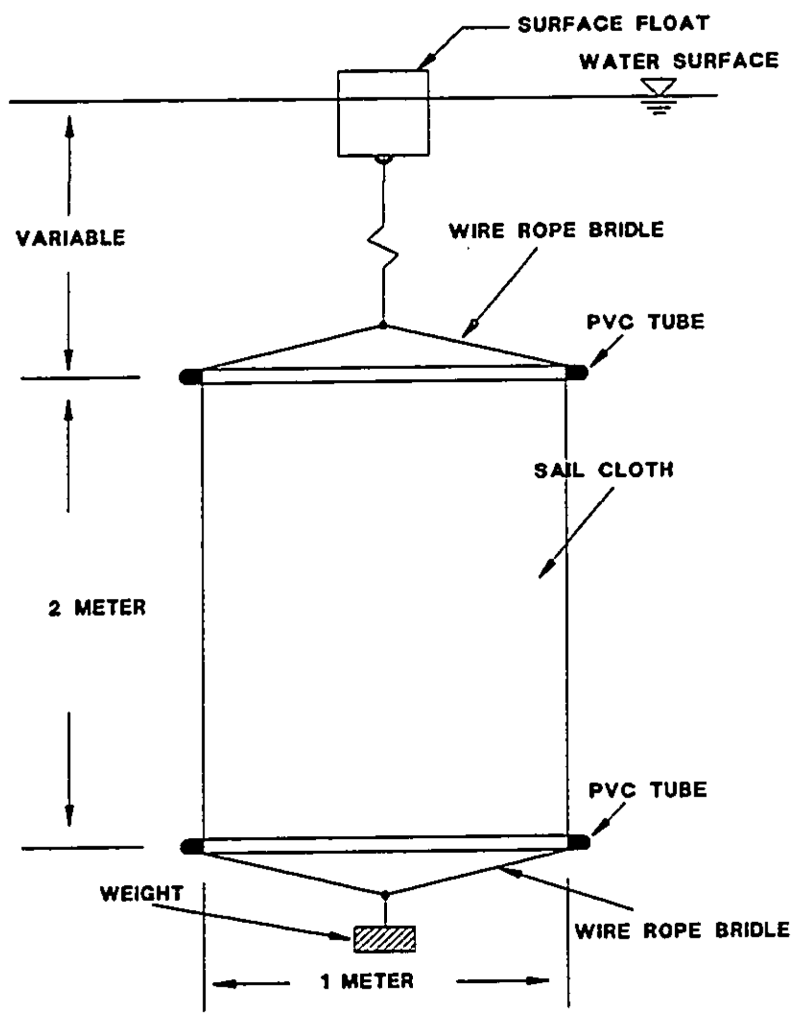
The processed current data from Stations 1 and 3 are shown in Appendix C. A comparison of the current data recorded at these two stations show great similarity. This indicates that the current flow processes in this nearshore coastal area of Mamala Bay are essentially homogeneous, and that the loss of current data from the Ala Wai Boat Harbor entrance channel location is not critical. The measured current data shows



ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	Current Meter Locations, Deployed September 20, 1991	FIGURE 2-14

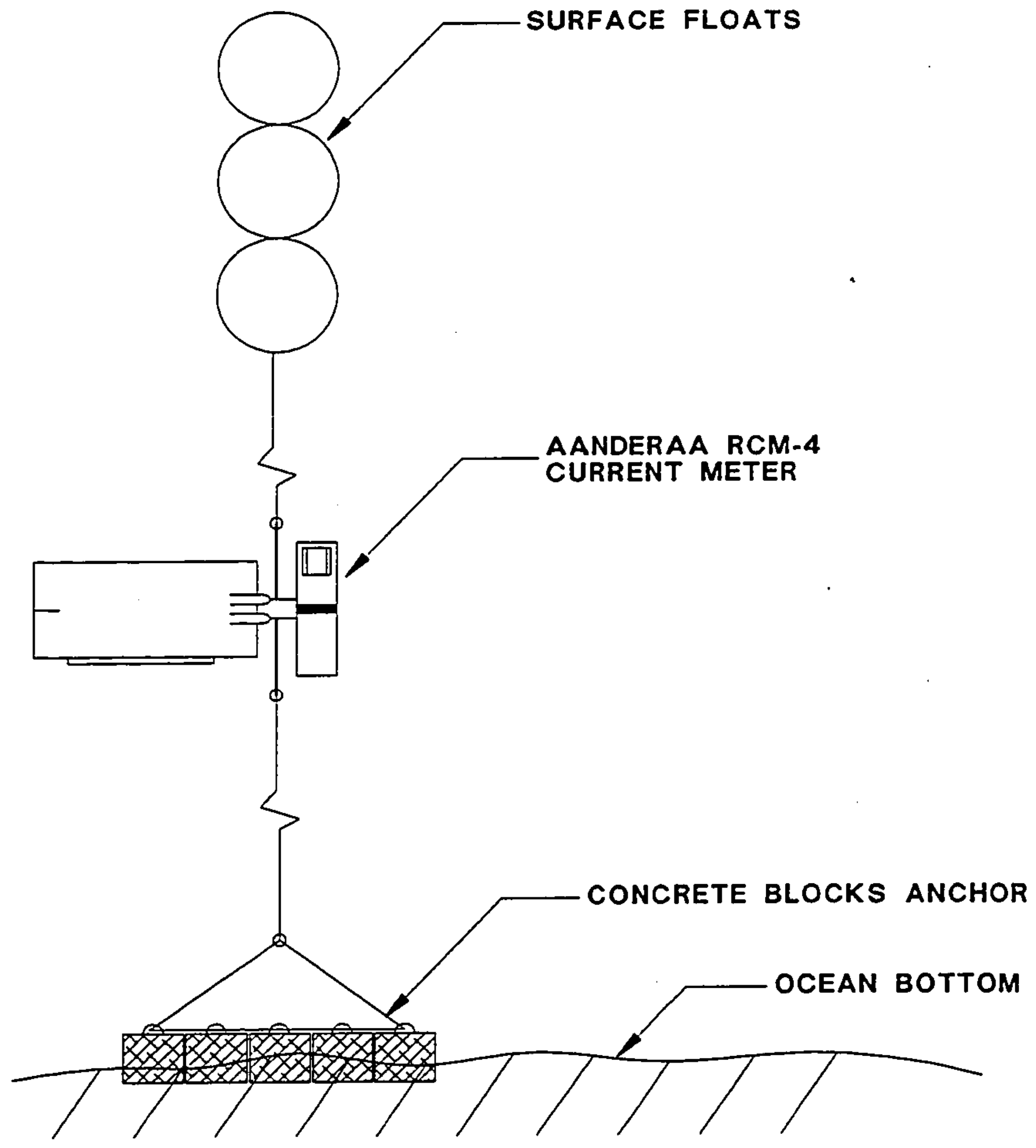


ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	Schematic Design Of Ala Wai Canal Current Meter Mooring	FIGURE 2-12



NOT TO SCALE

ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	Schematic Representation Of A Typical Window Shade Drogue	FIGURE 2-13



ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	Schematic Design Of Current Meter Mooring For Coastal Current Measurements	FIGURE 2-15

a strong correlation with tidal processes, and the currents are primarily oriented along the bathymetry contours. There is a preference for current flow towards the southeast, which is parallel to the bathymetry contours, both in terms of the frequency of occurrence and the magnitude of the current speed. This current flow towards the southeast occurs primarily during the ebb flow part of the tidal cycle. Due to this southeast direction preference, the progressive vector diagrams of each of the two current meters shows a mean drift towards the southeast.

The maximum current speeds recorded during the 3-month deployments were 40.6 cm/sec (0.79 knots) and 55.0 cm/sec (1.07 knots) at Stations 1 and 3 respectively. These current data sets are very similar to other current data recorded off Waikiki and Kakaako.

In addition to the current meter measurements, current circulation in the nearshore coastal area was measured using current drogues. The current drogues utilized for this effort were essentially identical to the drogues used for current measurements in the Ala Wai Canal. The "surface" drogues were either 1 gallon plastic containers or the full extended sail drogues shown in Figure 2-13. The "mid-depth" and "bottom" drogues were the fully extended sail length drogues with the distance between the surface float and the sail adjusted depending on the drogue release water depth.

For the nearshore coastal area, 40 individual current drogue deployments were performed under varying wind conditions (Kona winds, and light and typical tradewind conditions), varying tidal conditions (flood and ebb tide), varying surface runoff conditions, and variable depth drogue settings. The focus of the drogue deployments was in the area of the Ala Wai Boat Harbor entrance channel and the coastal waters in close proximity to the entrance channel. Appendix C provides the results of each individual current drogue deployment and includes discussions of the individual drogue results.

The results in Appendix C indicate the similar two-layer characteristics of the discharged flow from the AWC as was shown in Ala Wai Canal drogue measurements. During moderate and heavy surface runoff discharges into the AWC, the surface layer drogues exhibit strong seaward velocities, while simultaneously released mid-depth and bottom drogues in the entrance channel area tend to flow parallel to the bottom depth contours. During heavy rainfall events, the surface layer plume discharged from the Ala Wai Boat Harbor entrance channel was clearly visible by the sharp boundary line between the silt-laden brown discharged waters and the clearer green ocean waters. The surface layer drogue velocities show strong offshore components, which dominated the tide driven currents that tended to flow parallel to the bottom depth contours.

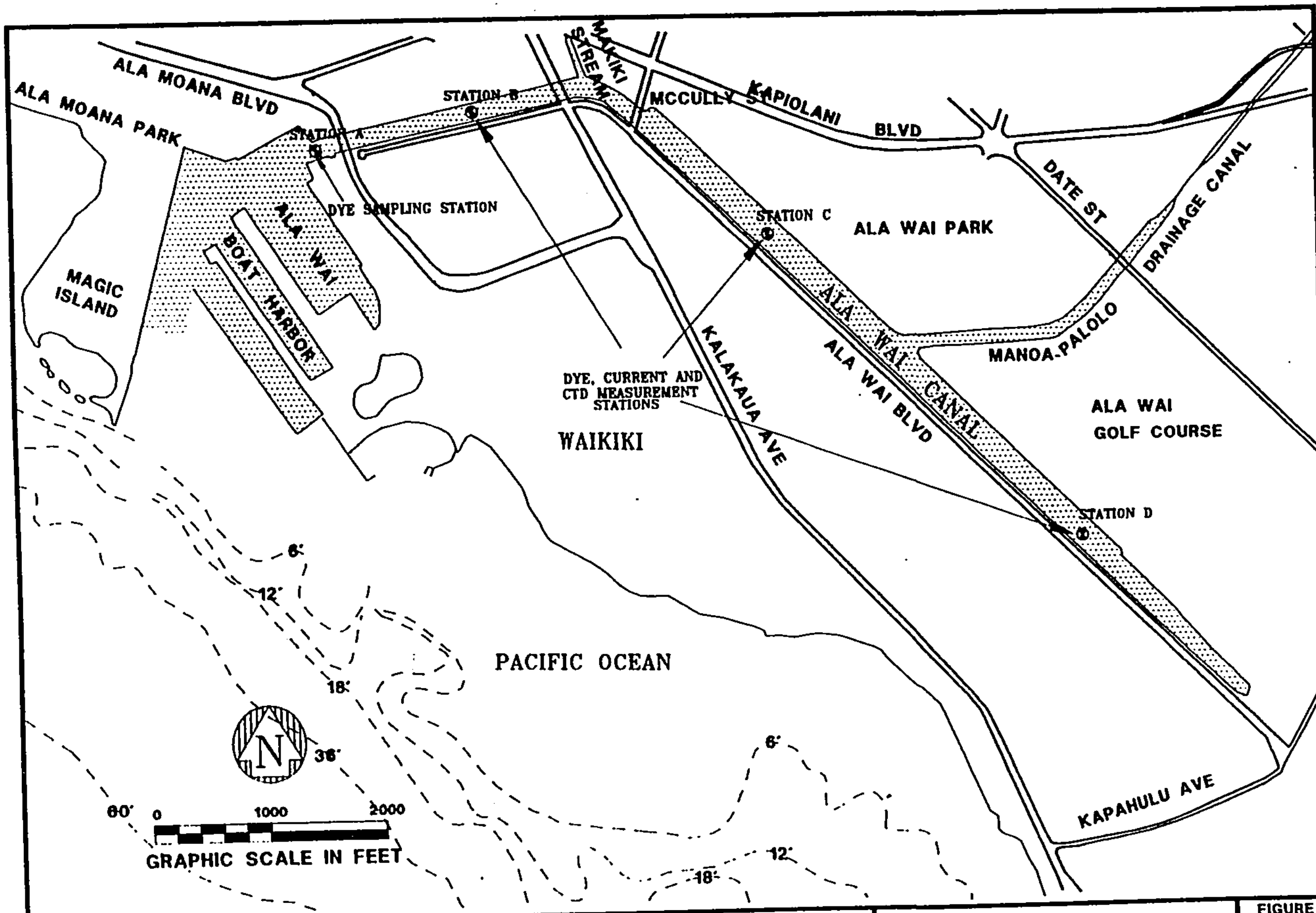
2.4. DYE, CURRENT PROFILE AND CTD SURVEY

In order to credibly and accurately calibrate the hydrodynamic part of the computer model, information was required on the existing flushing rates in the Ala Wai Canal. To provide this important data, direct field measurements of dye flushing rates were carried out in the AWC. The selected dye was Rhodamine WT, which is a pinkish fluorescent dye commonly used in ocean circulation and flushing studies. The advantages of Rhodamine WT dye are associated with the fact that it does not react with other constituents in the water, does not attach to particles (sediment absorption) and solids (vessel hulls), and is very stable to photochemical decay. In addition, the fluorescence can be measured to values as low as 0.1 parts per billion (ppb), thereby reducing the volume of dye necessary to seed a large body of water such as the AWC.

The dye flushing survey was initiated on March 2, 1992, where Rhodamine WT dye was diluted and injected into the entire Ala Wai Canal waters between the Kapahulu end of the Canal and the Ala Moana Bridge during the flooding tide (10:00 am through 3:00 pm). About 5 gallons of liquid dye was pumped into the Canal, evenly distributed by sections in order to obtain an initial concentration of about 1×10^{-7}. Just prior to the dye injection, water samples were obtained from the surface, 0.5 meters below the surface, at mid-depth and 0.5 meters above the bottom at 4 stations in the Canal as shown in Figure 2-16 in order to obtain background fluorescence concentrations.

Water samples were obtained daily from March 3 to 15, 1992 at the four station locations and at the four depth levels. The water samples were analyzed for fluorescent dye concentrations and the tabular results are provided in Appendix D. The sample descriptions in Appendix D are designated by two letters; the first letter is the station location as shown in Figure 2-16, and the second letter describes the vertical location within the water column, where S = Surface, T = Top (0.5 meter from the surface), M = Mid-Depth, and B = Bottom (0.5 meter off the bottom).

The decay rate of a conservative constituent which is initially injected into a semi-enclosed body of water that exchanges water with the ocean environment and is dominated by a tidal forcing process, such as a harbor or canal system, can usually be described by the following:



ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	Ala Wai Canal Dye, Current And CTD Sampling Stations	FIGURE 2-16

$$C = C_o e^{-t/T} \tag{4}$$

where
: C = the concentration of the dye at time t,
: C_o = the initial dye concentration at time t = 0,
: T = the time constant, or the "flushing time constant".

The flushing time constant, T, has also been referred to as the "e-folding" time (Schwartz and Imberger, 1988; Brown, et al., 1990) since this is the time that it takes for the dye concentration to fall to 1/e (0.37) from its initial value, C_o.

Taking the natural logarithm (ln) of Equation 4 yields

$$\ln C = \ln C_o - \frac{t}{T} \tag{5}$$

Thus, a plot of ln C versus time will define a straight line with the slope of the line, as (-t/T) and the intercept at ln C_o. Note that the value of C_o is not related to the flushing time constant determination, and consequently, it is not necessary to determine C_o. However, the relative changes in the concentration C as a function of time is necessary to determine the flushing time constant, T.

A more practical representation of the flushing time constant is when the concentration falls to 50% of its initial value, designated T_{50}. Figures 2-17 to 2-20 provide an analysis of the dye concentration data based on the form of Equation 4, where the straight line provides the best fit to the data for each of the station locations and depth layer. In general, the form of Equation 4 agrees well with the dye decay rate in the Ala Wai Canal, and the flushing time constant is surprisingly consistent throughout the Canal, with typical T_{50} of the order of 40 to 60 hours.

In addition to the water sample measurements for dye, conductivity-temperature-depth (CTD) and current profile measurements were obtained on March 3, 1992 at the 3 dye station cross-section locations (B, C and D) shown in Figure 2-16. At each of the 3 cross-sections, CTD and current profile data were obtained laterally across the canal width at locations about 1/4 the width from the mauka bank, at the center of the canal, and 1/4 the width from the makai side of the bank, designated locations 1, 2 and 3 respectively. The processed current profile data is provided in Appendix D as a function

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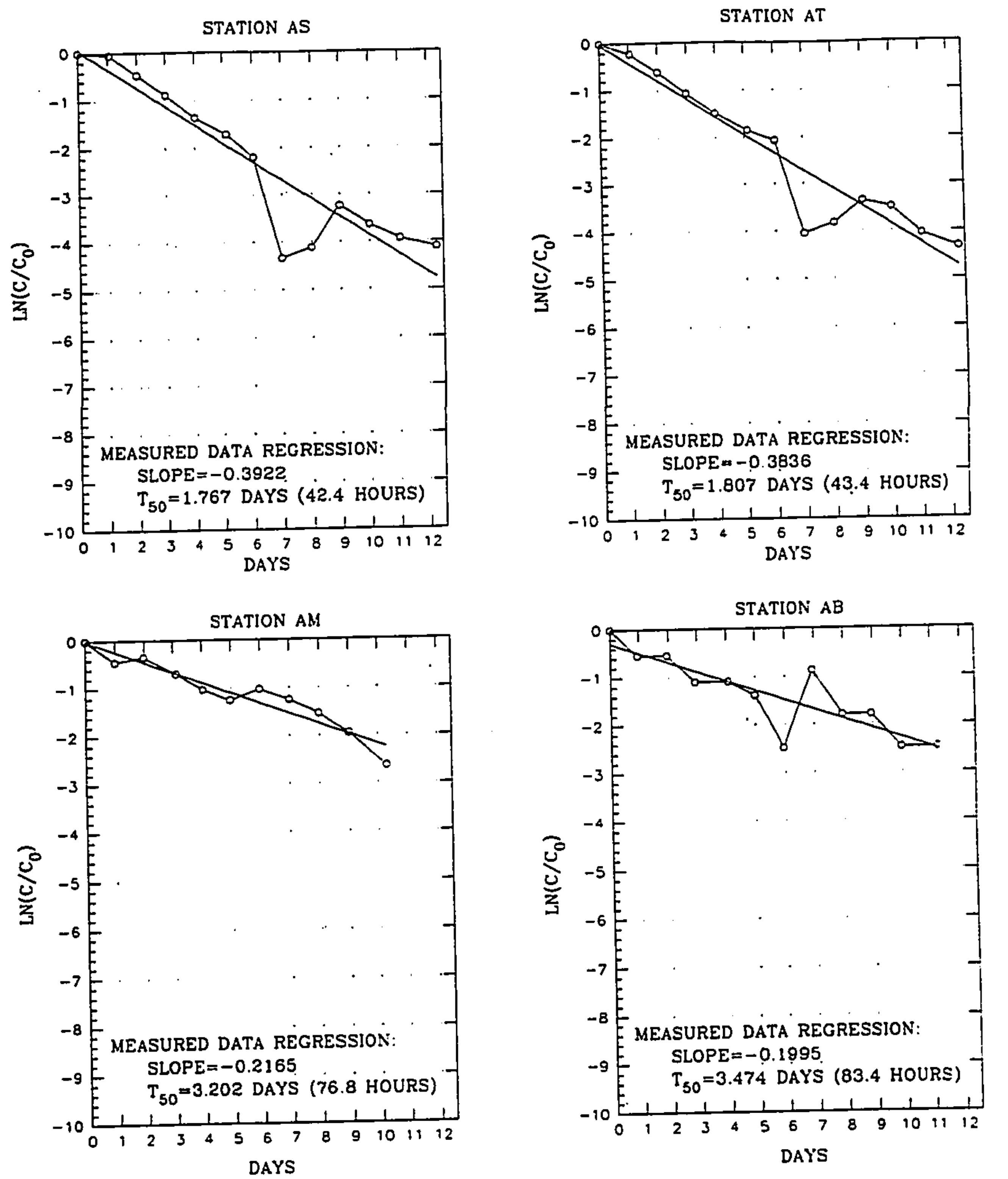
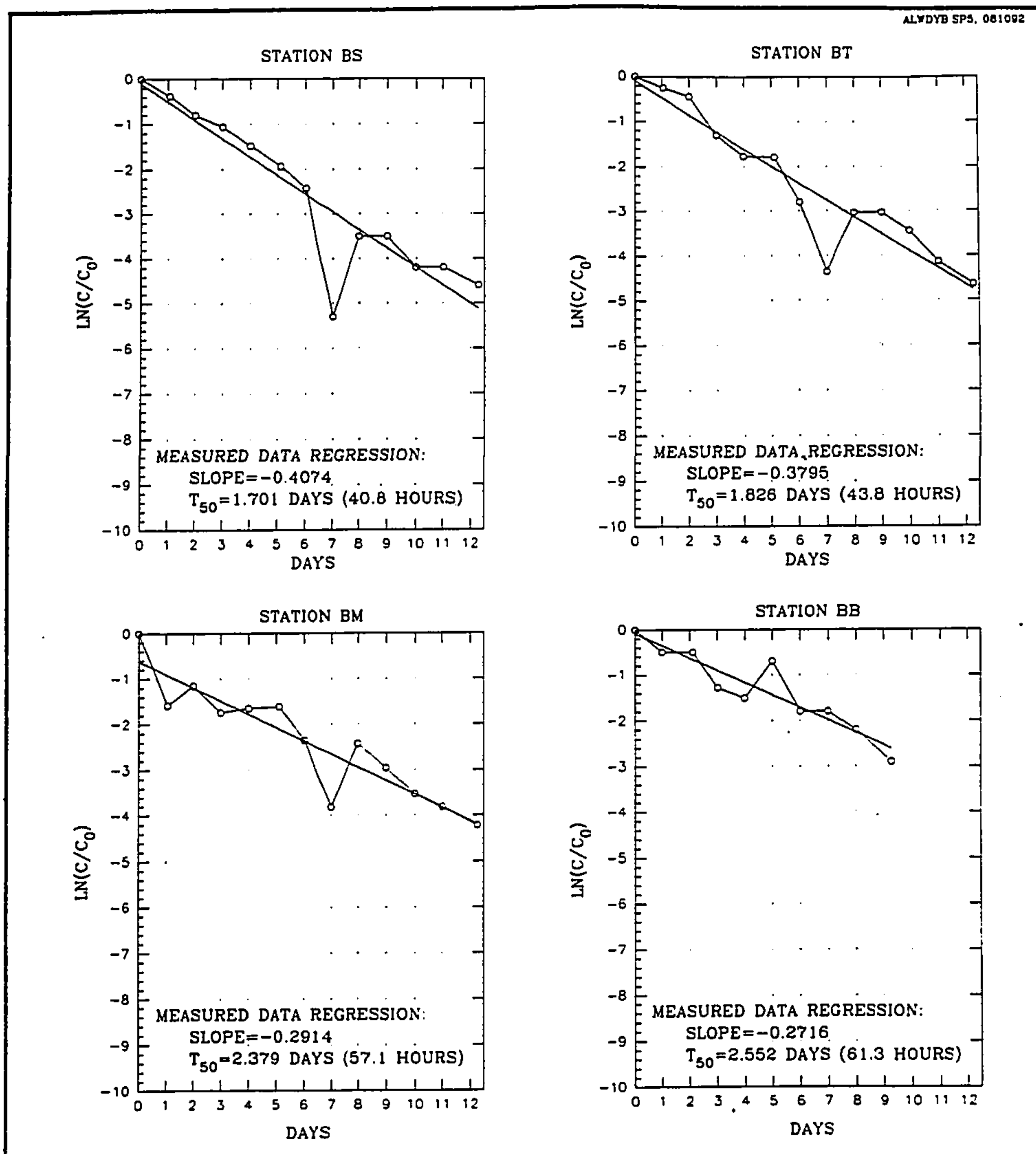


o MEASURED. STRAIGHT LINE: LINEAR REGRESSION LINE.

ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	Analysis Of The Ala Wai Canal Dye Measurements At Dye Sampling Station A	FIGURE 2-17



o MEASURED. STRAIGHT LINE: LINEAR REGRESSION LINE.

ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	Analysis Of The Ala Wai Canal Dye Measurements At Dye Sampling Station B	FIGURE 2-18

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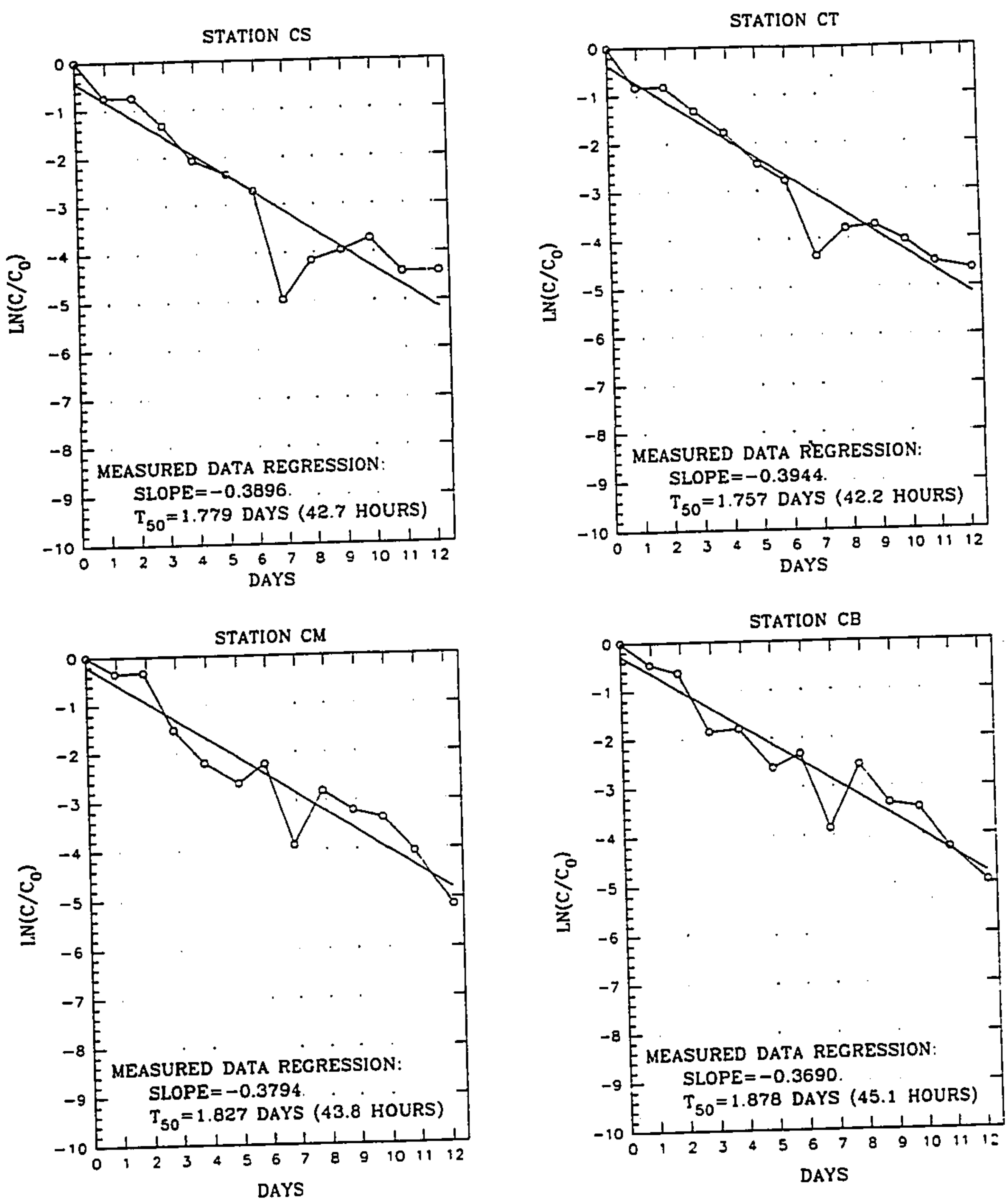

o MEASURED. STRAIGHT LINE: LINEAR REGRESSION LINE

ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	Analysis Of The Ala Wai Canal Dye Measurements At Dye Sampling Station C	FIGURE 2-19

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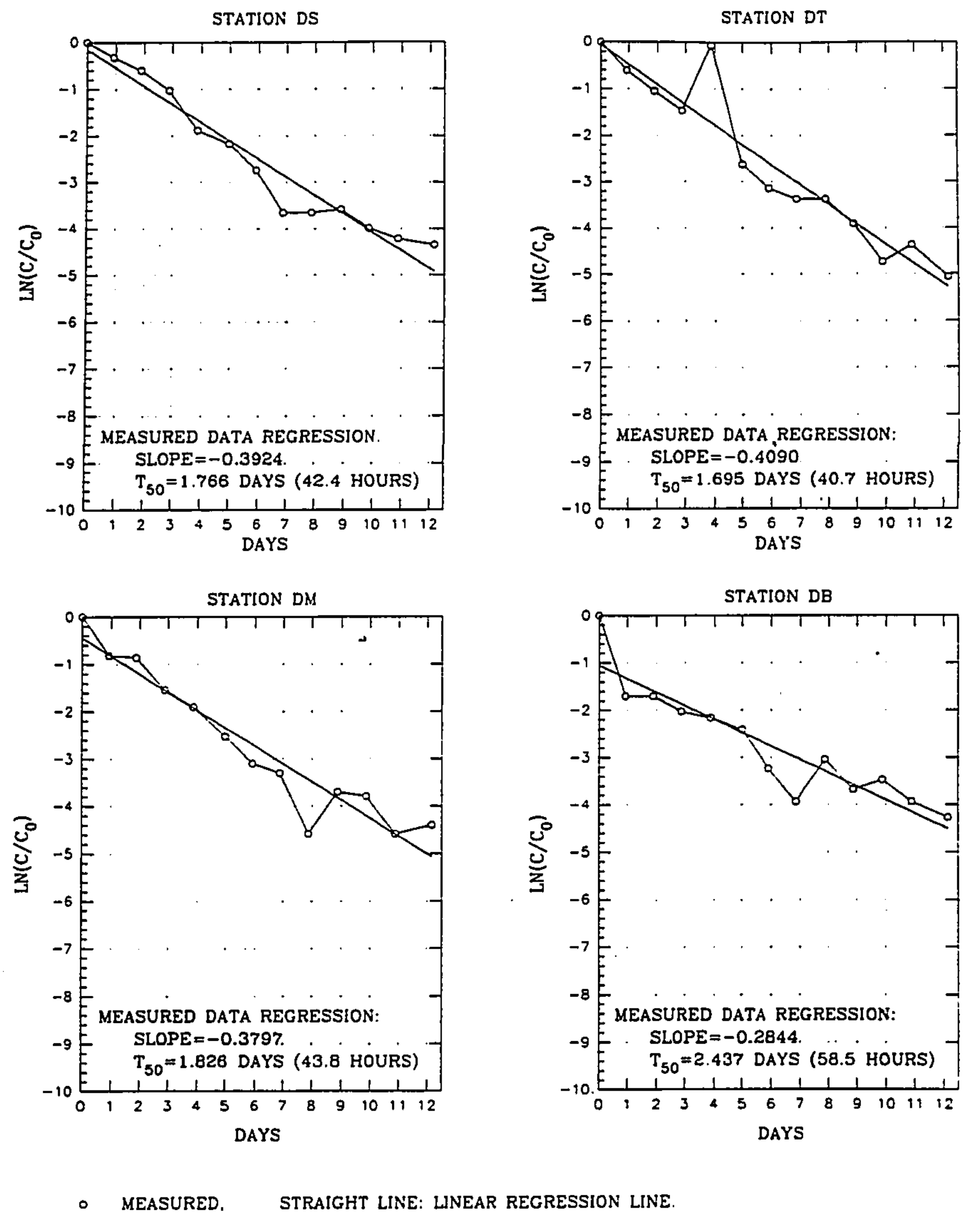


ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	Analysis Of The Ala Wai Canal Dye Measurements At Dye Sampling Station D	FIGURE 2-20

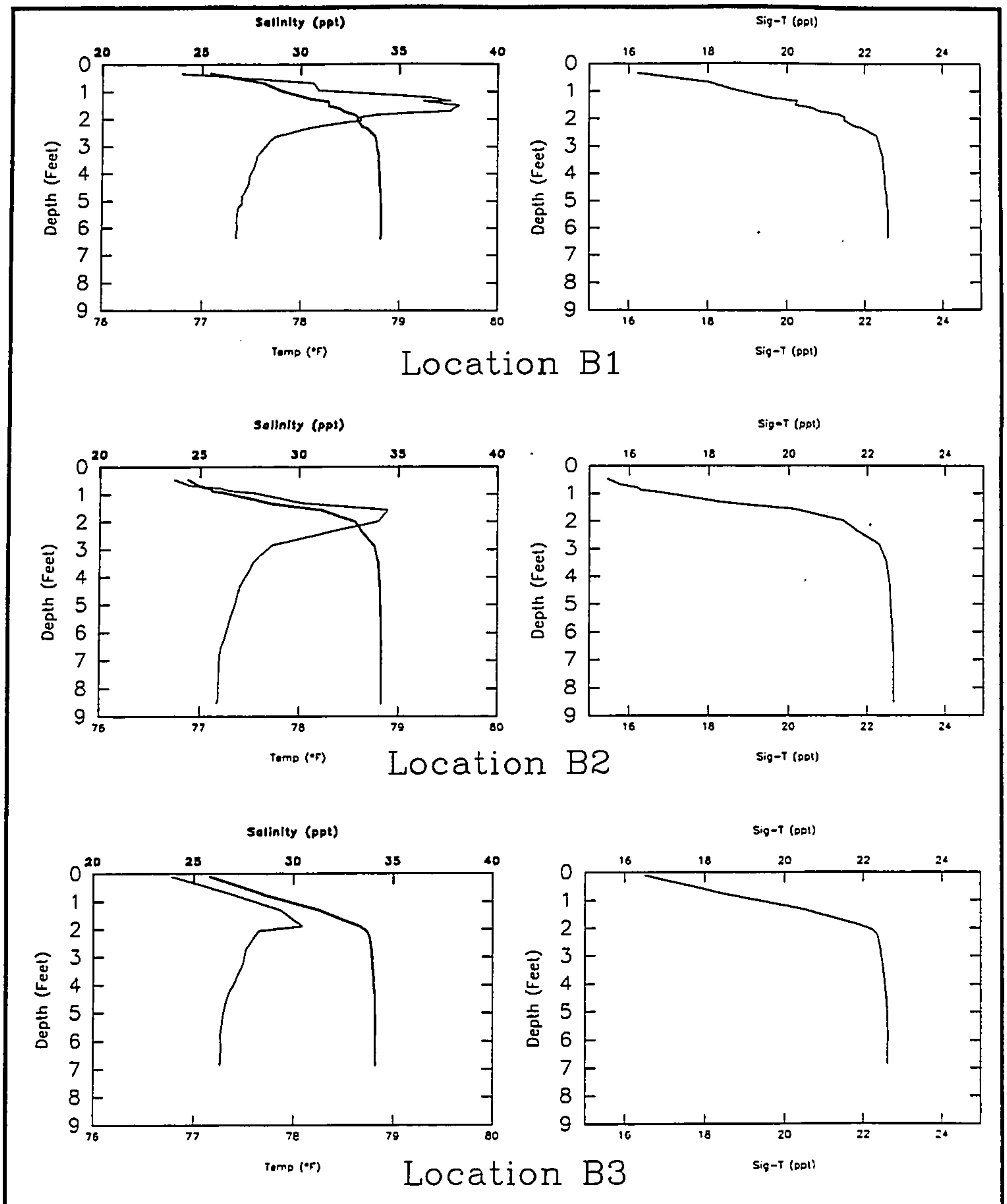
of the station location and time of day. The station number designation such as B2 refers to dye station B in Figure 2-16, and the number 2 refers to the center station.

Figures 2-21 to 2-23 describe the salinity-temperature-depth profiles at each of the station locations, where salinity is calculated from the conductivity measurements. Figures 2-21 to 2-23 also show the water density as measured in sigma-T units. The results in Figures 2-21 to 2-23 clearly show the very distinct two-layer characteristics, particularly at Station B and C located downstream from the Manoa-Palolo Stream, where both the salinity and water temperatures vary considerably in the upper 2 to 3 feet near the surface, and stabilize to near-oceanic salinity conditions in the lower part of the water column. Notice the temperature variations in the upper layer at Stations B and C where the near surface temperature is lowest due to the colder, fresh water inflows primarily from the Manoa-Palolo Stream, mixing with the sun-heated surface waters. Since the lighter surface fluid is restrained by buoyancy forces to the top layer, the effects of sun-heating causes the water temperature to reach a maximum in the lower part of the brackish layer. The temperature and salinity profiles then transition to near ocean water conditions in the lower depths.

At Station D located between the Manoa-Palolo Stream confluence and the Kapahulu end of the AWC, the water temperature profiles shown in Figure 2-23 display a monotonically decreasing function with depth. This indicates the reduced influence of fresh water inflow into this section of the Ala Wai Canal.

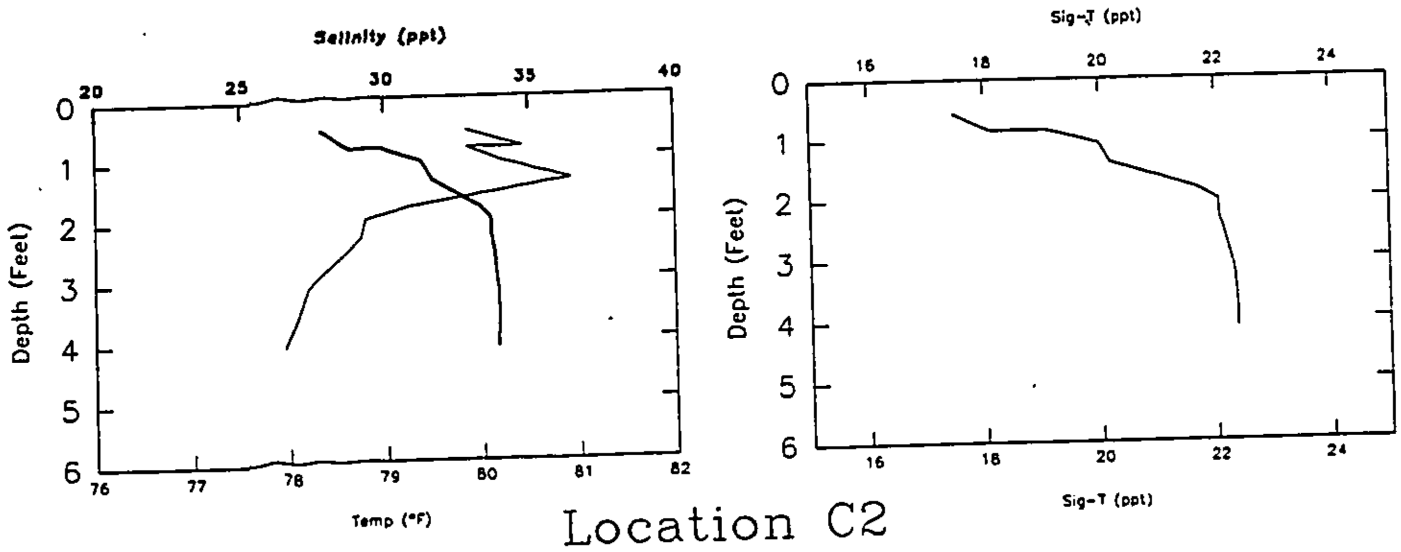
Figures 2-24 and 2-25 show a summarized display of the current speeds in and out of the Ala Wai Canal as a function of the dye sampling station locations B, C and D (Figure 2-16), and as a function of both water depth and time of day. The multi-layer flow characteristics of the AWC are clearly evident in Figures 2-24 and 2-25.

For reference, the wind data from the Honolulu International Airport (HIA) during the period of the dye study is provided in Figures 2-26 and 2-27. Gonzalez (1971) concluded that the wind speed and direction data recorded at the HIA were fairly good indications of the wind vectors at the Ala Wai Canal, for the exposed quadrants of the Canal. Also, Figure 2-28 presents the discharge flow rates from the Waiakeakua Stream U.S. Geological Survey (USGS) gaging station. It should be noted that the Waiakeakua Stream gaging station is located in the very upper part of the Manoa watershed, and thus provides only a relative indication of the surface runoff discharge conditions.

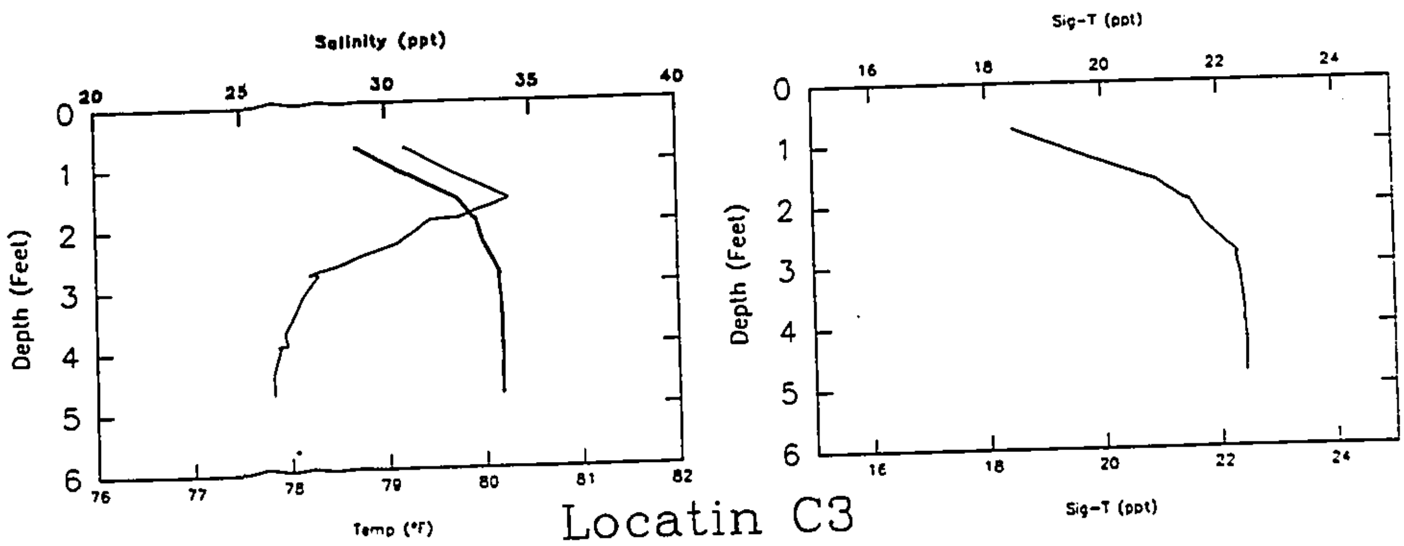


ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	Salinity, Temperature And Density Profile At Station B	FIGURE 2-21

INVALID DATA OBTAINED AT Location C1

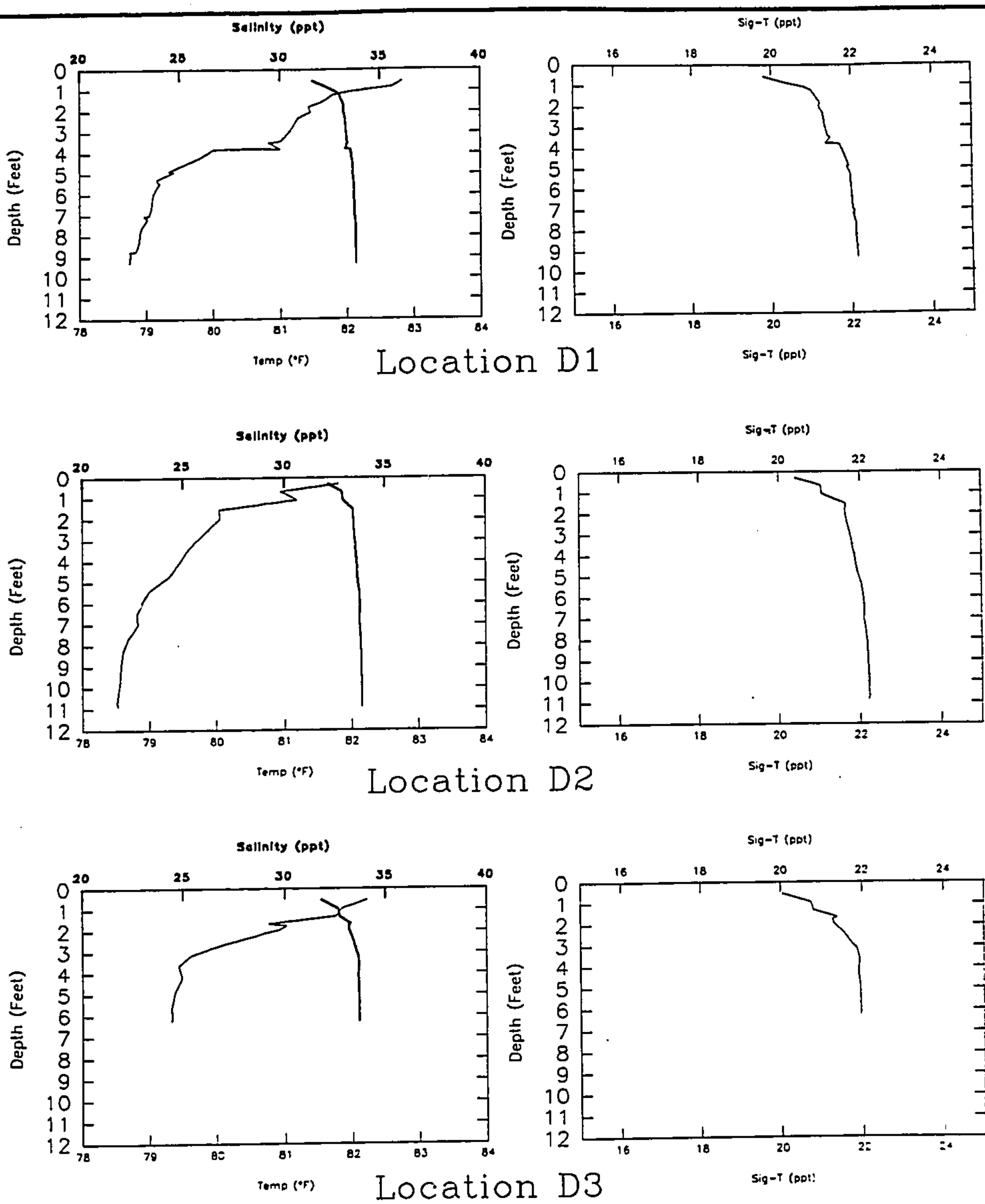


Location C2

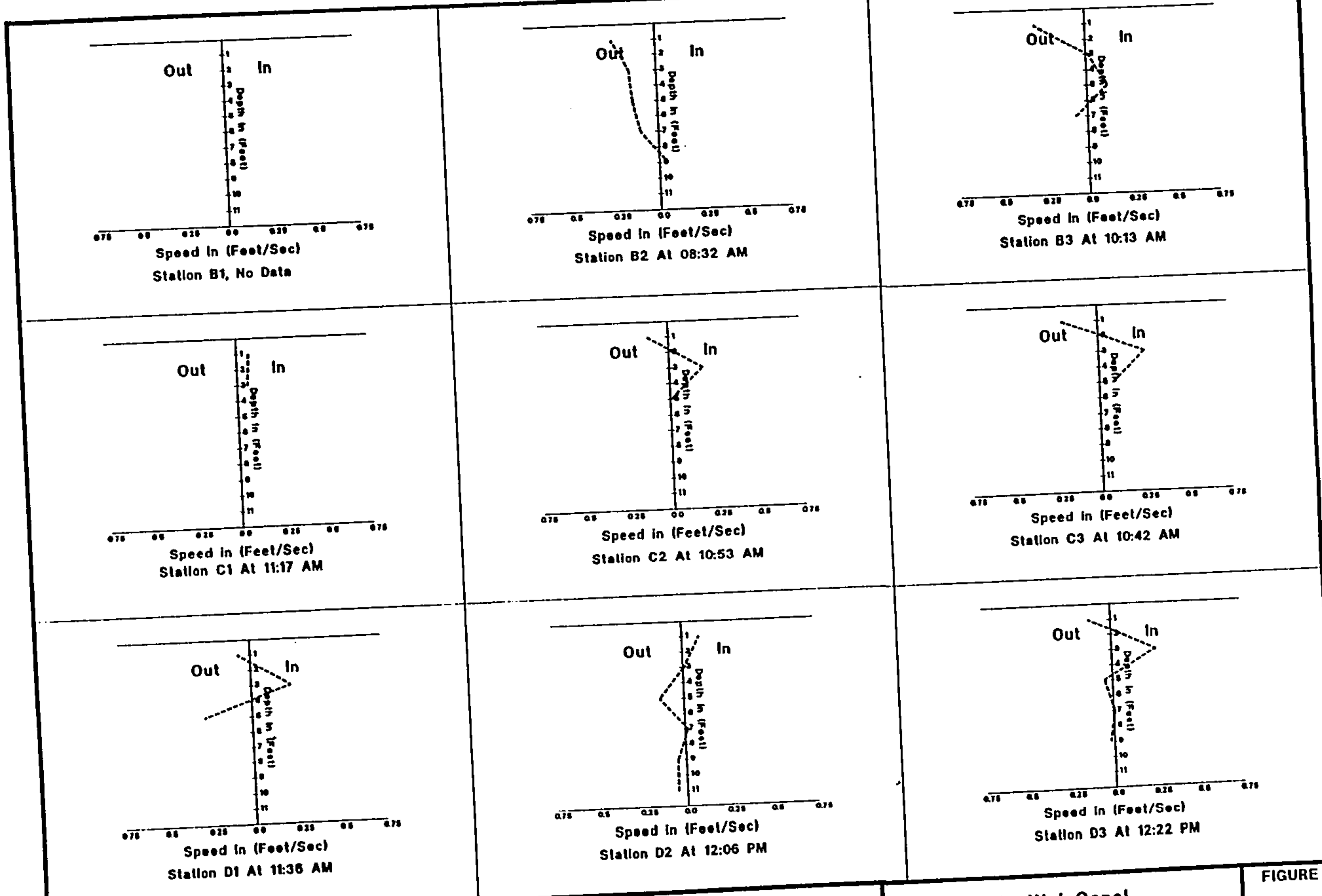


Locatin C3

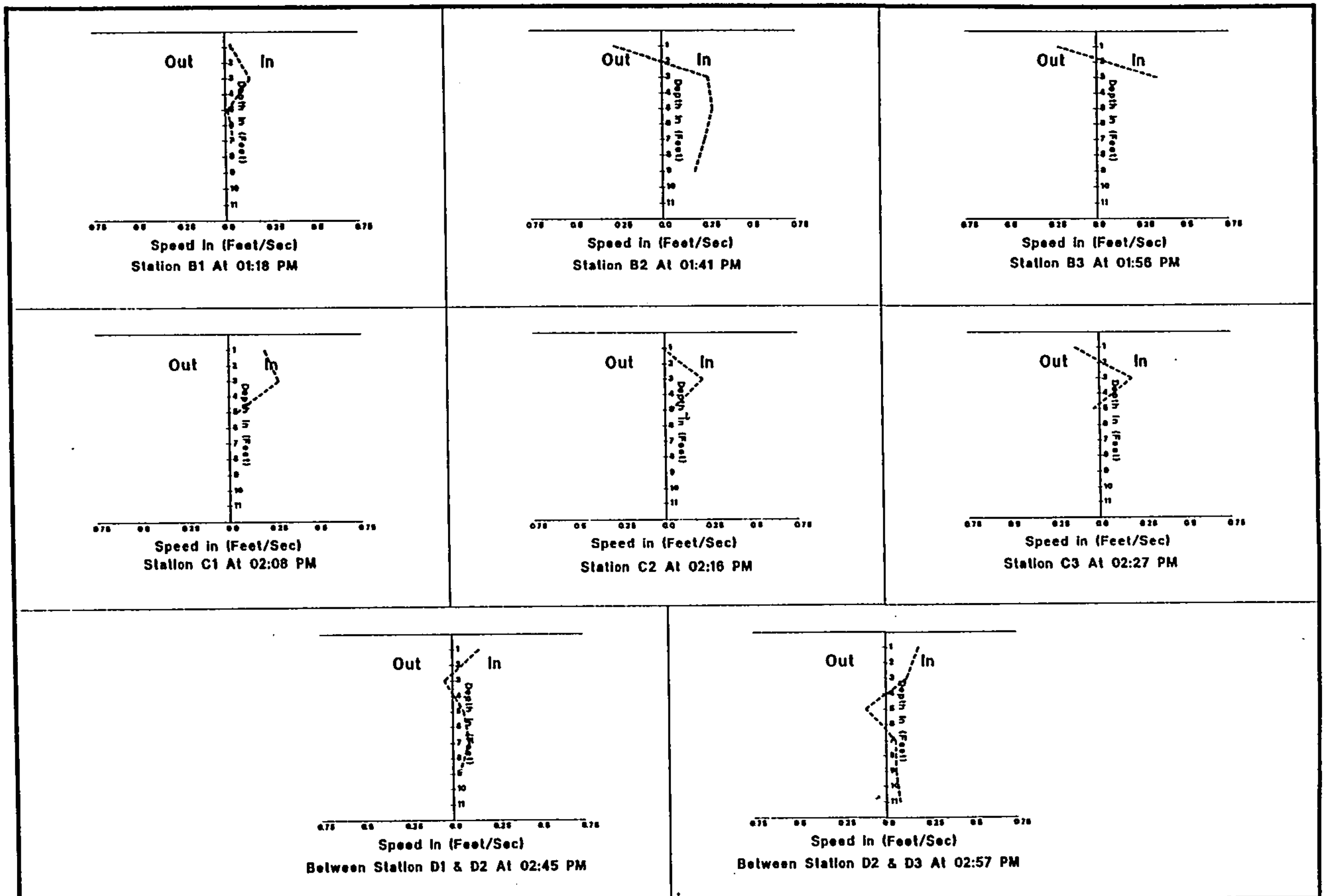
ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	Salinity, Temperature And Density Profile At Station C	FIGURE 2-22



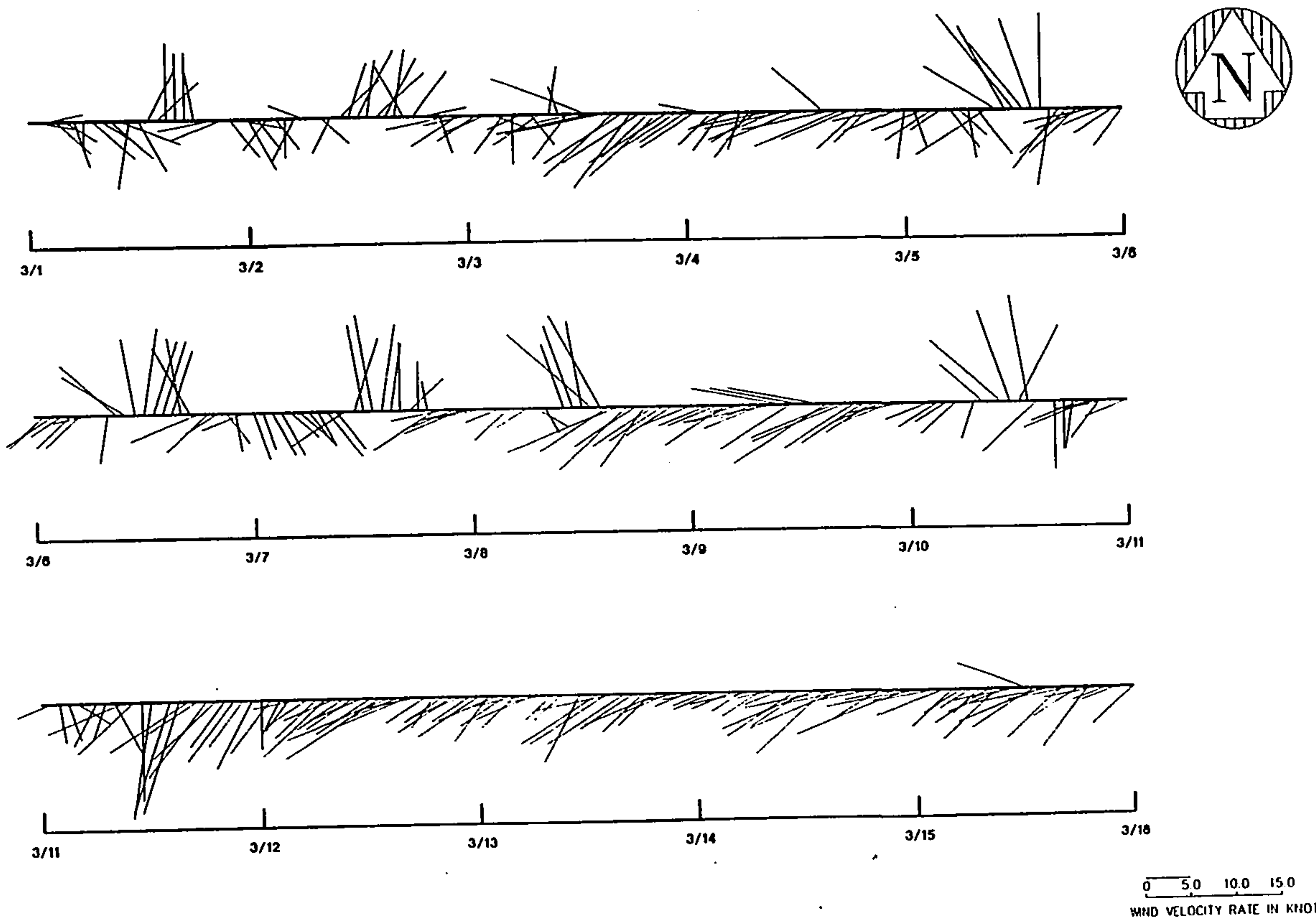
ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	Salinity, Temperature And Density Profile At Station D	FIGURE 2-23



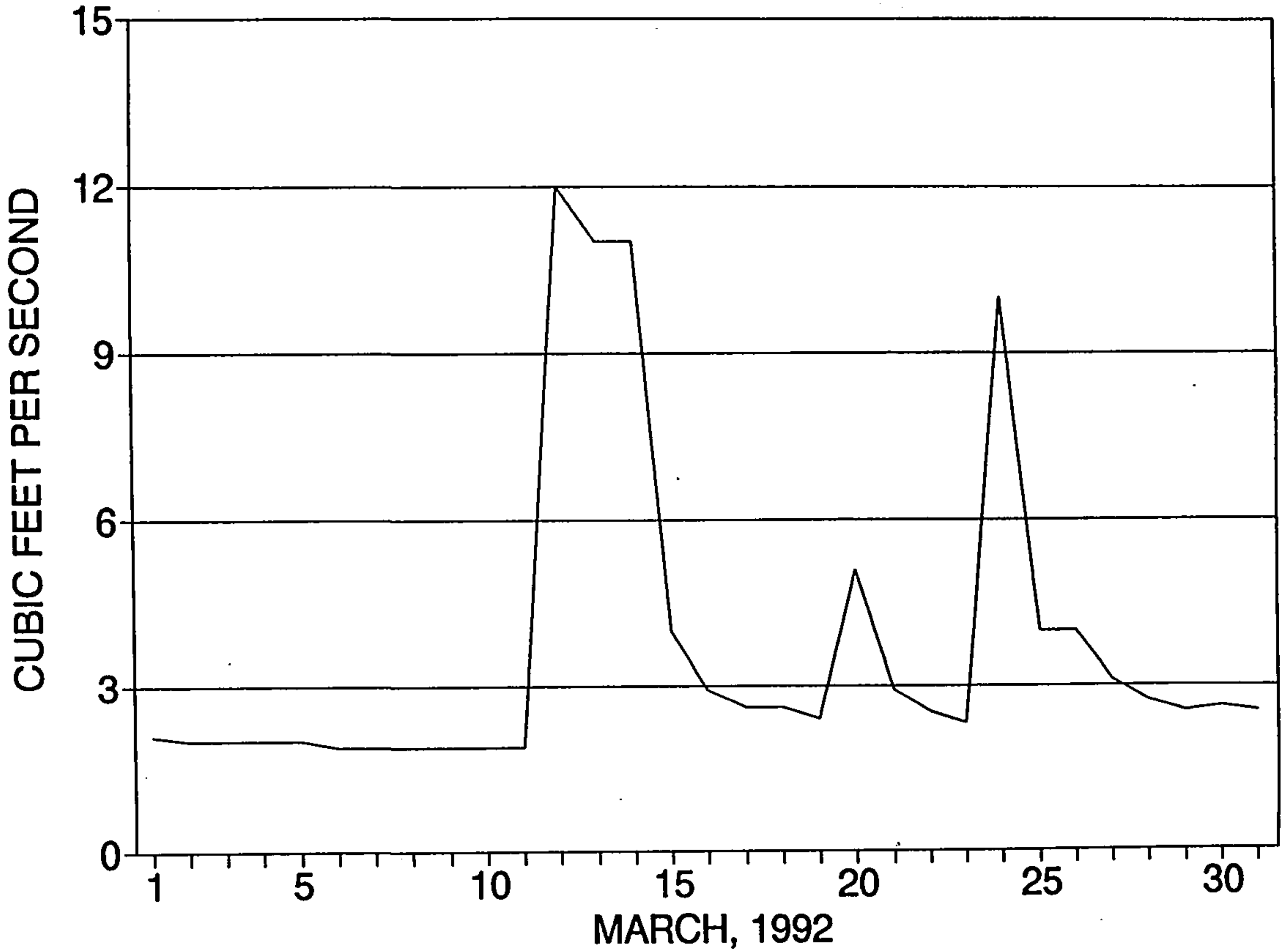
ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	Ala Wai Canal Vertical Profile Of Currents Measured On March 3, 1992	FIGURE 2-24



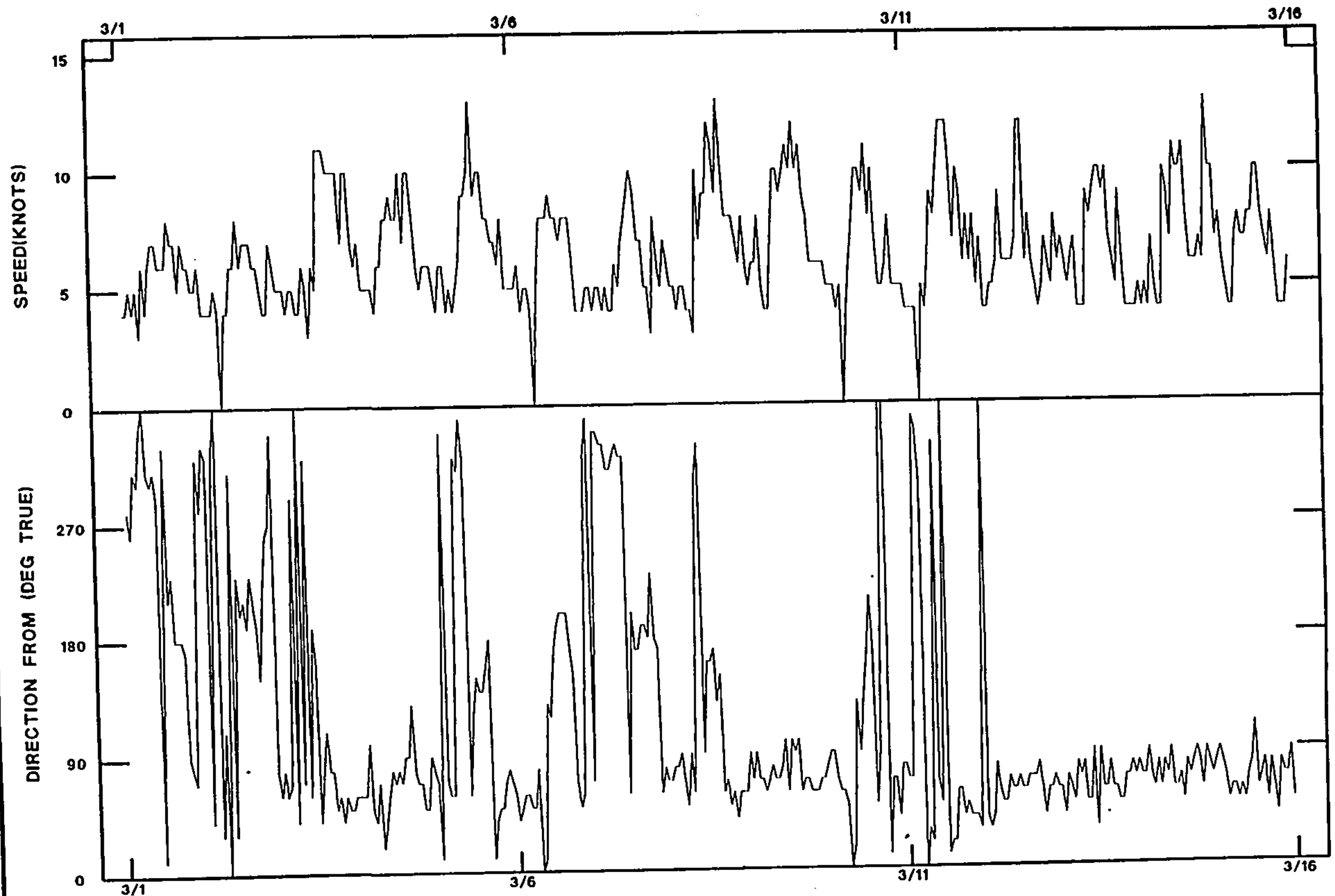
ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	Ala Wai Canal Vertical Profile Of Currents Measured On March 3, 1992	FIGURE 2-25



ALA-WAI CANAL IMPROVEMENT	Edward K. Noda and Associates, Inc.	NOAA WIND DATA FROM 3/1 TO 3/15 OF 1992	FIGURE 2-26



ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	WAIAKEAKUA STREAM WATER DISCHARGE	FIGURE 2-28



ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	WIND DATA AT HONOLULU INTERNATIONAL AIRPORT FROM 3/1 TO 3/15, 1992	FIGURE 2-27

CHAPTER 3.0

BIOLOGICAL AND WATER QUALITY ENVIRONMENT

CHAPTER 3.0
BIOLOGICAL AND WATER QUALITY ENVIRONMENT

3.1. INTRODUCTION

The Ala Wai Canal is a man-made tidal estuary which serves as the major drainage conduit for the Waikiki District of Oahu as well as the approximately 16.3 square mile watershed directly mauka of the Canal (Makiki, Manoa, St. Louis Heights, Palolo, Moiliili, Kapahulu and parts of Kaimuki and Diamond Head). As the collecting point for this watershed, the Canal accumulates sediments, nutrients, some heavy metal contamination, and solid waste trash. The results of these contaminations are reflected in discoloration of the water due to phytoplankton growth and suspended sediments, and visually objectionable trash; in addition, some incidence of bacterial infections has been reported.

The original Ala Wai Canal design was part of the Waikiki reclamation project (1919). The intent of that project was to reclaim the adjacent swamps and marshlands (Waikiki, Kapahulu and Moiliili) for flood control and sanitary reasons, and the Canal was to serve as a collection system and siltation basin for runoff and stream flow from the adjacent watershed. Since that time, the perception of the Canal has changed from being merely a collection and siltation basin to being an important water feature with potentially great impact to the surrounding resort and residential neighborhoods. For that reason, the State of Hawaii desires to study the feasibility of cleaning the Ala Wai Canal to improve water quality in the Canal to levels acceptable for recreational activities. This objective could be met by a combination of engineering modifications, including increasing water flow and circulation in the Canal, while at the same time addressing environmental concerns, decreasing the sources of pollutants through watershed management, and establishing routine maintenance and management practices for the Canal.

The primary objectives of this chapter's efforts are to describe the existing environmental conditions within the Canal, and to provide input data for a hydrodynamic-ecological model of the Canal. This model will serve to identify pivotal parameters which affect water quality within the Canal, and establish targets which can be used to examine the effectiveness of different engineering alternatives such as routine maintenance measures (e.g., dredging), improved flushing rates and water circulation in the Canal. In order to choose the best of several engineering solutions to the water quality issues for the Canal, a series of water quality samples were collected to characterize the water quality conditions within the Canal and within the source waters (streams, ground water, ocean water) for the Canal. These data are analyzed and compared with the available historical water quality data base for development of the Canal model.

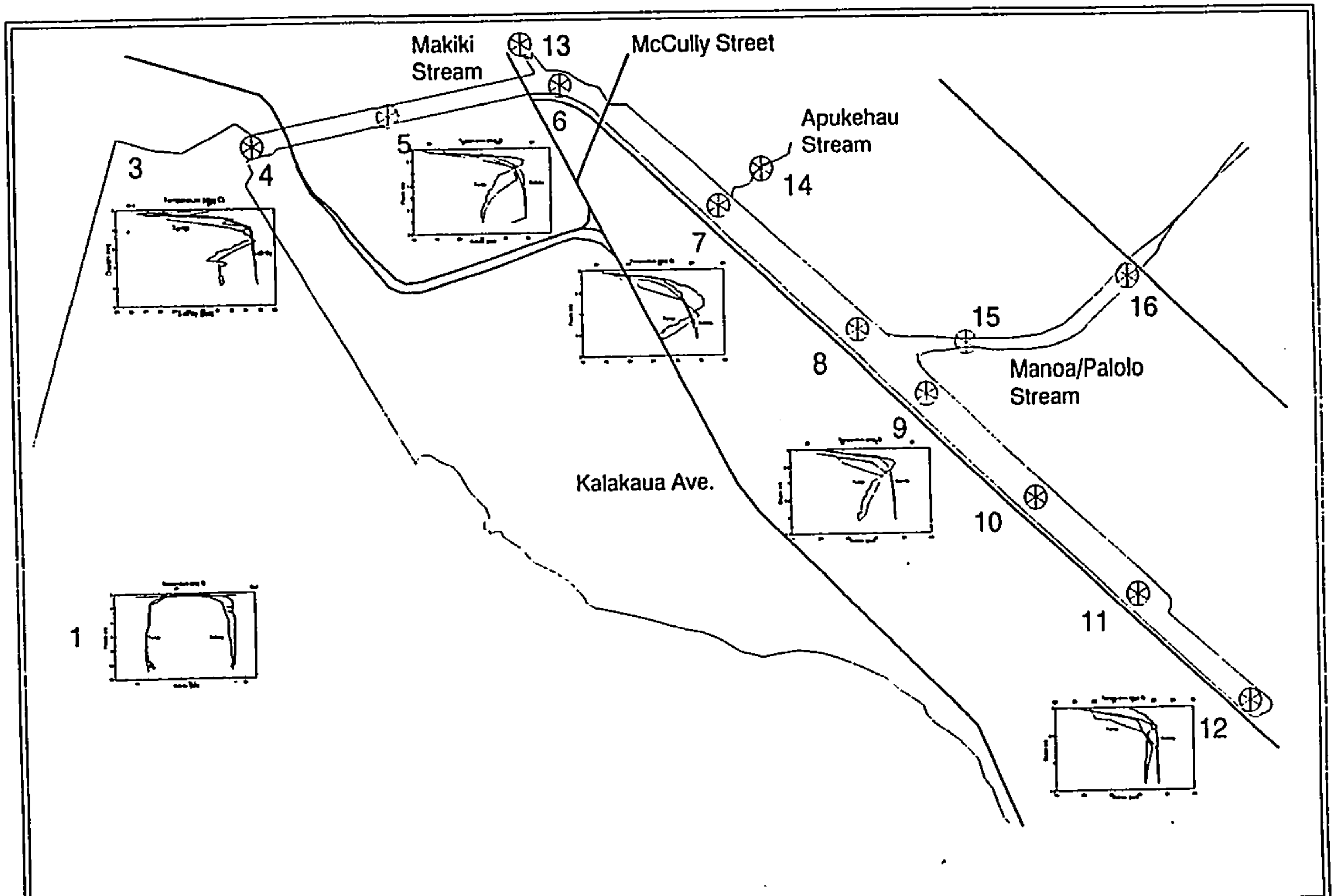
3.2. METHODS

Water quality samples were collected at sixteen stations within and offshore the Ala Wai Canal, and in the major streams discharging into the Canal (Figure 3-1). Samples were collected at or near high tide on six sampling days: October 3, November 1, December 3, 1991, January 7, February 8, and March 3, 1992. Samples were collected at three depths at most stations within the Canal and nearshore marine waters: 0.5 m below the surface, 0.5 m above the bottom, and at mid-depth. Only surface or surface and bottom samples were taken at Station 8, the shallow mud flat at the confluence of the Manoa-Palolo Stream. Samples within the major streams feeding the Canal were taken at mid-depth. Samples were collected with Niskin bottles closed at the target depth, or with 500 ml polyethylene bottles for the stream samples. Samples for bacteriological analysis were collected directly into 100 ml specimen cups and placed in a cooler at ambient temperature; all other samples were collected into 1 liter polyethylene bottles and placed over ice until processed in the lab. Continuous profiles of temperature and salinity were taken on several dates utilizing a conductivity/temperature/depth recorder with fine (10 cm) vertical resolution.

Water quality parameters to be measured included those listed in the State of Hawaii water quality standards for open coastal and estuarine waters, and additional parameters which provide information on ground water sources and influence: temperature, salinity, total nitrogen, nitrate-nitrite, ammonium, total phosphorus, orthophosphate, reactive silicate, turbidity, suspended solids, particulate carbon and nitrogen, chlorophyll, dissolved oxygen, Ph, fecal coliforms and enterococci. The methods used for each analysis are presented in Table 3.1.

3.3. RESULTS

3.3.1. Temperature/Salinity. Continuous profiles of temperature and salinity for selected stations in the nearshore marine environment and the Ala Wai Canal on January 7, 1992, are presented in Figure 3-2. Features seen in the figure are typical for the Canal and adjacent waters under most tide and wind conditions. Nearshore waters (Station 1) show patterns of generally vertically uniform temperature and salinity below about 1 m depth, with a low salinity, higher temperature layer overlying this. The upper layer is the relatively unmixed outflow of brackish water from the Canal. The salinity profile at Station 3 reflects the greater influence of brackish water near the Canal mouth, with the brackish



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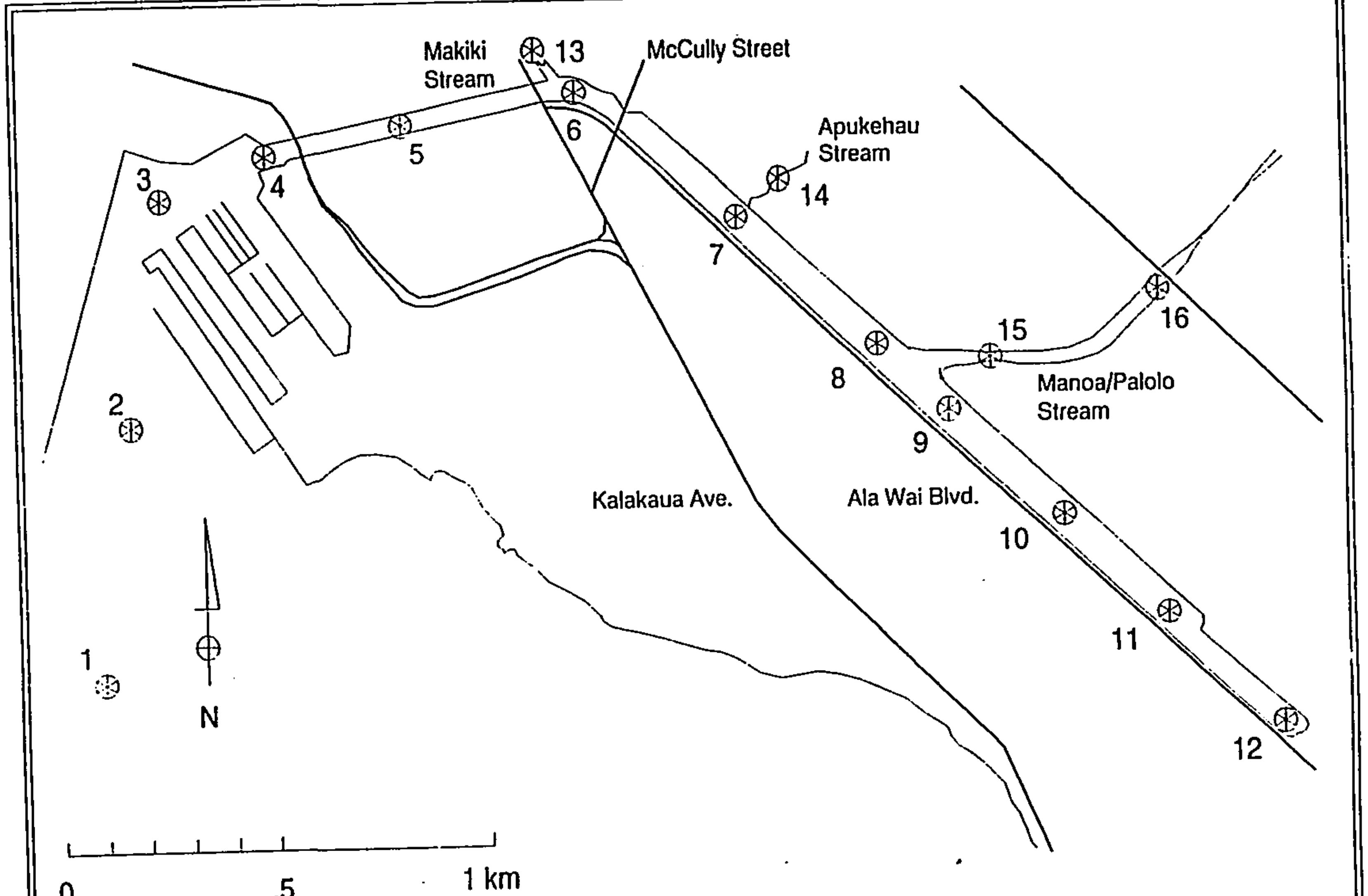
Temperature-salinity profiles for selected stations on January 7, 1992.

Figure 3-2



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WATER QUALITY STATIONS

Figure 3-1

layer extending to 2 m depth and surface salinity as low as 27 ppt. The temperature profile appears to reflect some degree of solar heating of the upper layer, also seen at Station 1, with a cooler surface (<0.5 m depth) layer.

TABLE 3.1
Collection and Analysis Methods for the Ala Wai Canal
Measured Water Quality Parameters

Water Quality Parameter	Collection and Analysis Method
Water Quality Samples	
Temperature	Precision thermometer
Salinity	Laboratory salinometer
Nutrients	
Total nitrogen	Technicon AutoAnalyzer II; D'Elia et al, 1977
NH4	Technicon AutoAnalyzer II; Solorzano, 1969
NO3/NO2	Technicon AutoAnalyzer II; Technicon Inc., 1977
Total Phosphorus	Technicon AutoAnalyzer II; Grasshoff et al, 1983
PO4	Technicon AutoAnalyzer II; Murphy and Riley, 1962
SiO4	Technicon AutoAnalyzer II; Strickland and Parsons, 1972
Particulate Carbon	Carbon-Nitrogen Analyzer; Grasshoff et al, 1983
Particulate Nitrogen	Carbon-Nitrogen Analyzer; Grasshoff et al, 1983
Chlorophyll	Turner Designs fluorometer; Strickland and Parsons, 1972
Turbidity	Turner Designs nephalometer; APHA, 1986
Suspended Solids	Filtration, electrobalance; APHA, 1986
Dissolved Oxygen	YSI laboratory oxygen meter
pH	Orion digital pH meter
Fecal Coliform	Filtration, incubation; APHA, 1986
Enterococcus	Filtration, incubation; APHA, 1986

Salinity profiles at stations 5, 7, 9, and 12 were generally similar, with a near-seawater salinity (34.5 ppt) layer extending from 1 m depth to the bottom, and a surface layer of brackish water, with salinities as low as 15 ppt at stations 5 and 7, and slightly higher salinity (20 ppt) toward the Canal head. Temperature profiles at these stations were also similar, with a temperature maximum at about 1 m depth, decreasing toward the bottom and toward the surface.

3.3.2. Groundwater Budget. The groundwater influx to the Ala Wai Canal was estimated from profiles of salinity taken at stations 3 - 12 in the Canal on February 8, 1992. For each station profile, the volume of fresh water necessary to decrease the salinity from the maximum observed to that observed at each sampling interval for the CTD was calculated from the equation

$$Vol_{(fw)} = 1 - \frac{Sal_{(obs)}}{Sal_{(max)}}$$

where $Vol_{(fw)}$ is the volume of fresh water (m^3) per unit area (m^2); $Sal_{(obs)}$ is the observed salinity at each depth interval; and $Sal_{(max)}$ is the maximum salinity observed at any station. The values of $Vol_{(fw)}$ for each depth interval were summed to give the areal fresh water at each station ($m^3\ m^{-2}$). The data are presented in the Table 3.2. The channel cross-sectional (x-section) distance (column 2) was determined from the bathymetric survey map for each station; the longitudinal (along-axis) distance (column 3) was determined from the same map for sections defined as being bound by the mid-point between stations. The sectional fresh water volume (column 7) was calculated from the areal volume times cross-section distance times sectional length. These values were then summed to calculate the volume of fresh water contained within the Canal at that particular time. The volume of fresh water was calculated as 111,053 m^3.

Since salinity profiles from different sampling days have been generally similar, we assumed that the ground water influx is in steady state with mixing and outflow. Recent dye studies (Chapter II.D) provide estimates of the T_{50} (the time to decrease the concentration of a material by 50%) for the Canal. For all shallow layers at stations within the Canal, the T_{50} times were generally 40-45 hours. The daily turn-over rate can be calculated from the T_{50} rate, and is estimated to be 33%; i.e., approximately 1/3 of the water in the canal is exchanged (removed) each day. Thus, at steady state, the volume of fresh water entering the Canal is approximately 36,647 $m^3\ d^{-1}$. Assuming that the influx is relatively constant over the length of the Canal (3,221 m), the calculated input per unit length is 11.4 $m^3\ m^{-1}\ d^{-1}$, or approximately 4.83 million gallons per day (mgd) per mile. This daily input rate is similar to that calculated for other islands (1 - 6 mgd per mile). The value is an estimate of the total freshwater inflow to the Canal. It actually includes both groundwater and stream input, although no estimate of fresh water input by streams was included. However, stream flows during the period of salinity profiling were low, so the estimate of groundwater influx is probably not a large overestimation.

TABLE 3.2
Calculation of Groundwater Influx into the Ala Wai Canal.

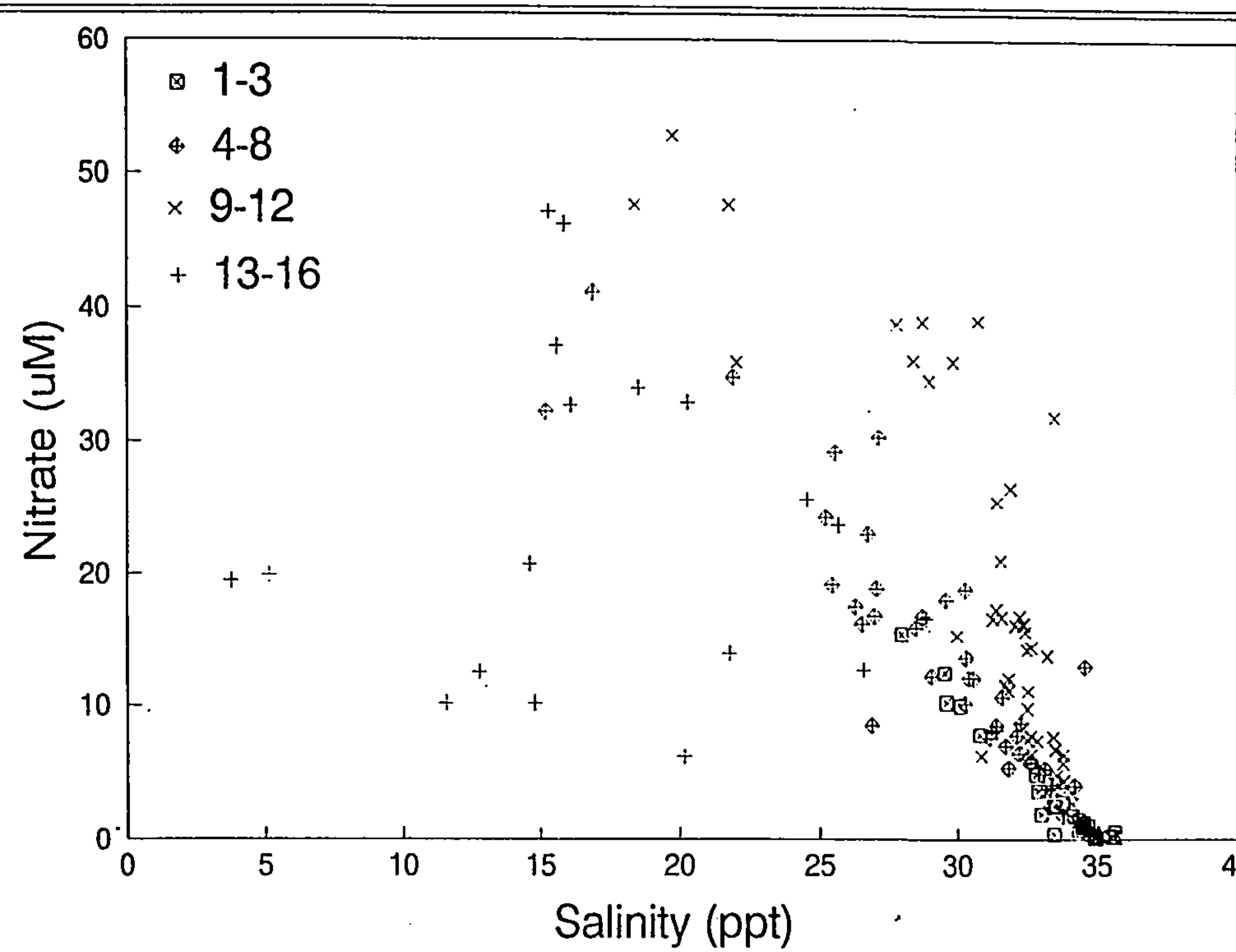
Station	Channel Width (m)	Section Length (m)	Section Area (m^2	Areal fw (m^3/m^2)	X-Section fw (m^3/m)	Section fw (m^3/section)
1	685	----	----	0.031	21	----
2	113	----	----	0.190	21	----
3	71	----	----	0.300	21	----
4	67	411	27,556	0.316	21	8,708
5	60	366	21,919	0.372	22	8,154
6	57	411	23,485	0.495	28	11,625
7	89	457	40,447	0.439	39	17,756
8	89	297	26,290	0.365	32	9,596
9	89	251	22,246	0.471	42	10,478
10	89	331	29,324	0.552	49	16,187
11	89	388	34,380	0.560	50	19,253
12	80	308	24,659	0.377	30	9,297
TOTAL		3,221	250,306		111,053 36,647 11.4 4.83	m3/canal m3/canal/d m3/m/d mgd/mile

3.3.3. Water Quality. Results of the water quality analyses for six sampling days are presented in Appendix E. The nutrient data show that the Canal can be regarded as having three distinctly different regions, as illustrated by the plots of dissolved nutrients against salinity. Figure 3-3 shows the plot of nitrate against salinity for samples from all six cruises. The data fall into four groups: stations 1-3, outside the Canal proper; stations 4-8, from the Canal mouth to the confluence of the Manoa-Palolo Stream; stations 9-12, the head of the Canal; and stations 13-16, the influent streams. These patterns are more or less consistent between monthly sampling periods for silicate, nitrate, ammonium and phosphate.

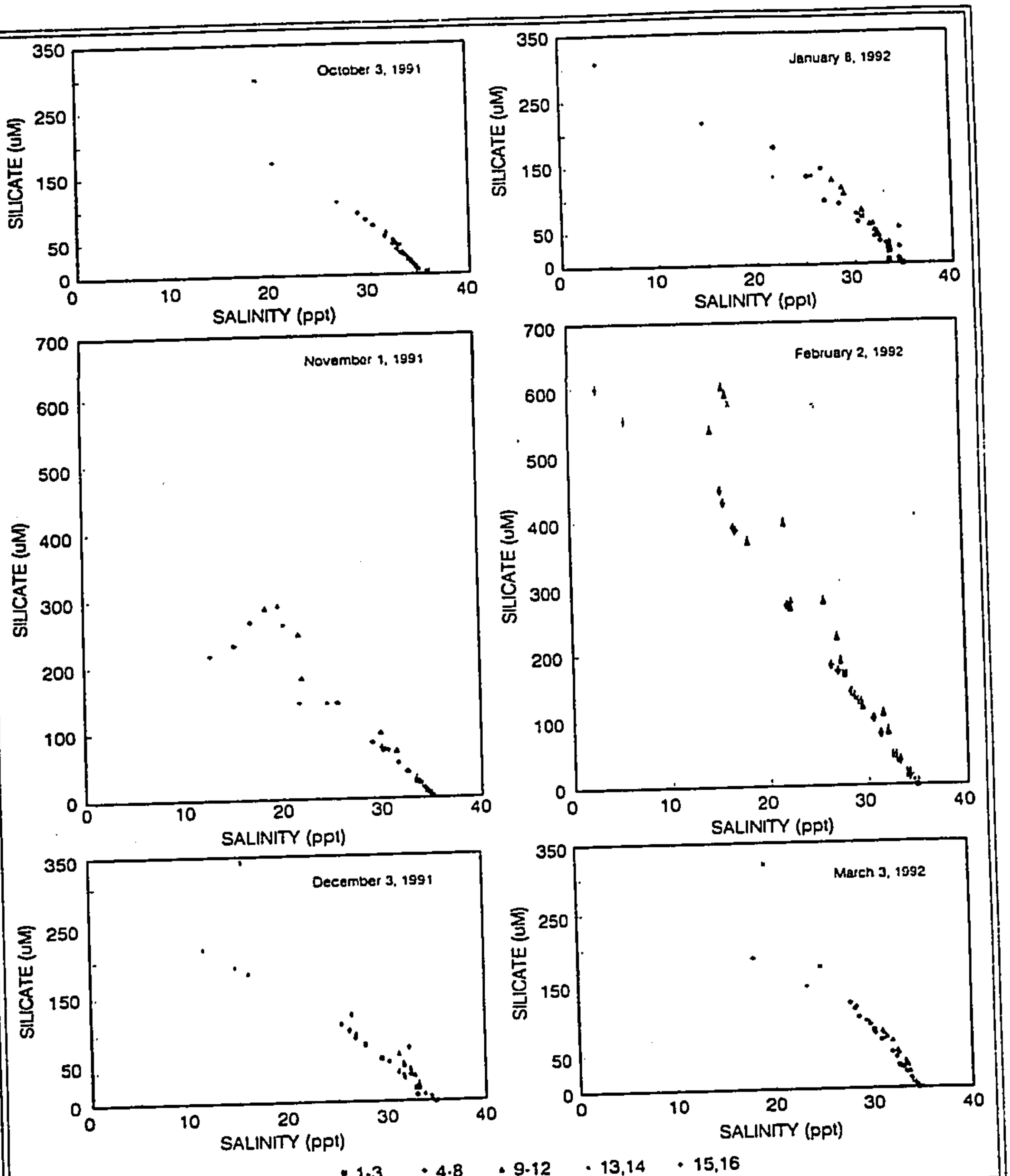
The samples collected in February and March provide particular information on the characteristics of stream inputs to the system. The data show (see Table 6b, Appendix E for example) that Makiki Stream is primarily a source of high-nutrient water with characteristics similar to groundwater (i. e., high silicate, nitrate and phosphate). Water of this type is found immediately downstream of the stream source during dry weather. Silicate levels remain relatively constant but levels of nitrate and phosphate decrease downstream, possibly due to active uptake by attached algae in the stream bed. In contrast, Manoa Stream shows the influence of surface runoff. Silicate levels are relatively low and constant throughout the Manoa-Palolo system (Manoa A-D, Palolo), indicating relatively low or no groundwater influx. Nutrient levels are very low at the head of Manoa Stream (Manoa A), and increase downstream. These stream water characteristics are reflected in the relationships between water quality parameters in the Canal.

Scatter plots of concentrations of water quality parameters against salinity provide a means of examining data for processes in addition to conservative mixing. In a plot of a parameter which is conservative (changed only by dilution, not by external inputs or uptake) against salinity, the data will fall on a straight line drawn between the end members of the data set, i. e., those data points which represent the minimum and maximum salinity values. In the case of groundwater or stream flow into the ocean, one end member is the undiluted groundwater or stream water (salinity = 0, other property generally high) and the other member is ocean water (salinity 35 ppt, other property generally low). If there is active uptake of the parameter (for example, algal uptake of nutrients), the data points will fall below the mixing line. If there is an external source of the parameter, data points will be found above the mixing line.

The plot of silicate versus salinity (Figure 3-4) illustrates the ideal conservative mixing pattern. In general, all the data points fall on a line connecting the low salinity, high silicate groundwater source (sampled in Makiki Stream, Station 13) and the high salinity,



OI Consultants, Inc. Makapuu Point Waimanalo, Hawaii 96795	ALA WAI CANAL ECOLOGICAL STUDY Nitrate-salinity relationship for all samples collected during this study.	Figure 3-3



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ALA WAI CANAL ECOLOGICAL STUDY

Silicate-salinity relationships for samples taken during six cruises during 1991-1992 at the Ala Wai Canal.

Figure 3-4

low silicate oceanic water. Note that stations 15 and 16 reflect water with different characteristics. These data from Manoa Stream suggest a different source of water in those streams.

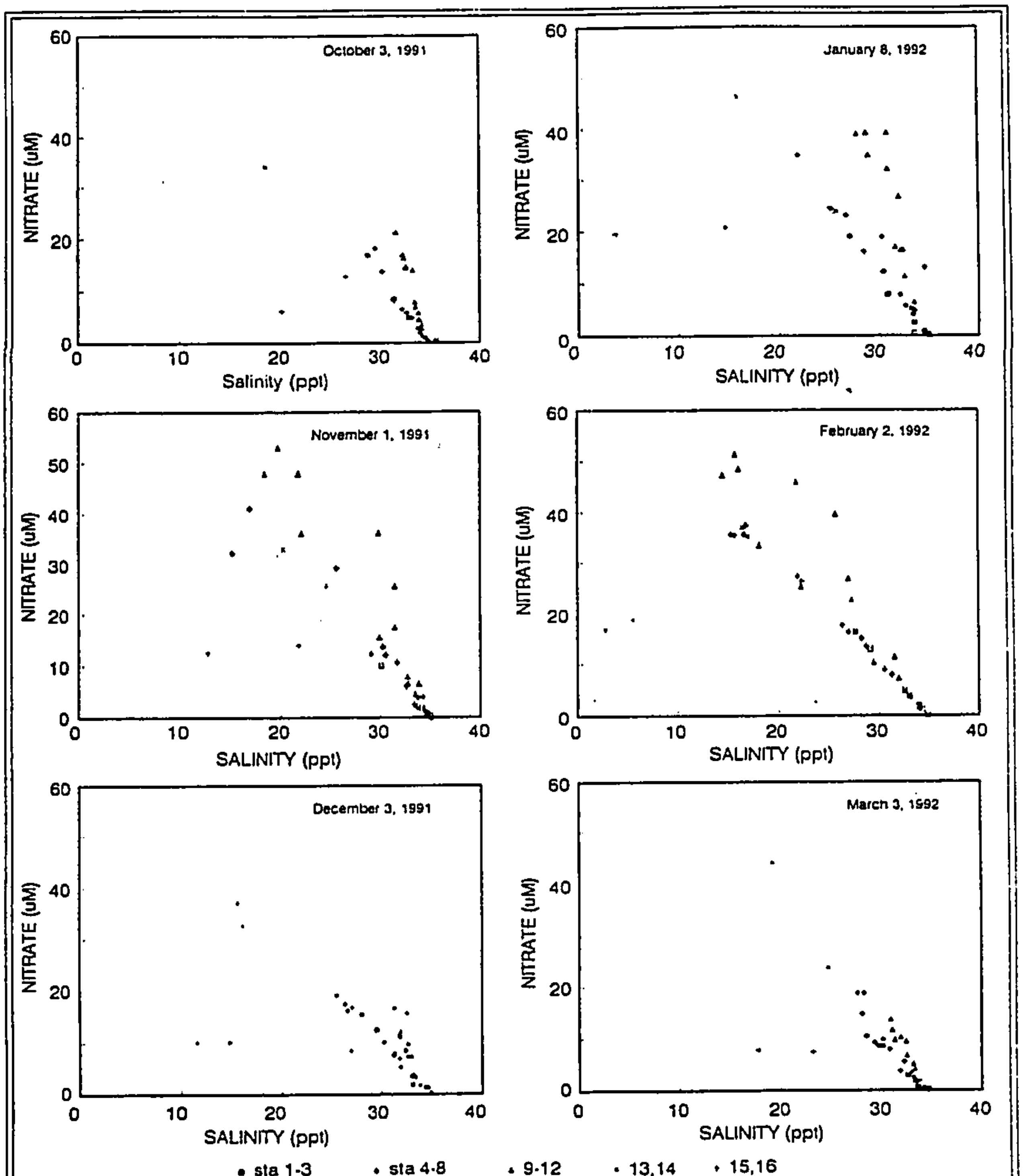
The nitrate-salinity plot (Figure 3-5) again shows the groundwater influence for most samples and the very different character of the Manoa Stream water. The plot also shows the increased nitrate levels in the Station 9 - 12 region, suggesting a terrestrial source. Note that the high nitrate levels at stations 9-12 are generally in the surface rather than bottom layer, suggesting a groundwater-related source rather than bottom-layer regeneration. Similar patterns are seen in the phosphate-salinity plot.

Nutrient ion concentrations, like silicate, generally have their highest concentrations in surface water. The concentrations increase towards the back of the canal up to station 8. From there to station 12 they remain relatively constant. At the Kapahulu end of the Canal (stations 10-12), ammonium is often elevated in bottom water, while nitrate-nitrite and phosphate maintain their maxima in surface water. This distribution pattern suggests freshwater as source of the oxidized nutrients (nitrate-nitrite and phosphate), while ammonium appears to be recycled in or at the sediment.

However, the correlation of the nutrient ions with silicate varies strongly depending on their origin. Water from the Manoa and Palolo streams (Figure E-7, Appendix E, Stations 15, 16) tends to be lower in phosphate than groundwater seeping into the Canal directly or via Makiki and Apukehau streams (Stations 13, 14). Often, a silicate- (i.e. groundwater) independent source of phosphate was found at stations 9-12, evidenced by data points above the conservative mixing line.

The composition of suspended matter varied (Figure 3-6), as indicated by the lack of consistent strong correlations between its components (chlorophyll, total suspended matter, turbidity, particulate carbon and nitrogen). Turbidity and total suspended solids were generally well correlated. Occasionally, high total suspended solids were not accompanied by high turbidity. Turbidity and chlorophyll were also well correlated. Total suspended solids tended to increase in bottom water from the mouth towards the end of the Canal, but varied little in surface water throughout the study area. Turbidity also tended to increase in profiles towards the sediment. Chlorophyll levels were generally highest in mid-depth and bottom samples.

Fecal bacteria counts appear to be related to surface runoff and stream flow. Highest numbers were found after periods of rain and increased stream flow. However, the numbers decreased rapidly in samples with near-seawater salinity.



OI Consultants, Inc. Makapuu Point Waimanalo, Hawaii 96795	ALA WAI CANAL ECOLOGICAL STUDY Nitrate-salinity relationships for samples taken during six cruises during 1991-1992 at the Ala Wai Canal.	Figure 3-5

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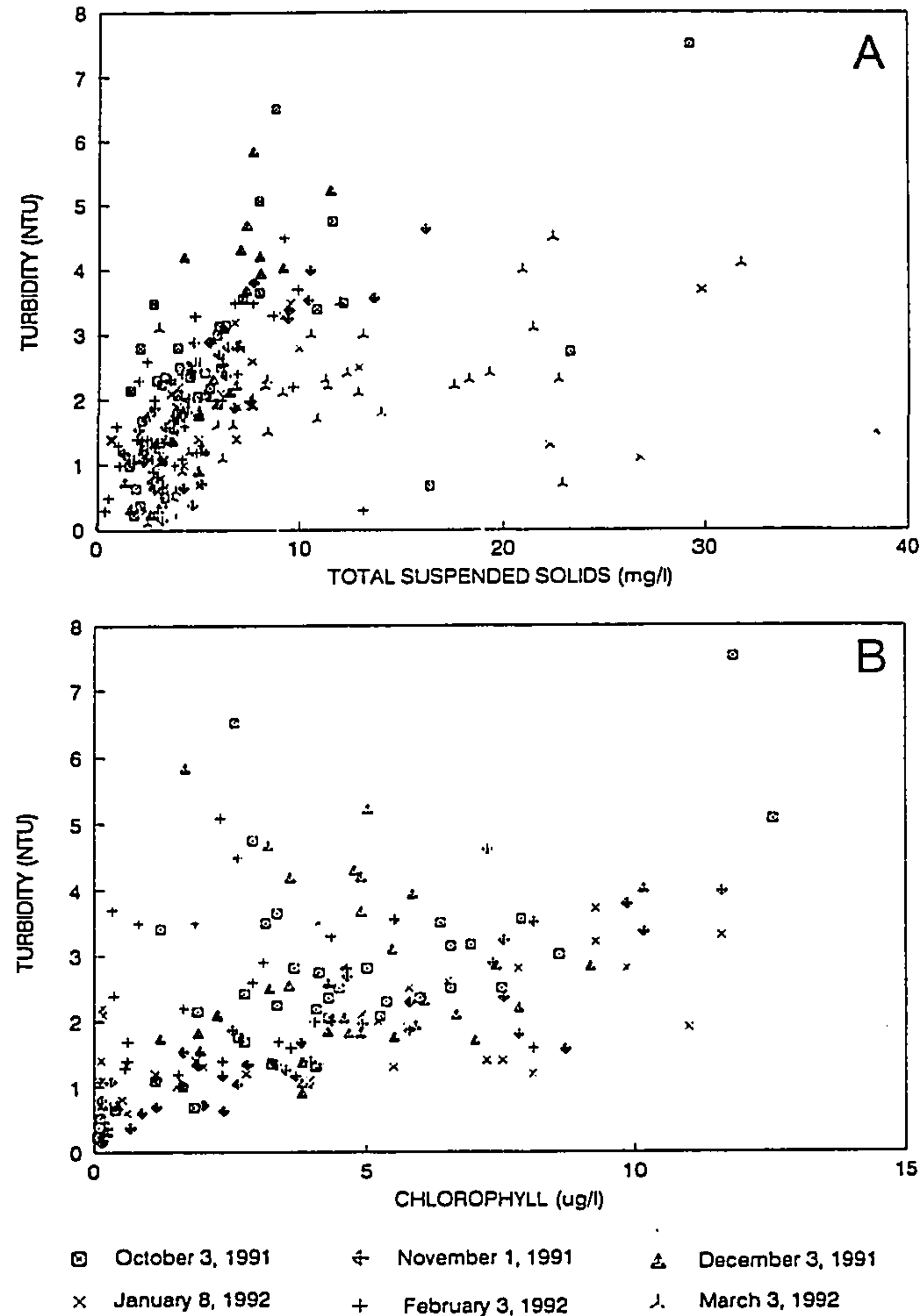


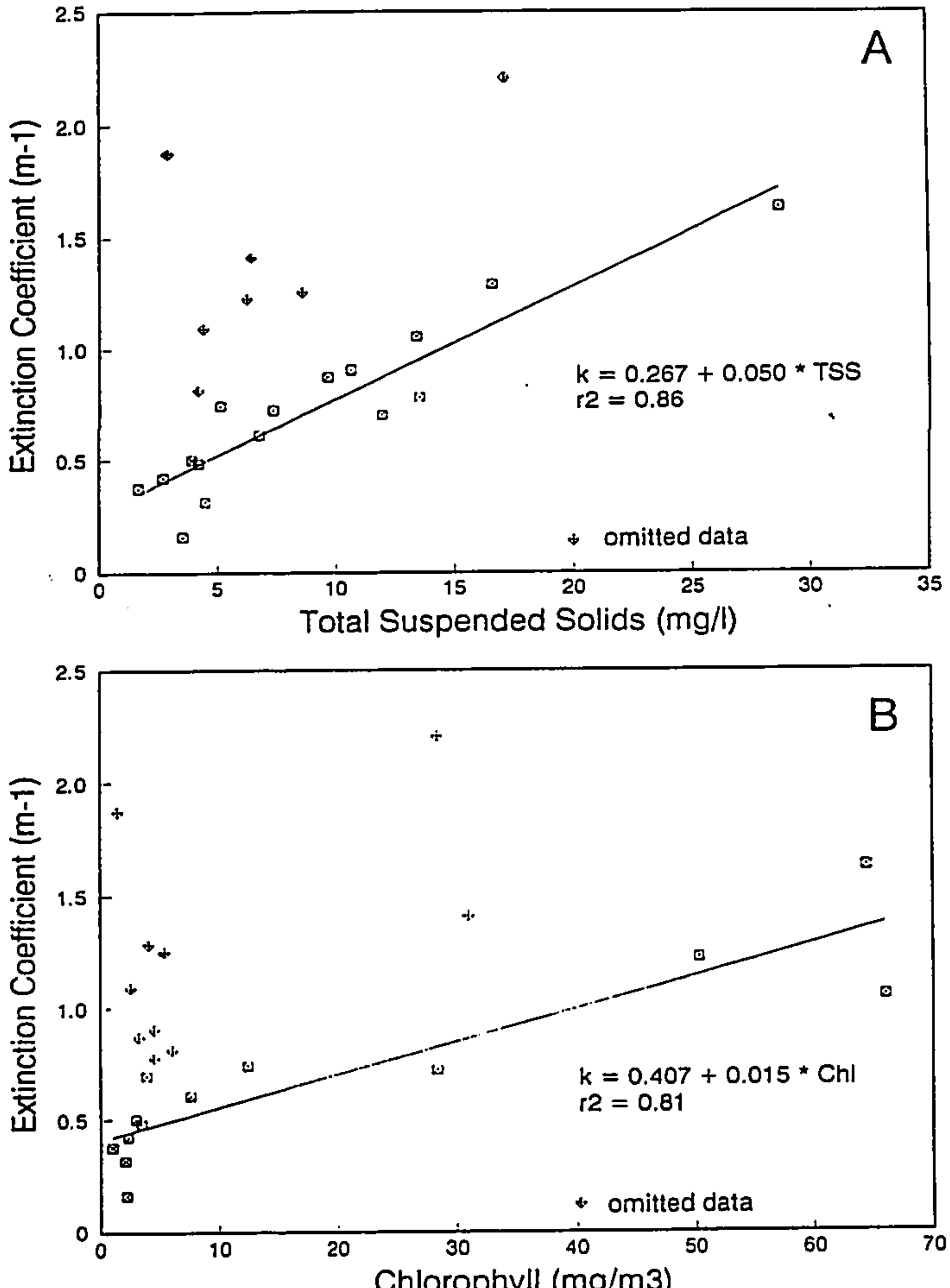
OI Consultants, Inc. Makapuu Point Waimanalo, Hawaii 96795	ALA WAI CANAL ECOLOGICAL STUDY A. Relationship between turbidity and total suspended solids. B. Relationship between turbidity and chlorophyll.	Figure 3-6

3.3.4. <u>Visual Water Quality.</u> The primary aspect of water quality in the Canal which has been targeted for improvement is water clarity. Water clarity is a function of several components within the water column: dissolved material which colors the water; inorganic particulate material such as suspended sediments; and organic particulate material such as phytoplankton. Dissolved color and inorganic particulate material are input to the Canal primarily in stream flows. The majority of these inputs occur during storm events, and their impacts on water clarity are relatively transient. The majority of the inorganic sediments input via stream flow are discharged directly to the ocean during storm flows; some settle to the Canal bottom and may be resuspended under strong winds and consequent vigorous vertical mixing.

The contribution of phytoplankton biomass to the total suspended solids load was estimated from relationships between phytoplankton chlorophyll, carbon and dry weight. Phytoplankton growing under light- and nutrient-replete conditions typically have carbon:chlorophyll ratios on the order of 50:1 by weight. Such cells also typically contain 6-7% of dry weight in carbon. By simple multiplication, the ratio of dry weight to chlorophyll is approximately 715:1. All the paired measurements of total suspended solids and chlorophyll taken during the six water quality surveys were compiled, the chlorophyll concentrations were multiplied by the factor of 715 derived above, and thereby calculated the percentage of total suspended solids which theoretically was derived from phytoplankton. The overall mean value was 65%.

The relationships between inorganic and organic particulates and water clarity was examined on a single cruise. Profiles of light at 0.2 m depth intervals were taken at stations 4, 6 and 12. At the same time, samples for the determination of chlorophyll and total suspended solids were collected at 0.5 m intervals. The extinction coefficient for each depth interval was calculated, and values were plotted against total suspended solids and chlorophyll (Figure 3-7). Regression equations were calculated for both curves. For both curves, some points were omitted from the regression calculation. For the chlorophyll relationship, the omitted data points probably represent samples in which a large portion of resuspended (non-pigmented) sediment was present. Such points for the total suspended solids relationship may represent the presence of flocculent material which adds little to filtered weight, but contributes a significant light attenuation effect.

The values derived from the regression analyses were used to establish target chlorophyll levels for the physical-biological model of the flushed Canal. A series of calculations were performed estimating the water clarity as a function of chlorophyll concentration. Two cases are presented in the Table 3.3. In one case, the water clarity is estimated utilizing the regression equation of extinction coefficient versus chlorophyll



OI Consultants, Inc. Makapuu Point Waimanalo, Hawaii 96795	ALA WAI CANAL ECOLOGICAL STUDY A. Relationship between extinction coefficient and total suspended solids. B. Relationship between extinction coefficient and chlorophyll.	Figure 3-7

derived from the light profiles. In the other case, a slightly lower intercept value (similar to that of the extinction coefficient versus total suspended solids regression) but the same slope value was used. Table 3.3 presents the calculated extinction coefficient ("k") value for each chlorophyll level. Also included is the estimated Secchi depth ("Secchi"). The Secchi depth is a standard oceanographic measure of water clarity. It is defined as the depth to which a disk of solid white or alternating white and black quarters can just be seen. Thus it represents a measure of water clarity to which most people can relate.

TABLE 3.3
Extinction Coefficients and Secchi Disk Depths
for Various Chlorophyll Concentrations in the Ala Wai Canal

k = 0.407 + 0.015 * Chl			k = 0.240 + 0.015 * Chl		
Chl ($\mu g\ l^{-1}$)	"k" (m^{-1})	Secchi (m)	Chl ($\mu g\ l^{-1}$)	"k" (m^{-1})	Secchi (m)
60	1.31	1.30	60	1.14	1.49
30	0.86	1.98	30	0.69	2.46
15	0.63	2.69	15	0.47	3.66
10	0.56	3.05	10	0.39	4.36
5	0.48	3.53	5	0.32	5.40
2	0.44	3.89	2	0.27	6.30
1	0.42	4.03	1	0.26	6.67

Based upon the above calculations, the target for maximum chlorophyll concentrations in the canal under active flushing has been set at 5 $\mu g\ l^{-1}$. Under the relatively conservative calculation of water quality presented above, the water clarity at a chlorophyll concentration of 5 $\mu g\ l^{-1}$ would be sufficient to see a light colored object on the bottom of the canal at a depth of 3.5 m (10 - 12 feet). The calculated water clarity for the second case may be more applicable, since the decreased regression intercept value would reflect the dilution and flushing of colored dissolved material and/or inorganic particulates. Under this scenario, water clarity would be such that a light object would be seen at depths near 5.5 m (18 feet), and the water clarity in the

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shallower Canal would be perceived to be significantly better than for the first case.

Some of the model runs resulted in chlorophyll levels higher than 5 $\mu g\ l^{-1}$ but less than 10 $\mu g\ l^{-1}$. In those instances where the chlorophyll levels were within this range, water clarity would be decreased somewhat, but under the more likely chlorophyll-visibility scenario, a light-colored object would be visible on the bottom even at 10 $\mu g\ l^{-1}$ chlorophyll.

3.4. DISCUSSION AND CONCLUSIONS

Water quality in the Ala Wai Canal is determined by its source waters (nearshore ocean water, groundwater, streams), mixing and tidal exchange, and input from the accumulated sediment via resuspension and regeneration. "New" nutrients (not recycled *in situ*) are derived from groundwater and the streams. Silicate concentrations, an indicator of groundwater, were usually higher in stream discharge than Canal water, but occasionally, surface water in the Canal contained concentrations exceeding the stream loads in the vicinity of discharge, and approached them on other occasions, despite higher salinity. Seawater dilution of the silicate input to the Canal is conservative, with steepest gradients in the Canal itself. Lesser gradients in the lowest reaches of the streams indicate lower silicate concentrations in the stream discharges than groundwater. Usually there is less silicate in water of the Manoa/Palolo streams than in the Makiki stream. However, the groundwater component in the streams varies, depending on the differences in rainfall in their respective water shed areas.

Phosphate ion concentrations are generally well correlated with silicate within the Canal proper. The distribution of silicate and phosphate in different source waters is not proportional, however. The highest concentrations of both silicate and phosphate were observed at the mouth of Makiki Stream (Station 13). The source water for this stream is apparently undiluted groundwater, and the concentrations in Makiki Stream are assumed to represent groundwater conditions. Flow in Manoa and Palolo Streams is primarily surface runoff, and the lower nutrient levels reflect this different source. The lowest concentrations occurred in the confluence of Manoa and Palolo streams, while dilution gradients were intermediate in the Canal itself.

In the Ala Wai Canal, not all the phosphate followed the simple physical dilution model observed for silicate. At the Kapahulu end, high phosphate concentrations often occurred in bottom samples with high salinity and low silicate concentrations; high ammonium levels were noted in the same samples. The Kapahulu end of the Canal serves as a trap for particulate materials. High organic matter and microbial activity cause oxygen deficiency in bottom water. Microbial activity releases regenerated nitrogen (as ammonium) and phosphate into the interstitial waters. Phosphate appears to be released from the sediment, like ammonium. Turbulence is not a likely physical mechanism for these releases. There are no waves and recreational activity (canoe racing) is infrequent. Rather, the release is likely through a process of simple diffusion from high concentrations in interstitial water to the overlying Canal water. The high proportion of phosphate to silicate in the Makiki and Apukehau streams probably reflects the groundwater ratio of these ions more closely, than that found in the Canal.

Nitrate-nitrite concentrations follow the distribution pattern of phosphate in the streams, but not in the Canal. Here, only low source concentrations of phosphate are correlated with low nitrate-nitrite concentrations. High source concentrations of nitrate-nitrite and phosphate occur independently of one another. The steepest nitrate-nitrite to silicate gradient (approximately 1/6, i.e., the highest apparent nitrate-nitrite concentration in groundwater) was observed commonly at the far end of the Canal, where freshwater made up only 10% of the volume. Groundwater is not the only source of this nitrate. The nitrate-salinity plots (Figure 3-3) show evidence of nitrate in addition to that provided by groundwater (i. e., data points above the conservative mixing line). Since these high nitrate values occurred in surface water, while bottom water was shown to be increased in regenerated ammonium, a source other than the sediments is required. One possible source is percolation of nutrients added to the adjacent Ala Wai Golf Course.

CHAPTER 4.0

HYDRODYNAMIC AND WATER QUALITY MODELING

CHAPTER 4
HYDRODYNAMIC AND WATER QUALITY MODELING

4.1. INTRODUCTION AND MODEL DESCRIPTION

One of the primary objectives of the extensive oceanographic field measurement program in the Ala Wai Canal was to provide the necessary field data of existing conditions in order to calibrate and verify the numerical model results.

The selected model for this project was the two-dimensional, laterally averaged hydrodynamic and water quality model CE-QUAL-W2, developed by the Environmental and Hydraulics Laboratories, U.S. Army Engineer Waterways Experiment Station (1986). For specific details on the analytical basis, development and operation of the model, the reader is directed to the operations manual described in the previous reference. A brief summary of the capabilities of the CE-QUAL-W2 model are provided below for general information.

CE-QUAL-W2 is a numerical computer model which describes the vertical and longitudinal distributions of thermal energy and selected biological and chemical materials in a water body as a function of time. It numerically simulates the dynamics of up to 20 water quality constituents in addition to water temperatures and circulation patterns. The model calculates the in-pool water volumes, surface elevations, densities, vertical and longitudinal velocities, temperatures, and constituent concentrations as well as downstream release concentrations. These computations require an extensive input data base that includes initial conditions, canal geometry, physical coefficients, biological and chemical reaction rates, and time sequences of hydrometeorological and in-flowing water quality quantities.

CE-QUAL-W2 is an unsteady free-surface model that handles variable density effects on the flow field. The model solves for the surface elevation implicitly, thus removing the restriction of the Courant gravity wave criterion, thereby permitting the use of longer time steps and the simulation of reasonable time periods for practical applications. The model simulates the interaction of physical factors (such as flow and temperature regimes), chemical factors (such as nutrients), and an algal assemblage. The constituents are arranged in four levels of complexity, permitting flexibility in model applications. The first level includes materials that are conservative, non-interactive, or do not affect other materials in the first level. The second level allows the user to simulate the interactive dynamics of oxygen-phytoplankton-nutrients. The third level allows simulation of Ph and carbonate species. The fourth level allows the simulation of total iron. Table 4.1 describes the constituents in each of the 4 levels.

TABLE 4.1
CE-QUAL-W2 Levels of Water Quality Constituent Simulations

Level 1	Level 2
Conservative tracer Inorganic suspended solids Coliform bacteria Total dissolved solids or salinity	Labile dissolved organic matter Refractory dissolved organic matter Phytoplankton Detritus Phosphate-phosphorus Ammonia-nitrogen Nitrate-nitrogen Dissolved oxygen Organic sediments
Level 3	**Level 4**
Dissolved inorganic carbon Alkalinity Ph Carbon dioxide Bicarbonates Carbonates	Total iron

CE-QUAL-W2 incorporates the capability of including head or flow boundary conditions, branches, multiple lateral inflows and withdrawals, and other features that allow applications to a wide variety of situations. Some of these attributes are listed below:

- Two-dimensional (laterally averaged) simulations of temperature, constituents, and flow fields.
- Hydrodynamic computations influenced by variable water densities caused by salinity, temperature, and dissolved and suspended solids.
- Simulation of the interaction of numerous biological and chemical factors affecting water quality.

- o Allowance for multiple inflow loadings and withdrawals from the following sources.
  - * Tributaries.
  - * Point and non-point loadings.
  - * Precipitation.
  - * Branch inflows.
  - * Outflow through a dam.

- o Simulation of multiple branches.

- o Allowance for a sequence of time steps.

- o Simulation for flow or head boundary conditions in-order to simulate reservoir and estuarine conditions.

- o Simulation of circulation patterns.

- o Simulation of evaporation in the water balance.

- o Heat transfer computations.

4.2. VERIFICATION OF EXISTING CONDITIONS

4.2.1. Hydrodynamics and Level 1 Constituents. The initial model verification process involved only the hydrodynamic portion of the 2-D CE-QUAL-W2 computer program. In order to verify the performance of the hydrodynamic output from the 2-D model, a series of simple geometric canal configurations were initially tested. These tests included a simple straight dead-ended channel, constant depth and rectangular cross-section geometry, no vertical variations in density, with sinusoidal tidal fluctuations at the open boundary. The hydrodynamic output results for the 2-D model were compared with results from an existing, in-house 1-D hydrodynamic model, and the comparison was very good. The 1-D model has been verified by comparisons with analytic solutions for very simplified conditions, and this model has been used extensively in past modeling projects.

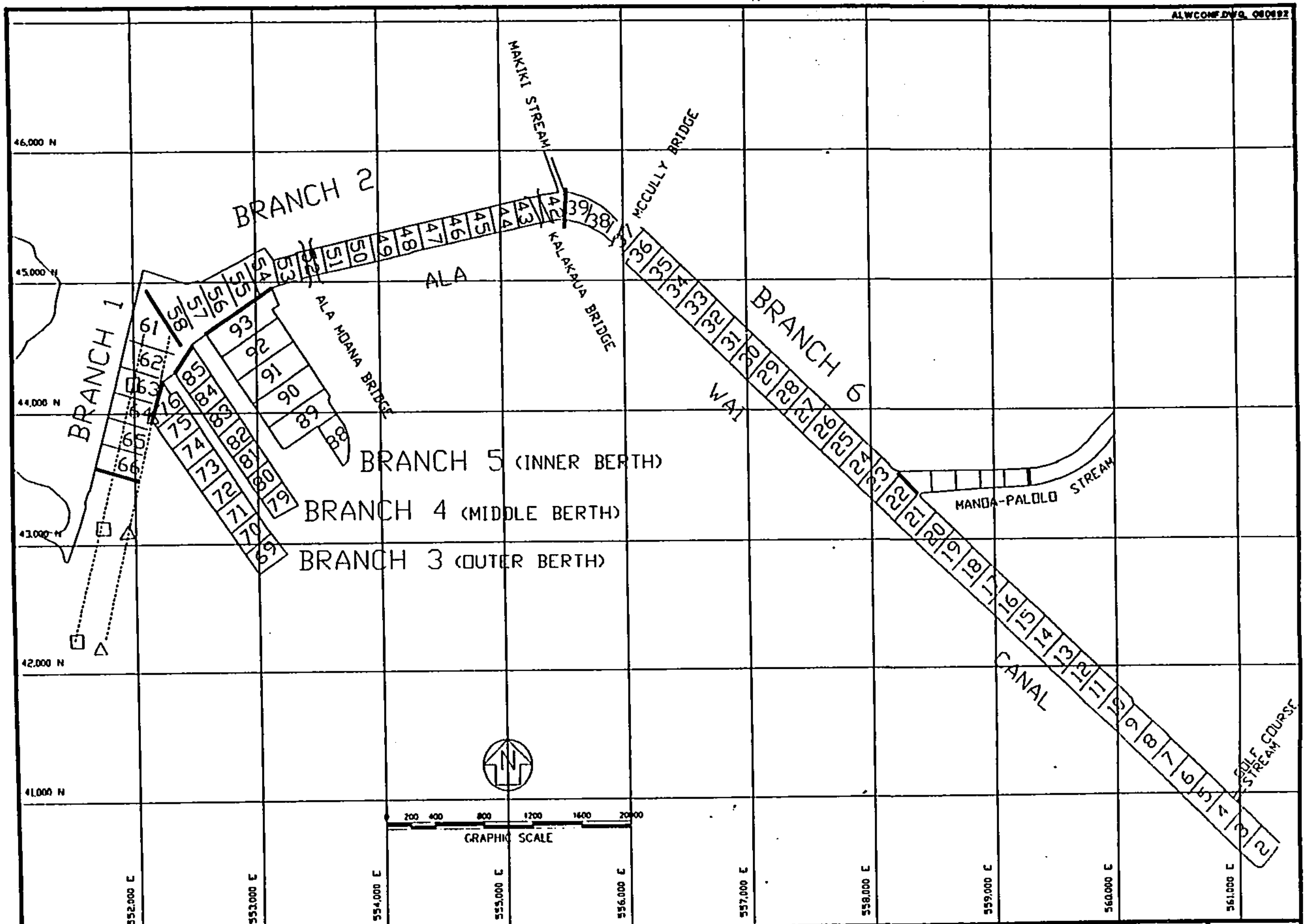
Besides the comparison of the water surface elevations and the flow velocities as a function of time, dye tracer half-life flushing time constants, T_{50}, were very similar in the 1-D and 2-D model results. Additional verification tests were performed using more complicated physical configurations, including lateral tributary in-flows and multiple branches, and the output results from the 2-D model compared very well to the in-house 1-D hydrodynamic model. The results of this extensive verification process showed that the 2-D hydrodynamic model produced very similar results as the 1-D hydrodynamic model for typical expected flow conditions in the Ala Wai Canal.

Following the initial hydrodynamic performance verification process, the calibration process for the existing physical geometry of the AWC was performed. While the Ala Wai Canal between the Ala Moana Bridge and Kapahulu terminus is the focus of the present study, the modeling must include the Ala Wai Boat Harbor and the entrance channel to the ocean, in order to fully understand the hydrodynamics and water quality effects within the entire system. Based on the Ala Wai Boat Harbor hydrographic chart and the bathymetry data shown in Figure 2-4, the physical geometry input data file was developed at model segment locations shown in Figure 4-1, with segment lengths of about 200 feet. Note that the segment numbering system is not continuous. The segments shown in Figure 4-1 are physically continuous, but for internal computation purposes the 2-D model requires "virtual" segments at the end of each branch. The Ala Wai Golf Course drainage channel and the Makiki Stream were modeled as tributaries, while the Manoa-Palolo Stream was treated as either a tributary or a branch in the final runs.

While the model is laterally averaged, the model allows the input of the width of the layer, thus, simulating the partial 3-dimensional aspect of the flow processes. Due to the very shallow water characteristics of the Ala Wai Canal near the Manoa-Palolo Stream confluence, a layer thickness of 1 foot was selected. For typical hydrodynamic runs, the vertical dimension was divided into 26 1-foot layers, two layers existing above mean sea level (MSL), in order to simulate the water depths in the Ala Wai Boat Harbor entrance channel.

The first task in the calibration of the 2-D model using existing conditions was to adjust the bottom friction coefficient to provide the same phase lag value as was measured during the tide measurement program. In anticipation of future calibration runs, instead of using a sinusoidal tidal boundary condition at the ocean entrance, the actual tidal water surface elevation between March 1-15, 1992 was utilized. After an interactive computation process, a Chezy coefficient of 35.0 $m^{1/2}$/sec was found to provide a similar phase lag of about 73 seconds. This Chezy coefficient was then used throughout the following modeling calculations.

The next task effort in the hydrodynamic calibration process was to compare the results from the 2-D model with the field measured data from the dye, CTD and current



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2-D Model
Segment Numbering

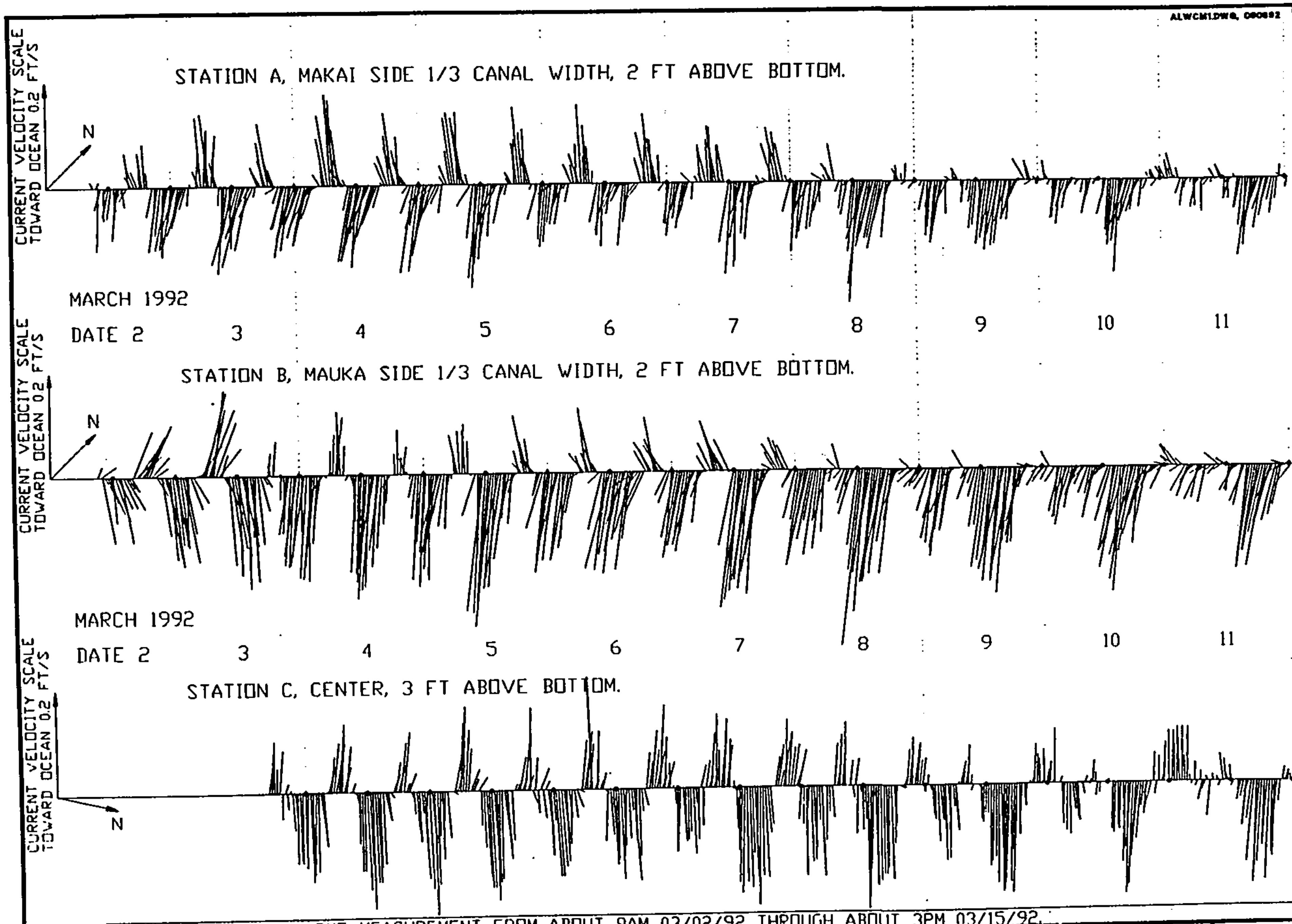
FIGURE
4-1

measurement program. This required that the 2-D model include wind stress forces and tributary in-flow components into the Ala Wai Canal model. From the data shown in Figures 2-26 and 2-27, the vector-averaged wind speed at HIA during the period March 1-15, 1992 was 4.1 knots from 70° T which is a light tradewind condition. During the dye flushing survey, it was noted that the wind direction tended to blow from a more easterly direction, probably directed by the adjacent tall building structures surrounding the AWC. Thus, a nominal 5 knot, East wind condition was used in this phase of the calibration process.

Based on watershed sizes and relative to the Waiakeakua Stream as shown in Figure 2-28, and water quality field measurements shown in Appendix E, the Manoa-Palolo Stream inflow was selected to be 10 ft^3/sec (cfs) with a salinity of 0 parts per thousand (ppt) and a water temperature of 25° C. The Makiki Stream inflow was selected to be 1.0 cfs, with a salinity of 0 ppt and a water temperature of 25°C. Groundwater inflow was selected to be 1.5 cfs, with a salinity of 19.2 ppt and a water temperature of 25°C. For modeling purposes, this groundwater inflow has been assumed to enter the AWC through the Ala Wai Golf Course drainage channel. A diurnal, sinusoidal air temperature variation was selected from 19° to 29.5°C, with the peak temperature occurring at noon. The vertical salinity and temperature profiles at the ocean entrance were selected from the field data provided in Appendix E. Finally, the actual tidal variations at the ocean entrance during March 1-15, 1992 were imposed at the ocean entrance. Table 4.2 summarizes the 2-D model hydrodynamic calibration conditions.

For comparison purposes, Figure 4-2 shows a graphical plot of the S-4 measured current vectors during the dye study, March 2-11, 1992, where the vectors have been rotated relative to the Ala Wai Canal axis, so that the outward (upper quadrant) and inward (lower quadrant) flows are easily defined. Figure 4-3 provides a comparison of the flow velocities at each of the 3 current meter locations shown in Figure 2-11 with the computer calculated velocities at the appropriate station and layer locations. In general, the measured and model-calculated velocities agree very well as shown in Figure 4-3.

Figure 4-4 shows the comparison of the measured (center location 2, Figure 2-11) and 2-D model-calculated salinity profiles at Stations B, C and D. Even though real tidal elevation boundary conditions were utilized beginning on March 1, 1992, the calculated salinity constituent stabilized very rapidly, such that only about 3-4 tidal cycles were necessary to reach a quasi-steady state condition. The results described in Figure 4-4 show a very reasonable correlation with the field measured results.



ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	Current Meter Vectors Oriented In And Out Of The Ala Wai Canal	FIGURE 4-2

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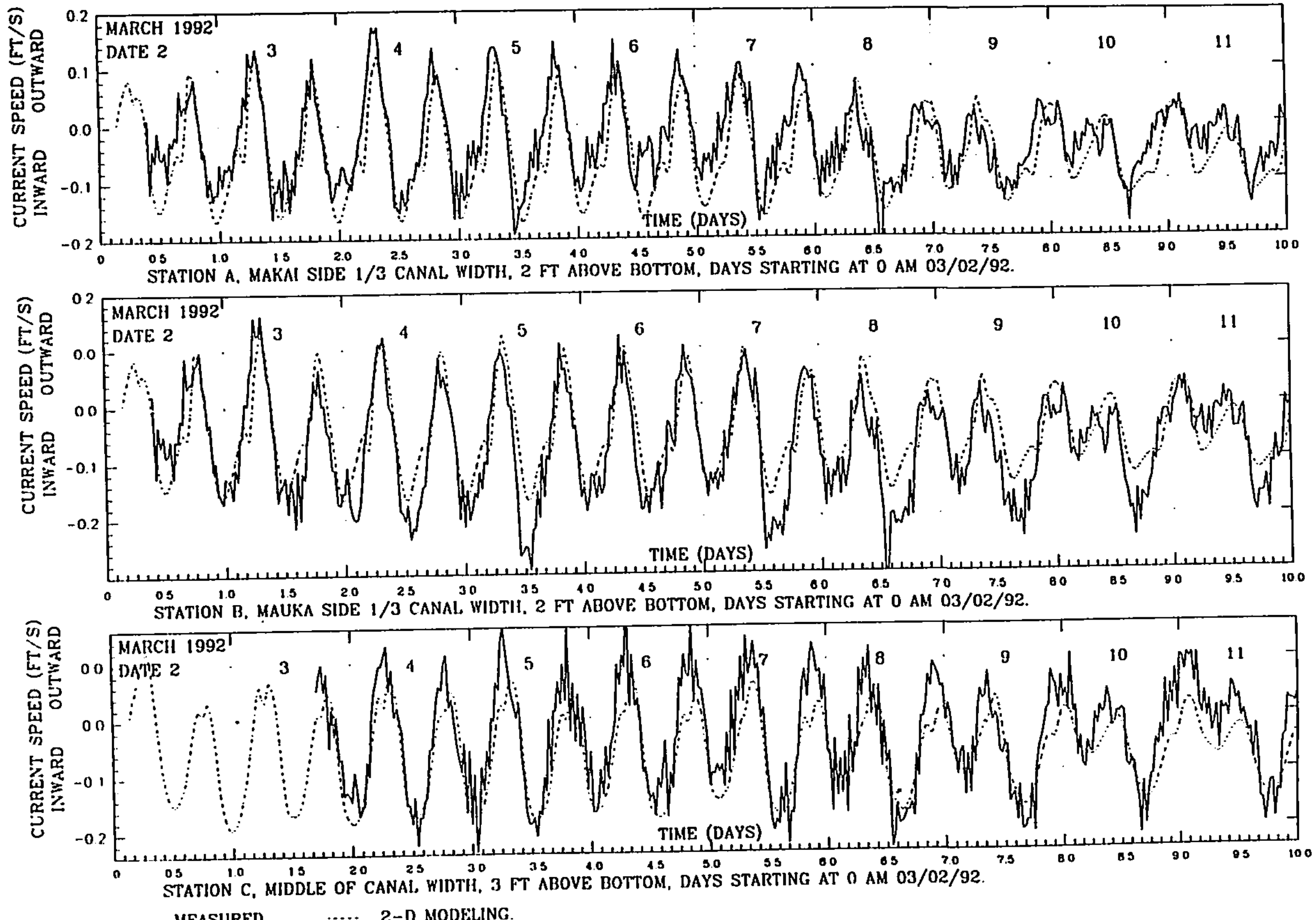

ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	Comparison Of Measured And 2-D Model Predicted Current Speeds In & Out Of The Ala Wai Canal	FIGURE 4-3

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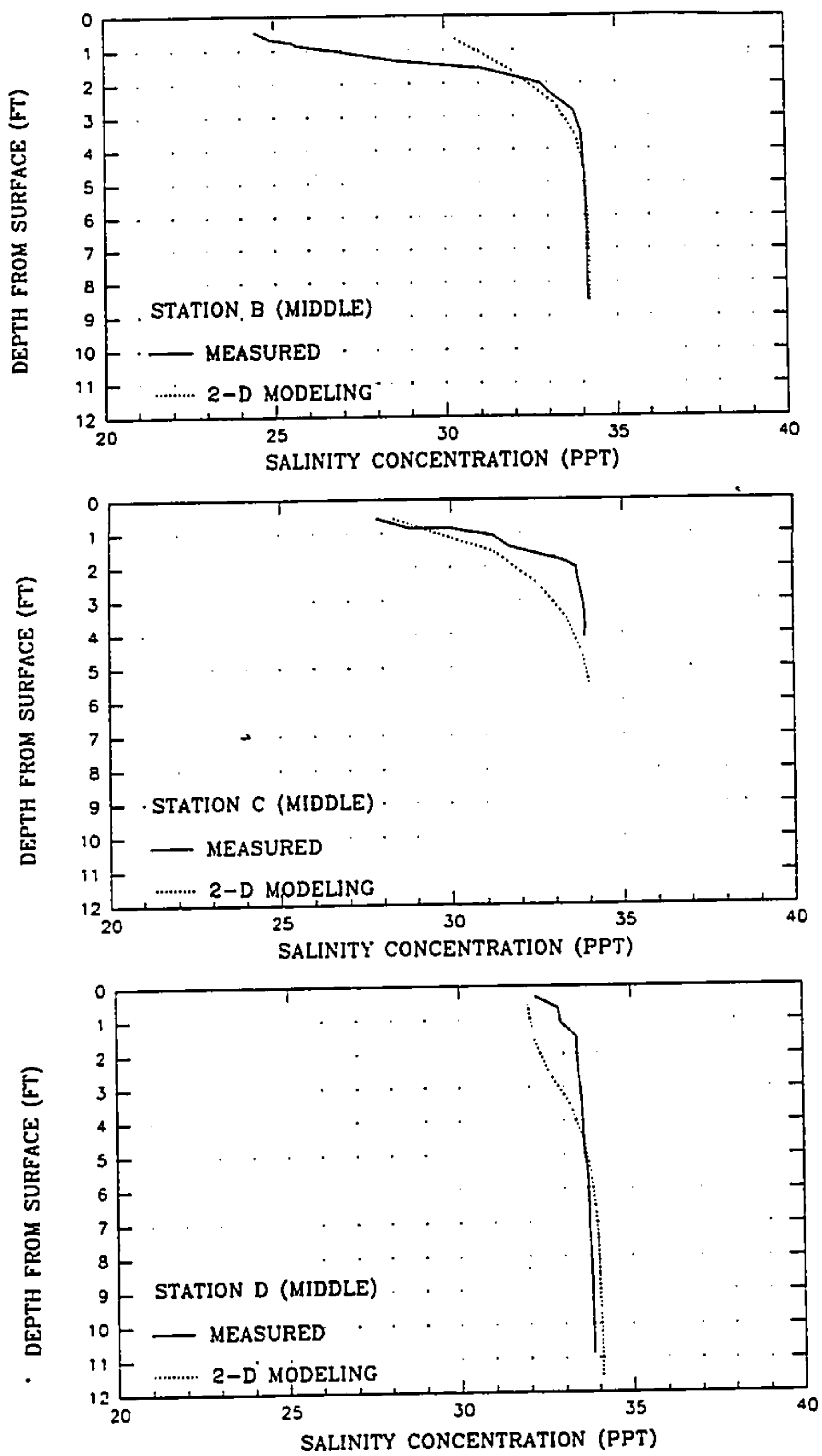

ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	**Comparison Of Measured And 2-D Model Predicted Salinity Profiles In The Ala Wai Canal**	FIGURE 4-4

TABLE 4.2

CE-QUAL-W2 Model Hydrodynamic Calibration Parameters

Tidal Boundary Conditions	Predicted tides starting at 3:00 am, March 1, 1992		
Wind Vector	5 knots from the East		
Air Temperature	Diurnally sinusoidal, 19°C at midnight to 29.5°C at noon		
Chezy Coefficient	35 $m^{1/2}$/sec		
Dye Tracer	Injected at 2:00 pm, March 2, 1992		
Time Step	100 seconds		
	Tributary Water Inflow		
Parameter	Ala Wai Golf Course Stream (groundwater)	Manoa-Palolo Stream	Makiki Stream
Flow Rate (cfs)	1.5	10.0	1.0
Salinity (ppt)	19.2	0.0	0.0
Temperature (°C)	25.0	25.0	25.0

Figure 4-5 shows the comparison of the measured and 2-D model-calculated water temperature profiles at the 8 AWC water quality station locations shown in Figure 4-6. While the 2-D model data have been calibrated for conditions that occurred during the March 2-15, 1992 dye study period, the measured water temperature data for both February 8, 1992 and March 3, 1992 from OIC have been plotted in Figure 4-5. The results in Figure 4-5 show a reasonable correlation with the range of measured water temperature data between February and March 1992.

Figures 4-7 to 4-10 describe the comparison of the measured dye concentration ratio versus the 2-D model-predicted dye concentration ratio based on the highest dye concentration values after the start of the dye measurement program. Besides the field measured and 2-D model-predicted dye concentration ratios, the best-fit slope to both dye concentration ratios are provided in the figures. In general, the 2-D model-predicted dye decay rates are similar to the field measured values.

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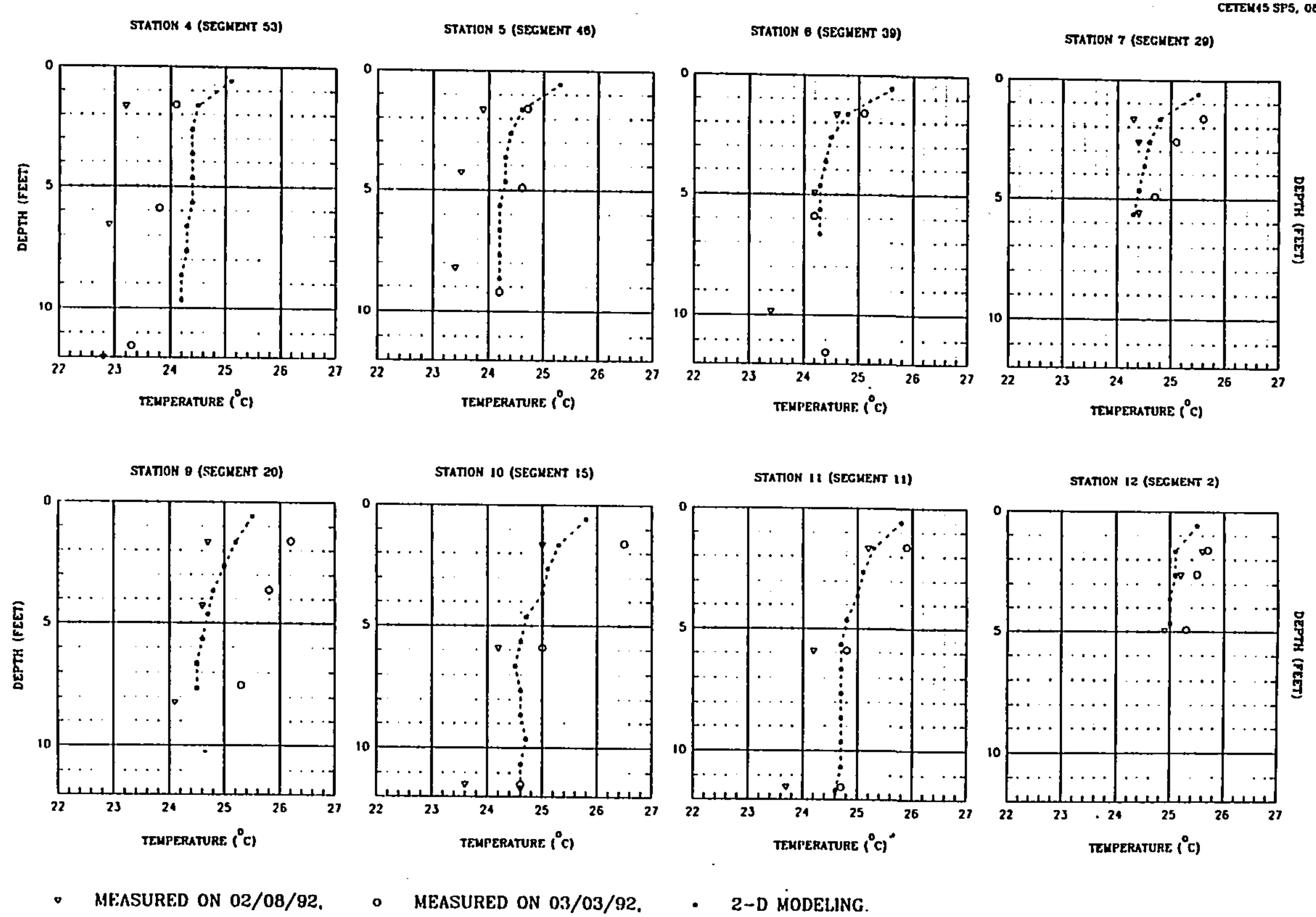
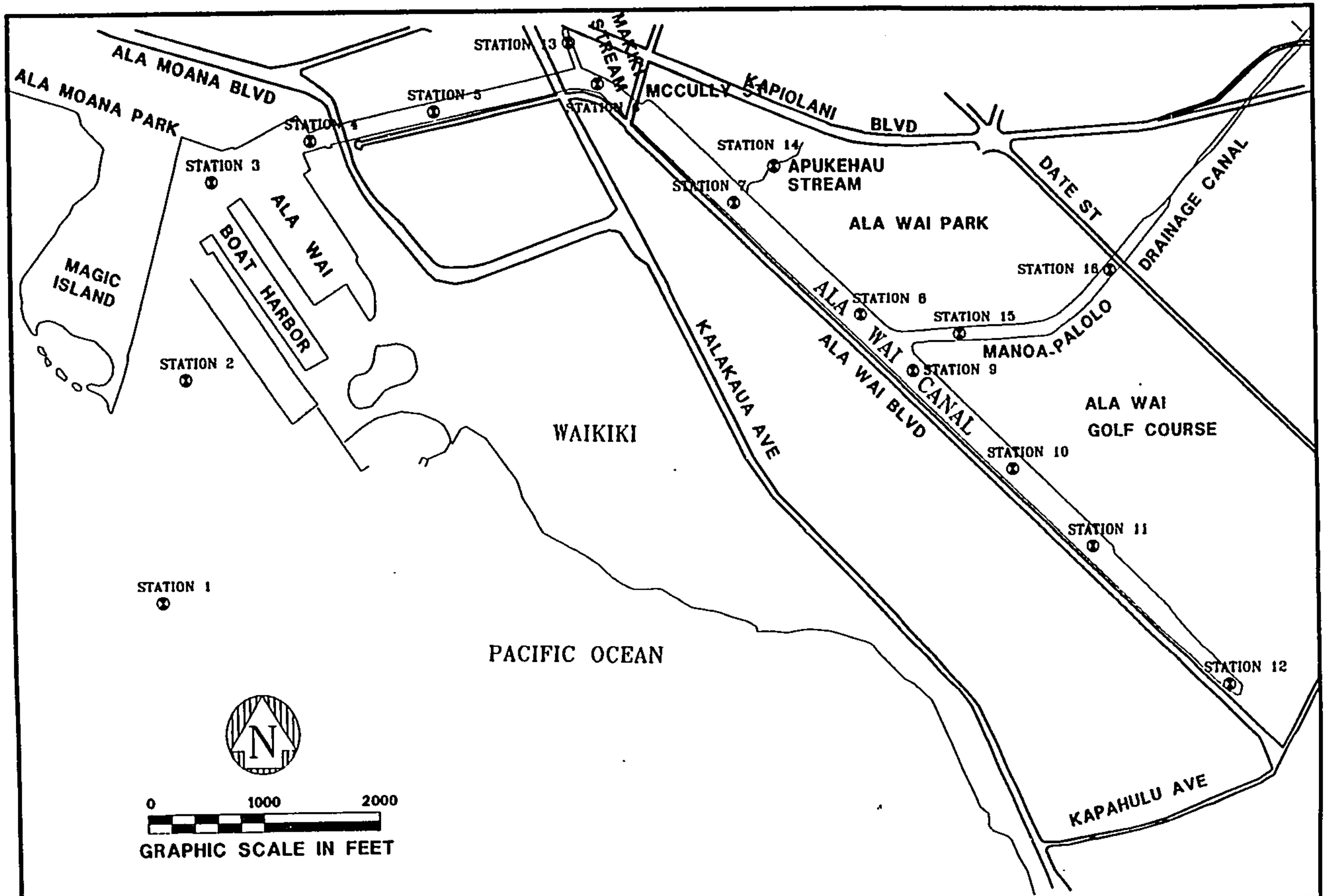
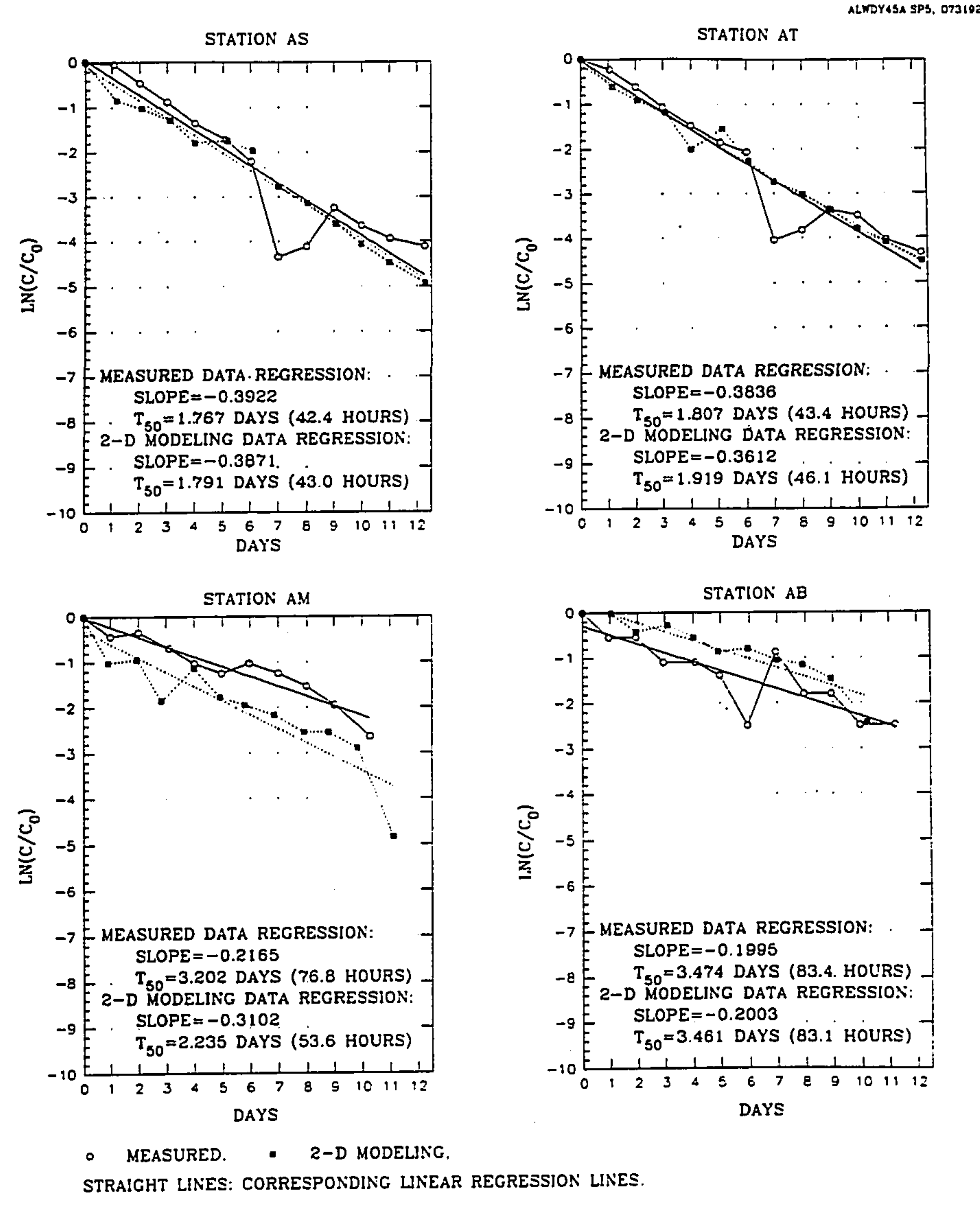


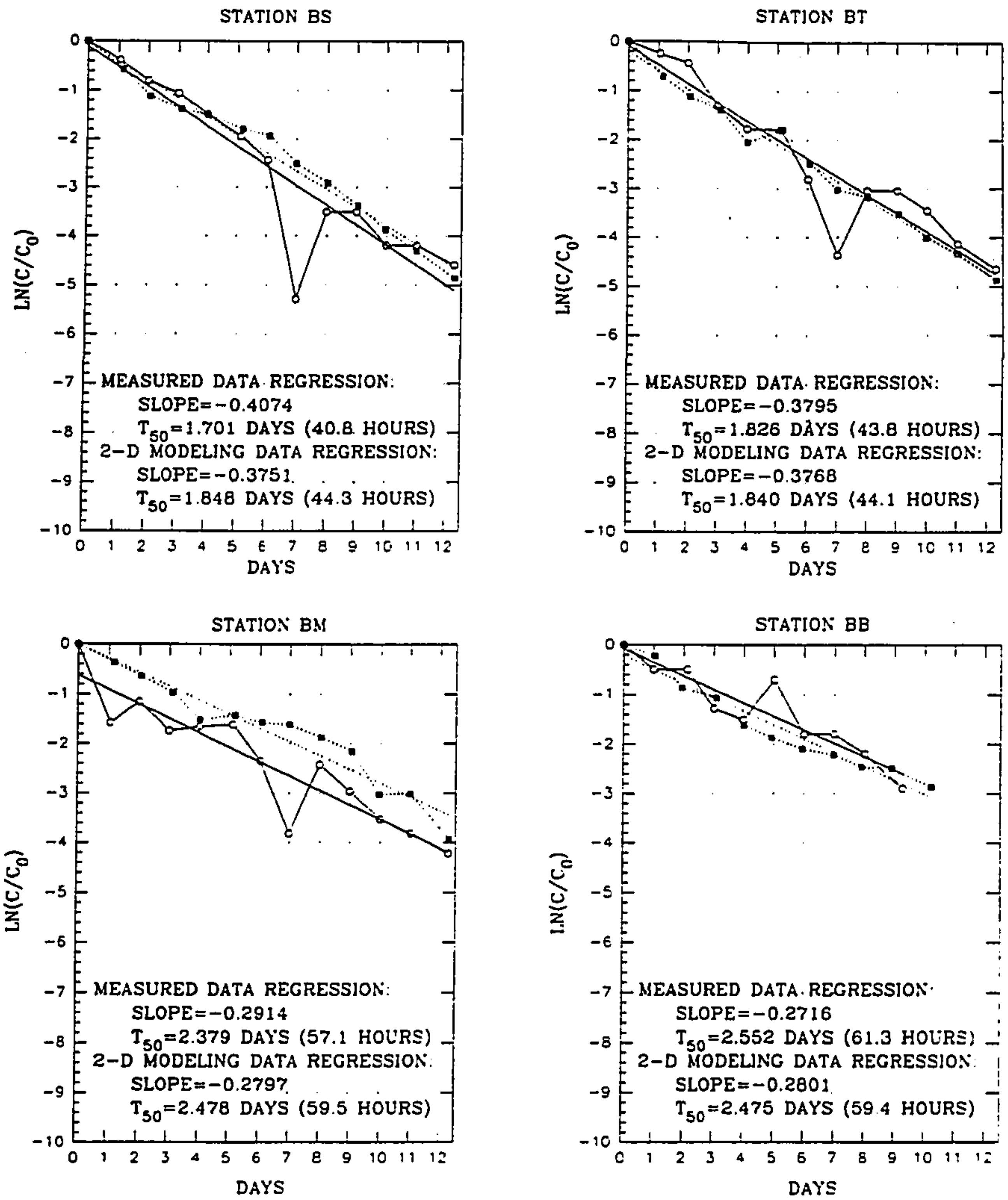
ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	Comparison Of Measured And 2-D Model Predicted Temperature Profiles In The Ala Wai Canal	FIGURE 4-5



ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	Ala Wai Canal Water Quality Stations	FIGURE 4-6



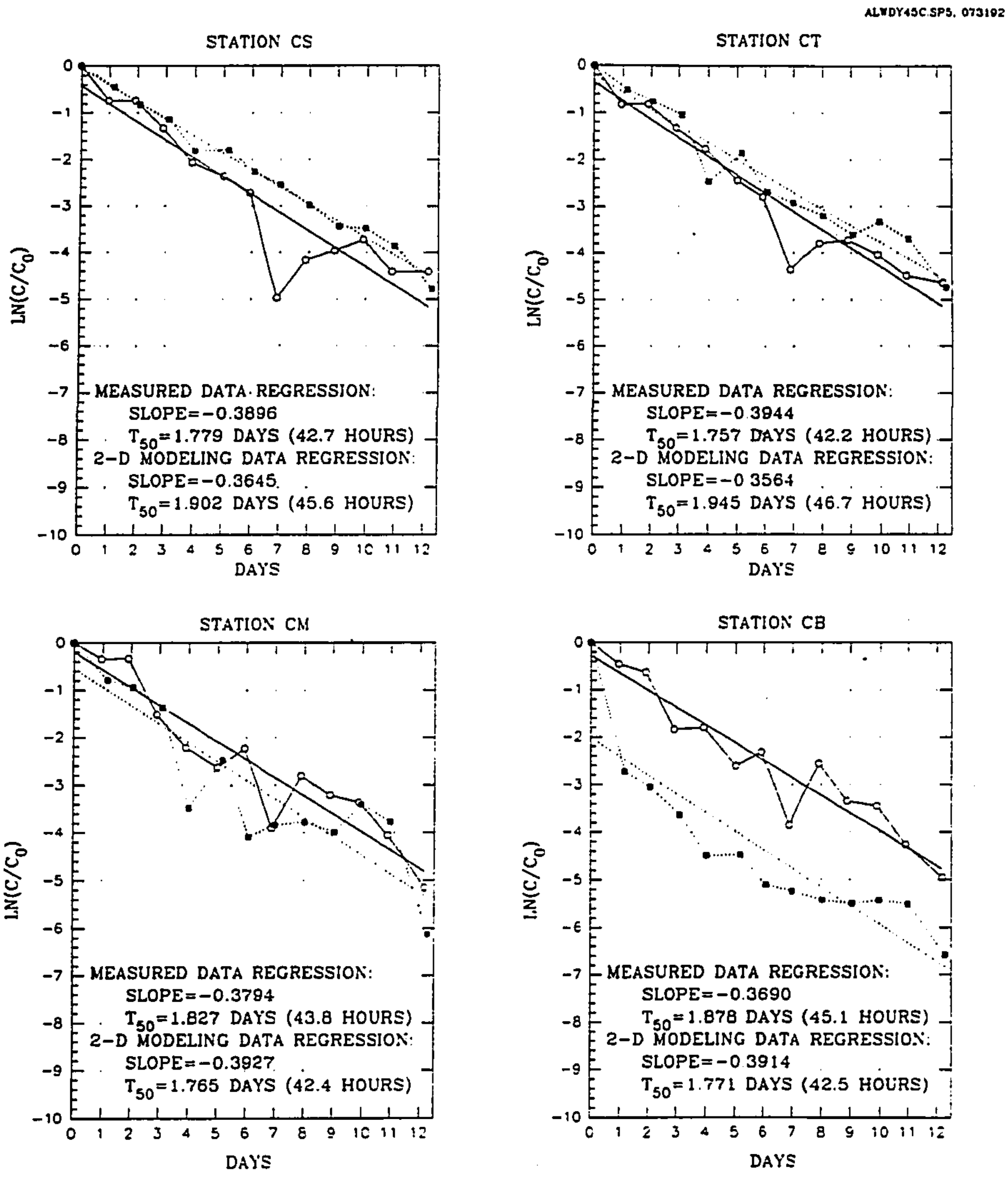
ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	Comparison Of Measured And 2-D Model Predicted Dye Concentrations At Station A	FIGURE 4-7



o MEASURED. ▪ 2-D MODELING.

STRAIGHT LINES CORRESPONDING LINEAR REGRESSION LINES

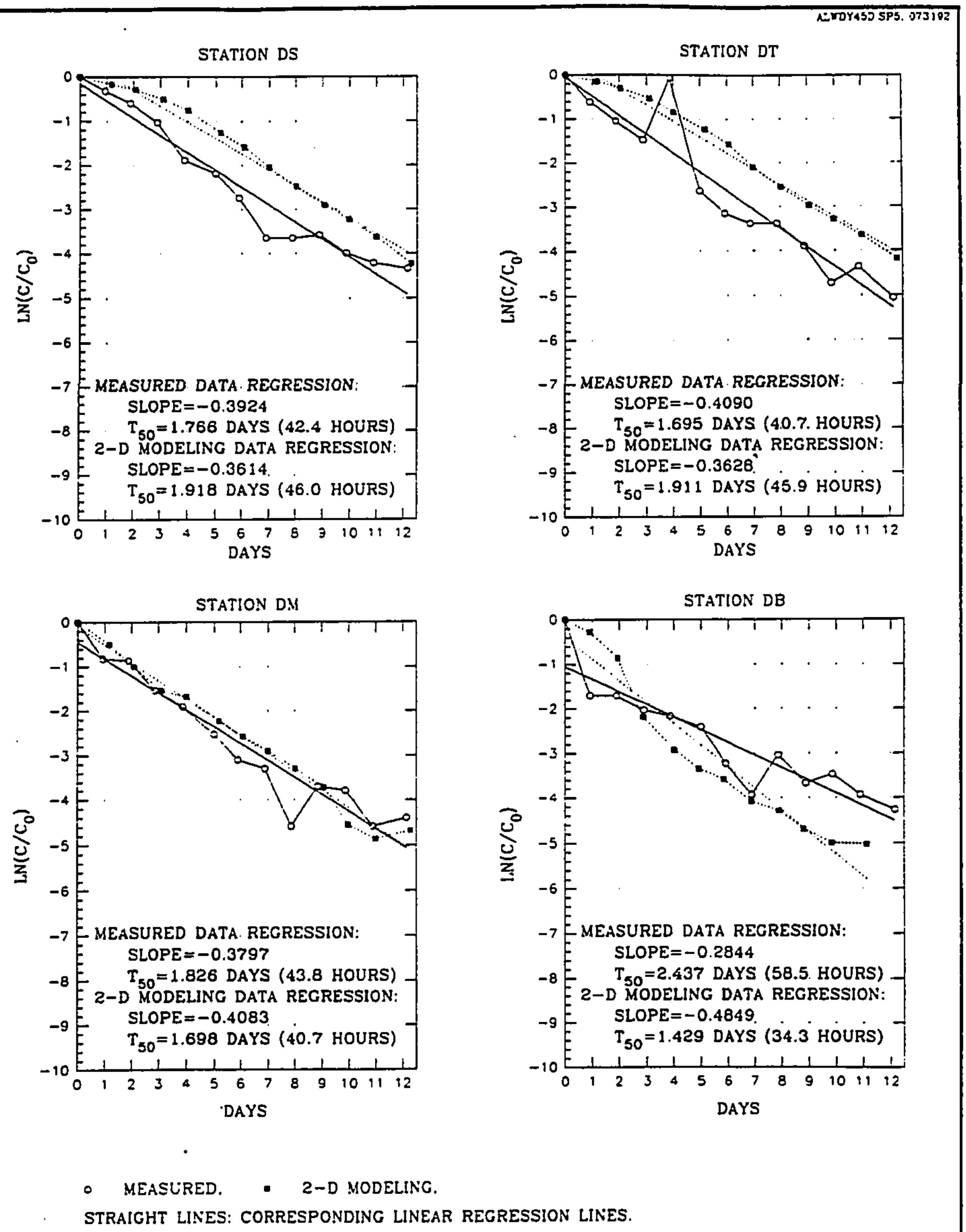
ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	Comparison Of Measured And 2-D Model Predicted Dye Concentrations At Station B	FIGURE 4-8



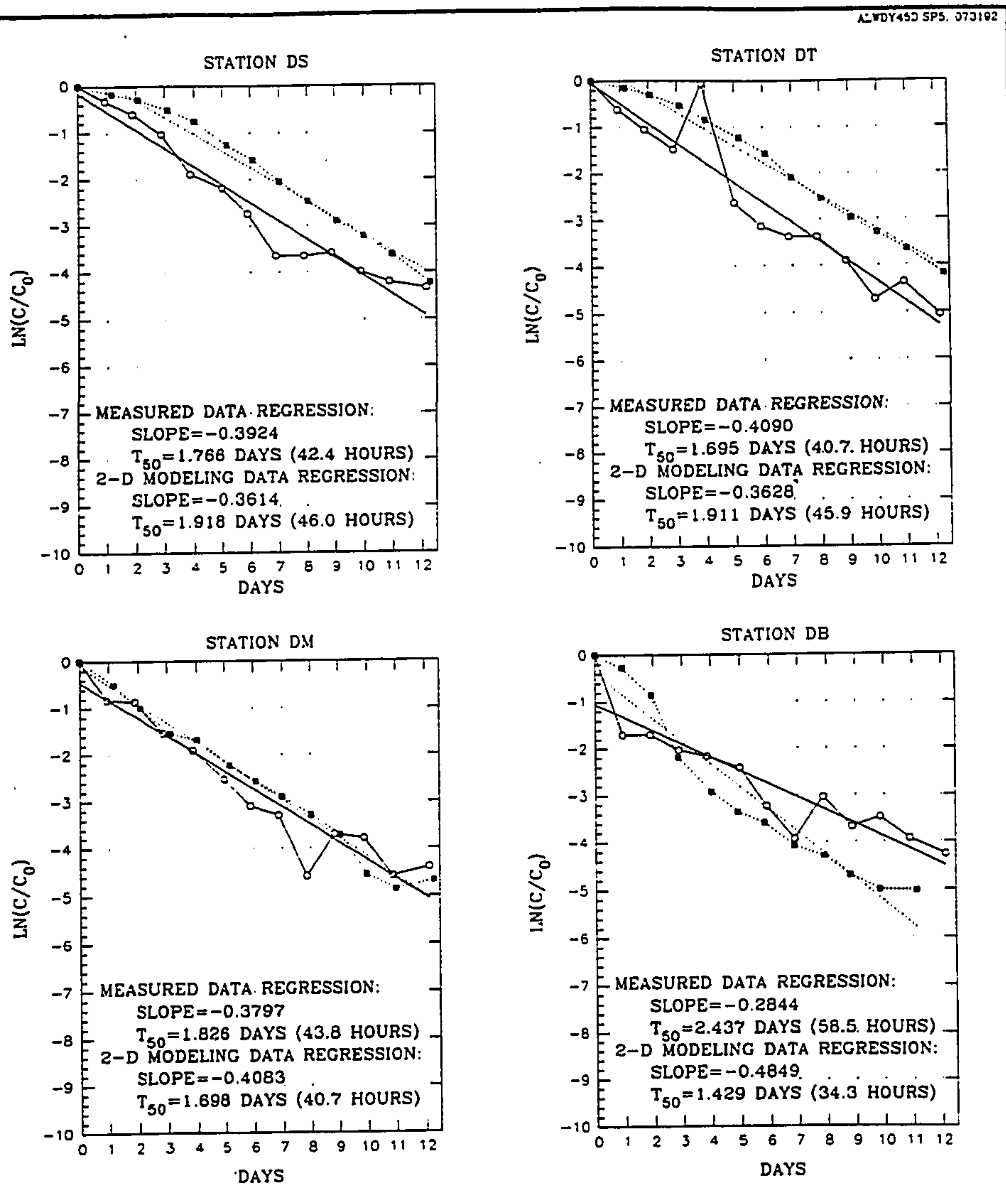
○ MEASURED. ■ 2-D MODELING.

STRAIGHT LINES. CORRESPONDING LINEAR REGRESSION LINES.

ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	Comparison Of Measured And 2-D Model Predicted Dye Concentrations At Station C	FIGURE 4-9



ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	**Comparison Of Measured And 2-D Model Predicted Dye Concentrations At Station D**	FIGURE 4-10



o MEASURED. ▪ 2-D MODELING.

STRAIGHT LINES: CORRESPONDING LINEAR REGRESSION LINES.

ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	Comparison Of Measured And 2-D Model Predicted Dye Concentrations At Station D	FIGURE 4-10

Based on the results of the above calibration effort, the 2-D hydrodynamic and mixing processes compare very favorably to the field measured results, thus confirming the validity of the 2-D hydrodynamic model.

4.2.2. Biological and Water Quality Processes. In the biological and water quality calibration process for the 2-D model, the previous hydrodynamic calibration parameters shown in Table 4.2 remained constant, except that for the tidal boundary condition at the ocean entrance, a sinusoidal tide was used with a tidal range = 1.3 feet (amplitude = 0.65 feet) and a wave period of 12.42 hours. The tidal range of 1.3 feet corresponds to an average tidal range. Preliminary test runs indicated that the biological and water quality processes had relatively long transient die-off times. Consequently, in order to determine when a well defined steady-state condition had been reached a sinusoidal tidal wave was used.

Table 4.3 from the CE-QUAL-W2 user's manual (Environmental and Hydraulics Laboratories, U.S. Army Engineer Waterways Experiment Station, 1986), shows the various interactions between constituents. Since one of our primary interests is algae, Table 4.3 provides the constituents that have both primary and secondary effects on algae dynamics. At the initiation of the biological and water quality calibration effort, 14 constituents were modeled. During the evaluation process, some of the constituents were found to have very little or no affect on algae, and in the final runs, some of these constituents were deleted from the modeled constituent list. The following provides a listing of the initial list of 14 constituents and a description of its status during the final calibration and production runs.

1) Tracer: This constituent was used as a hydrodynamic calibration parameter and has been included to provide checks on the model results.

2) Suspended solids: This constituent was found to have little affect on other constituents. Measured total suspended solids (TSS) data from OIC (Appendix E) was used to represent this constituent.

3) Coliform: This is an independent constituent which does not affect any other constituent. While this parameter was included, its performance was not monitored.

4) Salinity: This constituent was modeled and also served as a calibration parameter.

5) Dissolved organic matter (labile): This constituent was included in the model, but was not controlled by in-flow conditions (initial concentrations initially 0 and in-flow concentration = 0), nor monitored since there was no measured data. DOM (labile) was found to have very little effect on other constituents.

6) Dissolved organic matter (refractory): This constituent was initially included, but evaluation runs indicated that this parameter did not influence other constituents. Thus, DOM (refractory) was excluded from all production runs.

7) Phytoplankton (algae): This constituent is the target constituent in the biological and water quality modeling effort.

8) Detritus: This constituent was found to have little effect on the other constituents. Detritus was included in the model but not controlled by in-flow conditions nor monitored in the model output.

9) Phosphate: This is an important constituent associated with phytoplankton growth.

10) Ammonia: This is an important constituent associated with phytoplankton growth.

11) Nitrate: This is an important constituent associated with phytoplankton growth.

12) Dissolved oxygen: This constituent was included in the model.

13) Sediments: This constituent was initially included, but evaluation runs indicated that this parameter did not influence other constituents. Thus, sediments were excluded from all production runs.

14) Inorganic carbon: This constituent was included in the model.

As shown in Table 4.3, for each of the above selected constituents to be modeled, the interactive relationship between the dynamic parameters needs to be specified in the 2-D model through the application of input coefficients and rate constants. The details associated with the analytical form of the interactive relationships between constituents are very voluminous, and the reader is referred to the User's Manual for these details.

TABLE 4.3
Internal Process Interaction for Variables in CE-QUAL-W2

From	TO: Tracer	SS	TDS	DOM (L)	DOM (R)	Algae	Detritus	Ortho-P	Ammonia -N	Nitrate -N	Oxygen	Inorg. Carbon	Alkalinity	Sediment	Total Iron	Surface
Tracer	F															
SS		Y														
TDS			F													
DOM (L)				F	D			D	D			D				
DOM (R)					F			D	D			D				
Algae				M		Y	M	R	R		P	R		S		
Detritus							Y	D	D			D		S		
Ortho-P		A				P	A	F							A	
Ammonia-N		A				P	A		F	D					A	
Nitrate-N						P				F						
Oxygen				D	D	R	D		D		F			D		X
Inorganic Carbon						P						F				X
Alkalinity								D					F			
Sediment									D			D			D	
Total Iron															Y	
Surface											X	X				

NOTES:

D = decay, decomposition, release
F = diffusion and advection
M = mortality
P = photosynthesis
R = respiration
A = adsorption
Y = settling, diffusion, advection
X = exchange at air/water interface
SS = suspended solids
DOM = dissolved organic matter
(L) = labile
(R) = refractory

The actual calibration process was initiated by inputting the required listing of coefficients and rate constants as requested of and provided by OI Consultants. The process then continued by comparing the output at the 8 biological/water quality station locations in the AWC as shown in Figure 4-6, with the field measured data. The primary comparison parameters were chlorophyll (algae), orthophosphate (PO_4), nitrate (NH_4), ammonia (NO_3), and dissolved oxygen (O_2).

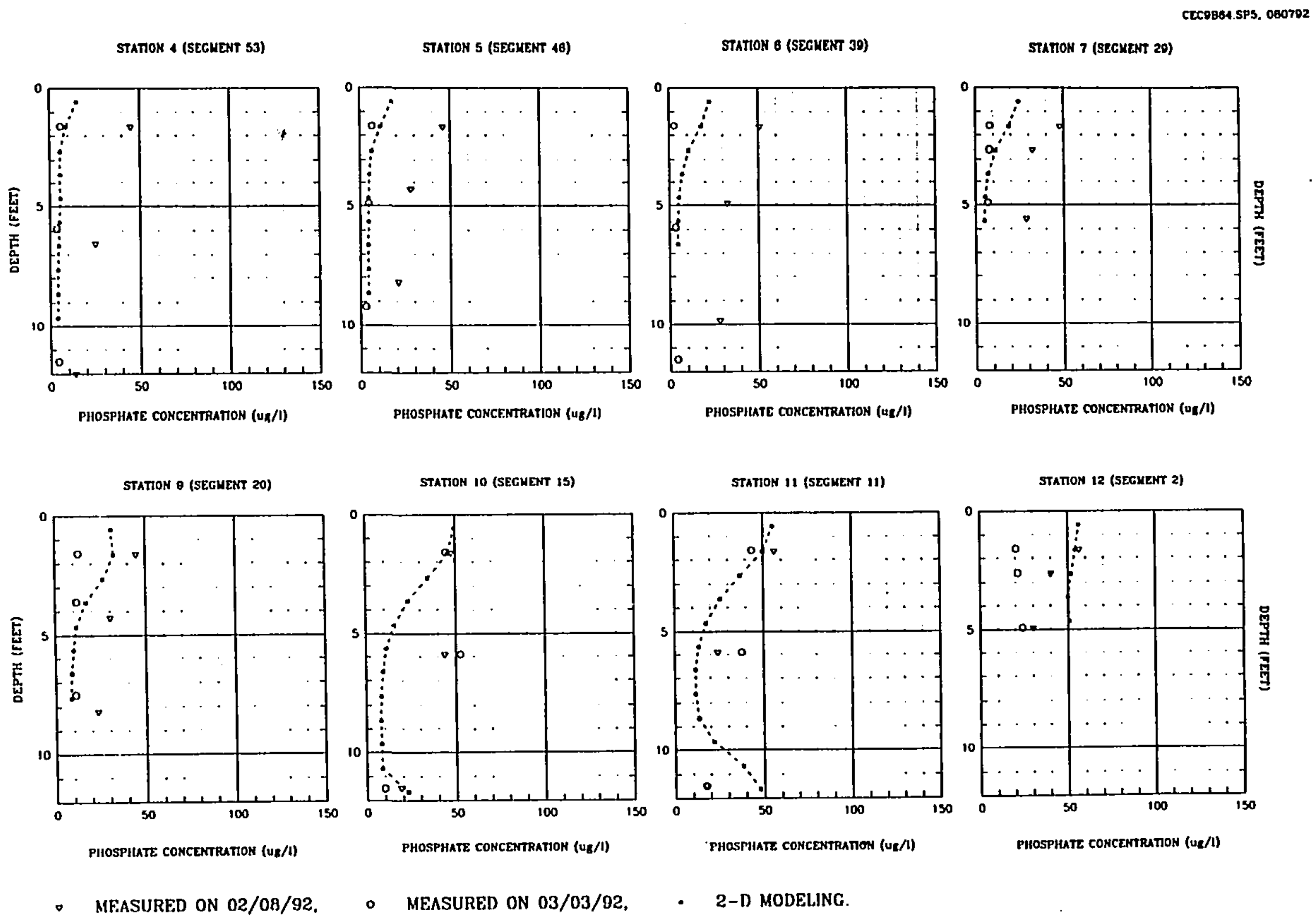
The difficulty with this process was that there were a very large number of constituents to evaluate, as each relationship between constituents required a large number of interactive coefficients and rate constants, and with the possible variation in the input flow parameters and concentrations during the field measurement program, the possible combinations and permutations were staggering. The selected methodology to effectively calibrate the model was to perform a "brute force" approach, where the sensitivity of each major constituent was evaluated by a sensitivity analysis of the input coefficients and rate constants. After many runs (literally hundreds), an understanding was developed as to the sensitivity of the constituent concentrations versus the input parameters. On this basis, discussions with OIC personnel served to focus on those input coefficients and rate constants that were both realistic and produced good correlation with the field measured data.

The results of this extensive 2-D model biological and water quality calibration process finally produced a set of input parameters which provided good results when compared to the field measured data. The listing of the biological and water quality inflow and boundary conditions are provided in Table 4.4.

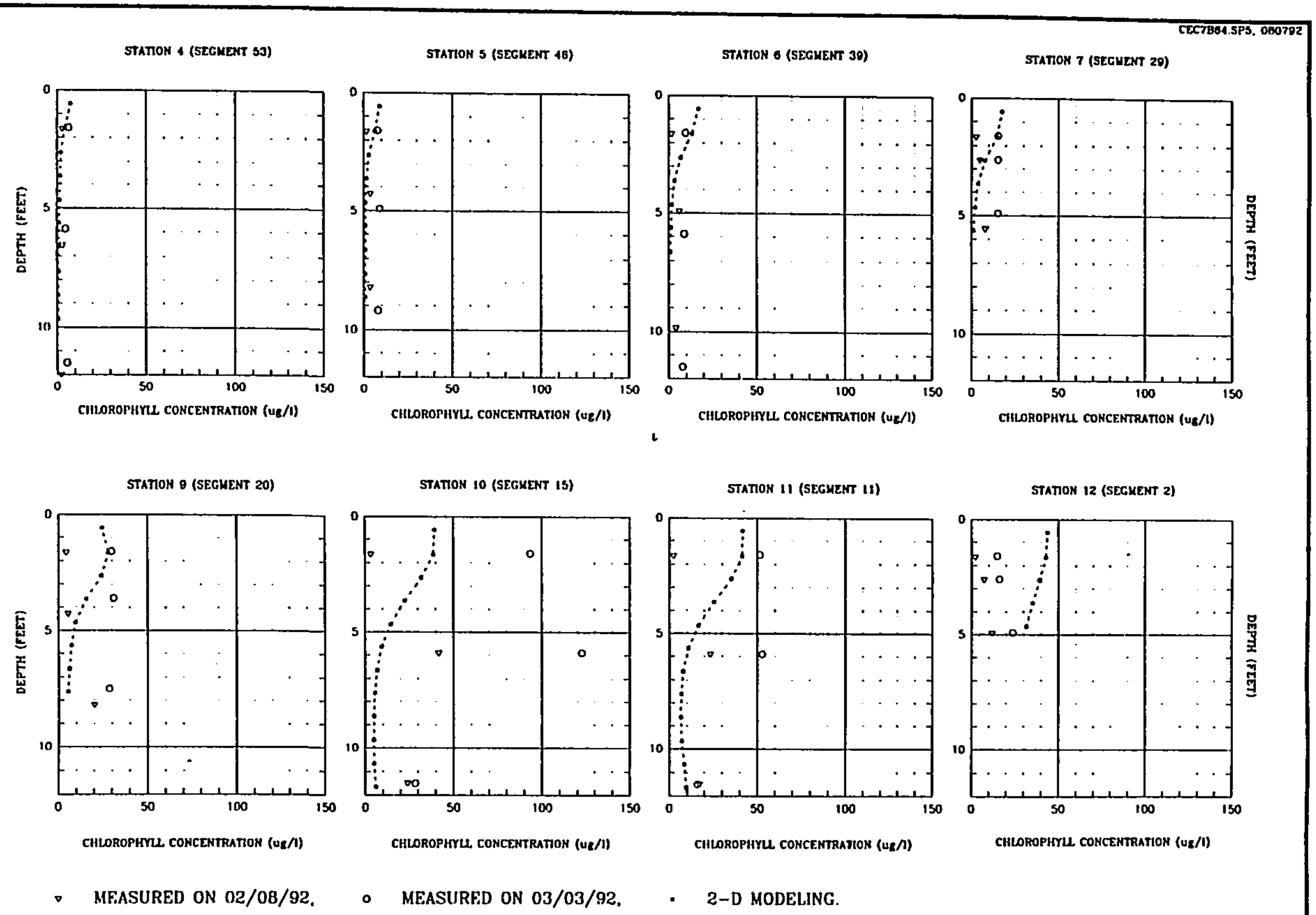
For reference purposes, a list of the coefficients and rate constants for the interaction relationships between constituents are provided in Table 4.5. For the specific definitions of the individual parameters, the User's Manual should be consulted.

Figures 4-11 to 4-18 show the final calibration results using the Table 4.2, 4.4 and 4.5 coefficients. Figure 4-11 shows the comparison between the field-measured and 2-D model-predicted chlorophyll concentrations at the 8 water quality station locations. The 2-D model results are provided after 12 tidal cycles of calculations. In general, the chlorophyll results agreed reasonably well with the field measured results, particularly for the March 3, 1992 measurements.

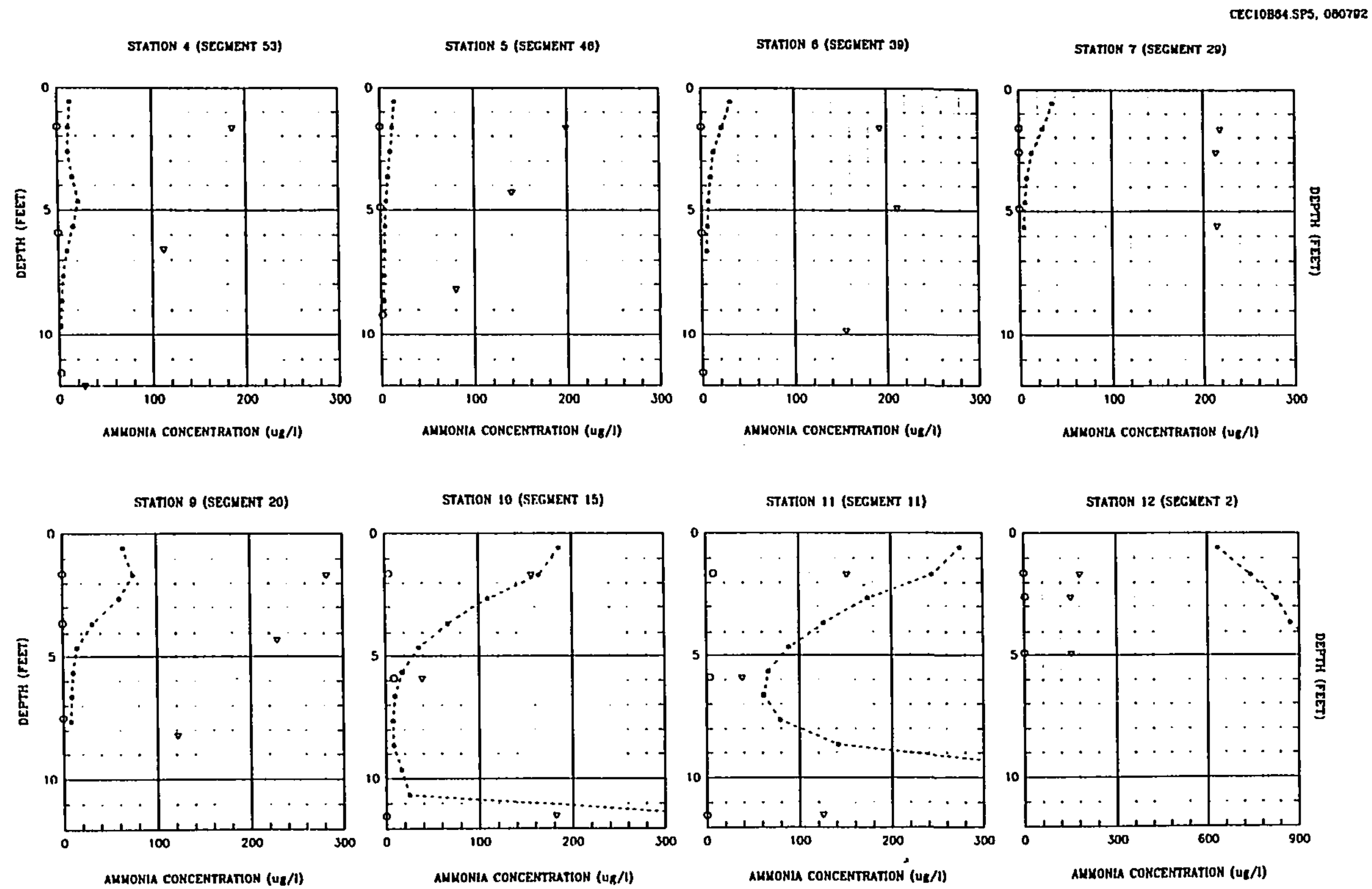
Figure 4-12 to 4-15 describe the comparison between the field-measured and 2-D model calibration results for PO_4, NH_4, NO_3 and O_2 respectively, at the 8 water quality station locations. For reference purposes, Figures 4-16 to 4-18 provide a graphical



ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	Comparison Of Measured And 2-D Model Predicted Phosphate (PO_4) Concentrations	FIGURE 4-12



ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	Comparison Of Measured And 2-D Model Predicted Chlorophyll Concentrations	FIGURE 4-11



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ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	Comparison Of Measured And 2-D Model Predicted Ammonia (NH_4) Concentrations	FIGURE 4-13

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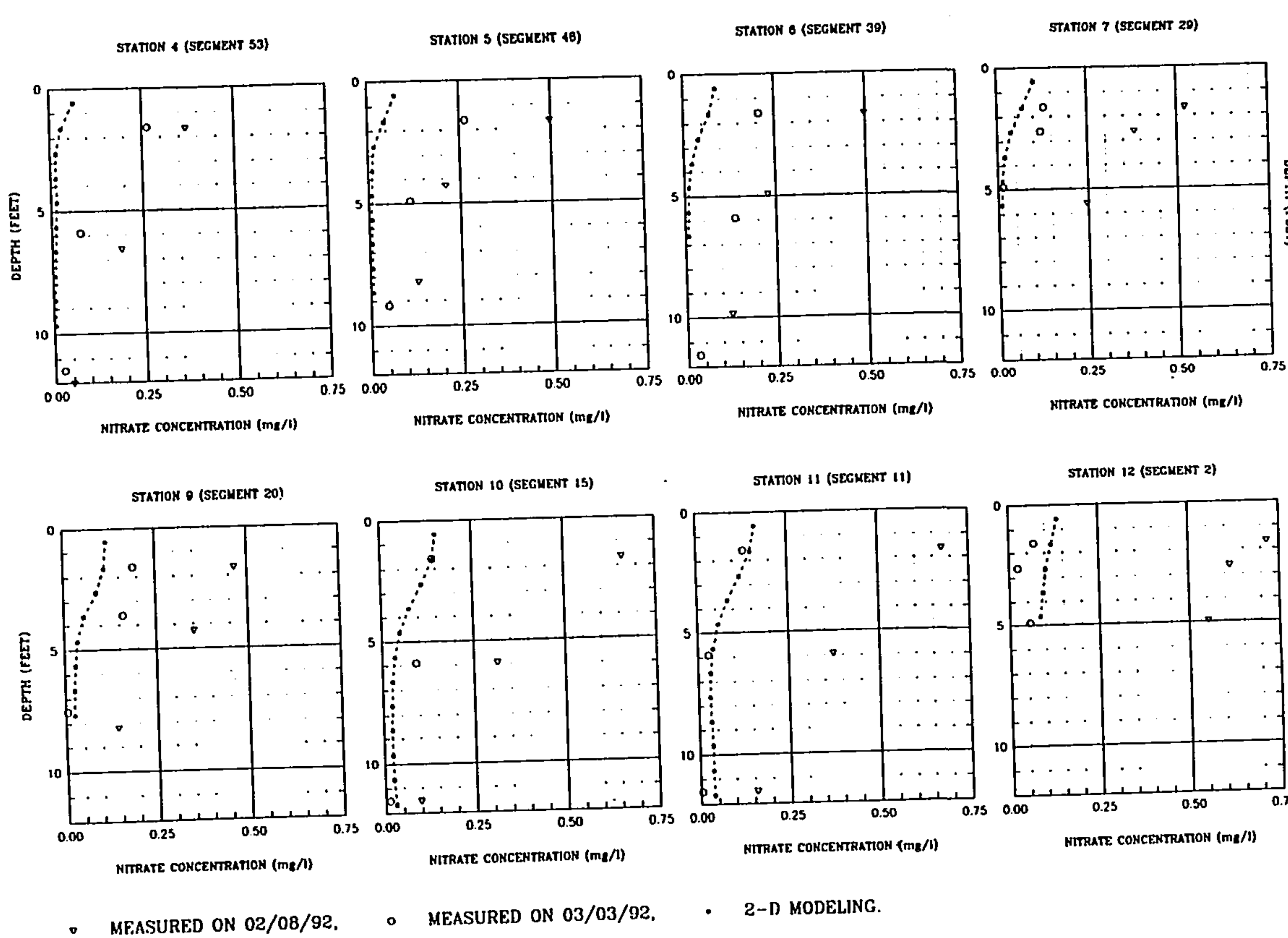

ALA WAI CANAL IMPROVEMENT PROJECT

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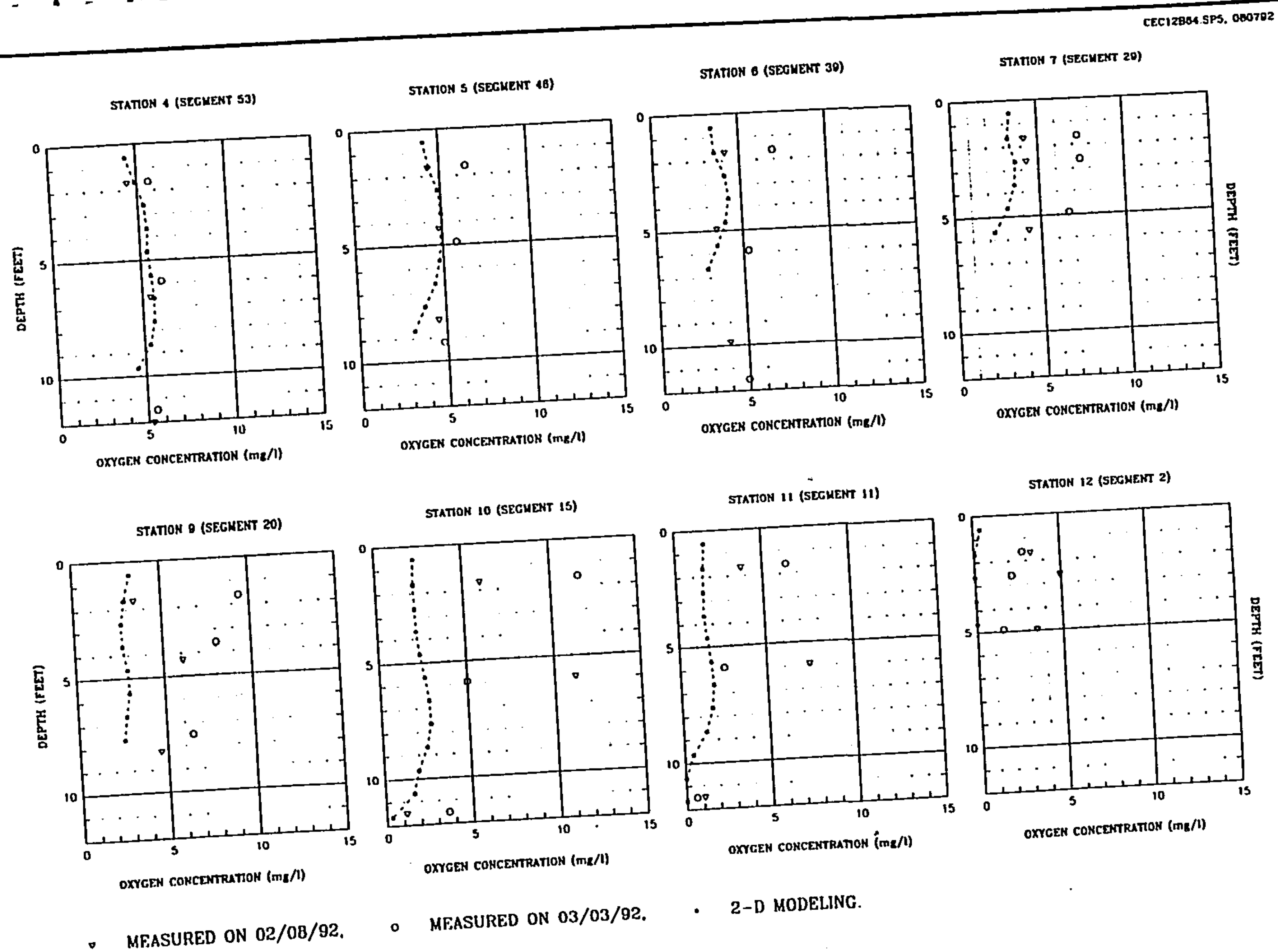
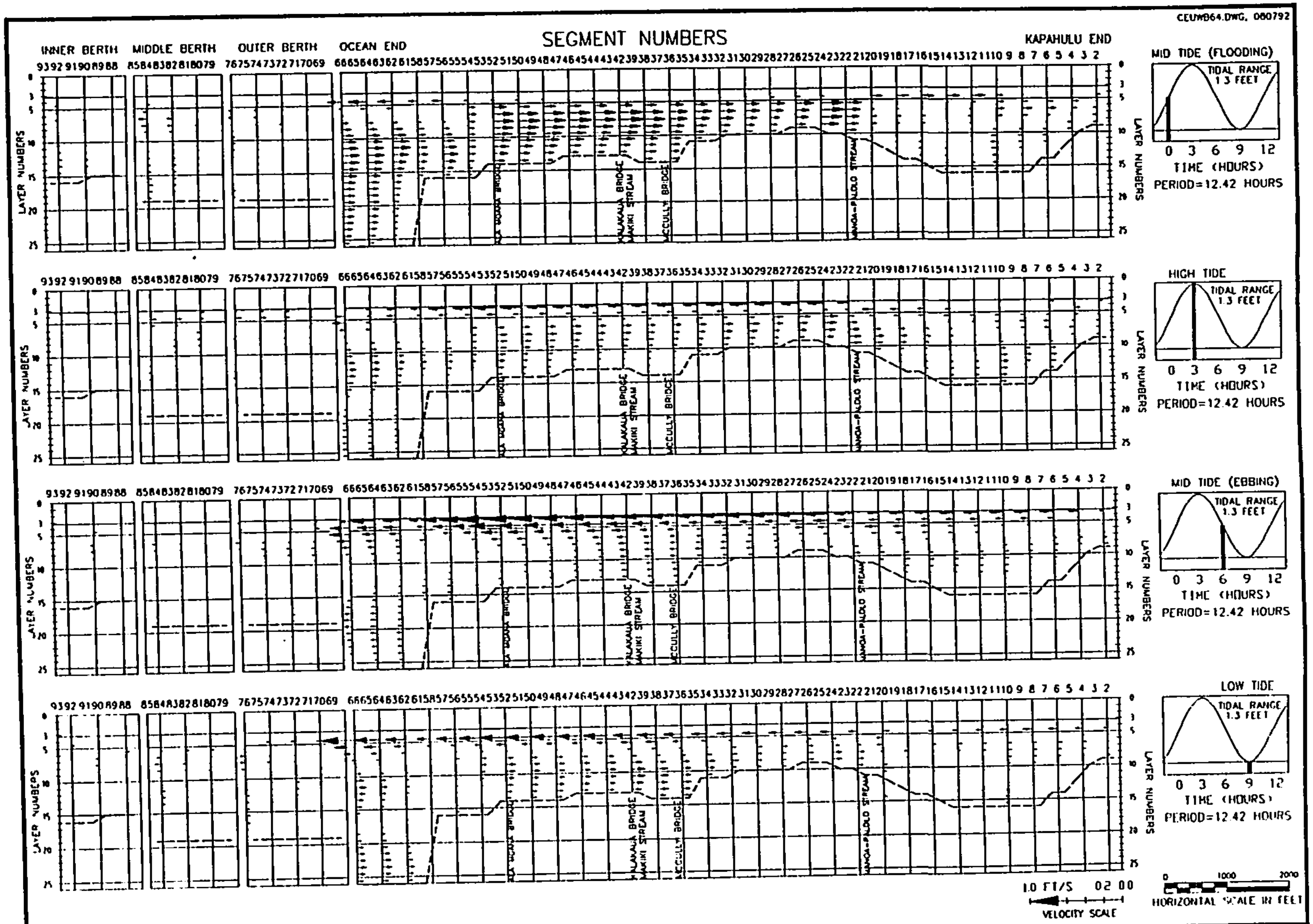
Comparison Of Measured And 2-D Model Predicted Nitrate (NO_3) Concentrations

FIGURE 4-14



ALA WAI CANAL IMPROVEMENT PROJECT		Edward K. Noda and Associates, Inc.	Comparison Of Measured And 2-D Model Predicted Dissolved Oxygen (O_2) Concentrations	FIGURE 4-15



ALA WAI CANAL IMPROVEMENT PROJECT

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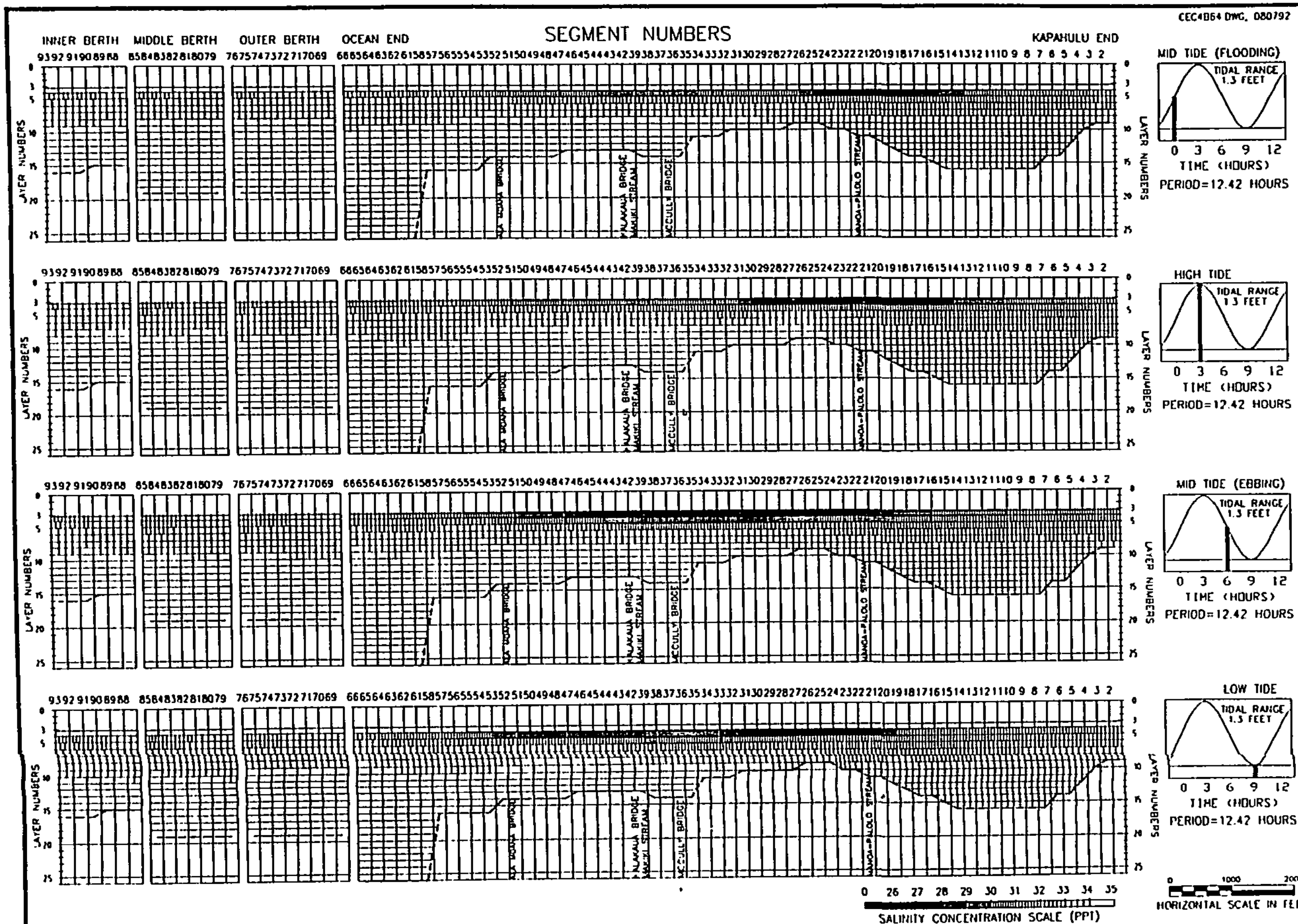
2-D Model Predicted Horizontal Flow Velocities For The Calibration Case

FIGURE 4-16



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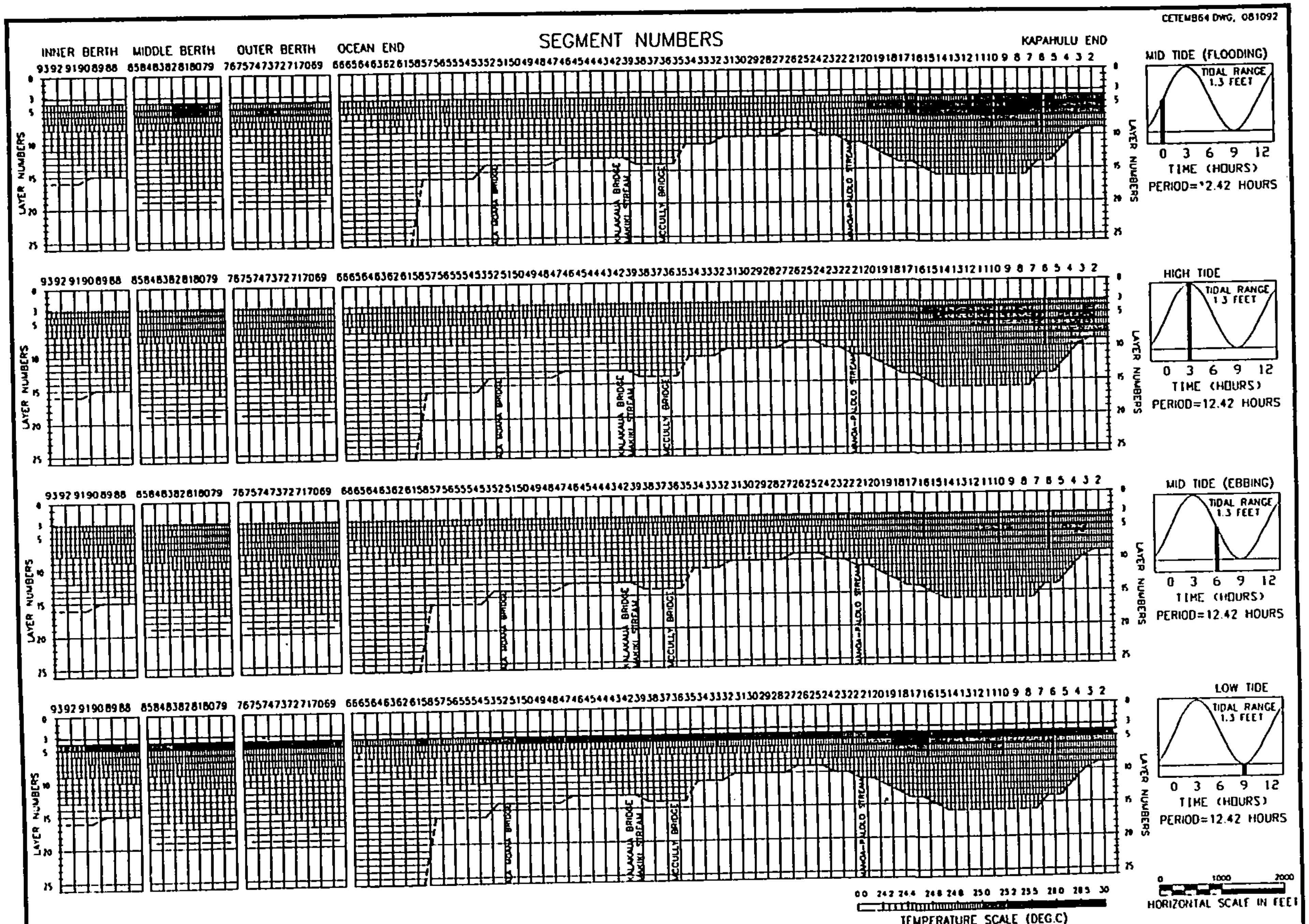
2-D Model Predicted Salinity Concentrations For The Calibration Case

FIGURE 4-17



ALA WAI CANAL
IMPROVEMENT PROJECT

Edward K. Noda and Associates, Inc.

2-D Model Predicted Temperature Distribution For The Calibration Case

FIGURE 4-18

representation of the horizontal current vectors, water salinity and water temperature respectively, as a function of segment locations along the entire modeled system, variations with depth and variations with tidal cycle phase. These types of representations quickly provide an overall view of the dynamics of the entire system. The segment numbers can be referenced to the locations shown in Figure 4-1. These types of graphical representations will represent a standard output format for all other 2-D model runs in this report.

In general, the extensive calibration process has clearly shown that the dynamics of the AWC, both hydrodynamically and biologically, are very complex both in time and space (both vertically and longitudinally). The 2-D model calibration results provide reasonable agreement with the field-measured values, and provide a verification of the ability of the CE-QUAL-W2 model to represent the complicated processes in the Ala`Wai Canal.

TABLE 4.4
CE-QUAL-W2 Model Biological-Water Quality Calibration Parameters

	Tributary Water Characteristics		
Parameter	Ala Wai Golf Course	Manoa-Palolo Stream	Makiki Stream
Suspended Solids kg/m^3	0.0	3.0	2.0
Coliform units/100 ml	0.0	400.0	290.0
Chlorophyll kg/m^3	0.0	0.0	0.0
PO_4 kg/m^3	0.28	0.031	0.1395
NH_4 kg/m^3	0.0112	0.0112	0.0112
NO_3 kg/m^3	0.56	0.252	0.56
O_2 kg/m^3	6.0	6.0	6.0
Dissolved Organic Matter kg/m^3	0.0	0.0	0.0
Detritus kg/m^3	0.0	0.0	0.0
Inorganic Carbon kg/m^3	0.0	1.1	1.0

Solar Radiation = 3.583E-6 °C*m/sec
Time Step = 100 sec

TABLE 4.5
CE-QUAL-W2 Interaction Coefficients and Rate Constants

Hydraulic Parameters

DATA INDEX	PARA-METER	VALUE	UNITS	DATA INDEX	PARA-METER	VALUE	UNITS
WP	AX	0.0	M*M/S		CHZY	35.0	SQRT(M)/S
	DXI	0.0	M*M/S		BETA	0.81	—
	DXC	0.0	M*M/S		GAMMA	1.01	1/M

Chemical and Biological Parameters

DATA INDEX	PARA-METER	VALUE	UNITS
RA	Q10COL	1.04	—
	TCOLDK	1.0	1/D
	TSSETL	20.0	M/D
RB	DMO2	0.204E-09	M*M/S
	DMCO2	0.204E-10	M*M/S
RC	EXCO	0.2	1/M
	EXTINS	0.1	L/M-mg
	EXTINP	0.1	L/M-mg
	ALDIGO	0.8	—
RD	TPMAX	2.0	1/D
	TSETL	0.2	M/D
	PS2PO4	0.1	mg/L
	PS2N	0.03	mg/L
RE	PISAT	15.0	W/M*M
	TPEXCR	0.03	1/D
	TPMORT	0.03	1/D
	TPRESP	0.2	1/D
RF	ALG1T1	10.0	C
	ALG1T2	25.0	C
	ALG1T3	28.0	C
	ALG1T4	35.0	C
RG	ALG1K1	0.1	—
	ALG1K2	0.95	—
	ALG1K3	0.98	—
	ALG1K4	0.1	—
RH	TDSETL	2.5	M/D
	DETT1	0.0	C
	DETT2	30.0	C
	DETK1	0.1	—
	DETK2	0.98	—
RI	TDOMDK	0.1	1/D
	TNH3DK	0.15	1/D
	TNO3DK	0.05	1/D
	TDETDK	0.05	1/D

DATA INDEX	PARA-METER	VALUE	UNITS
RJ	TRFRDK	0.05	1/D
	TDOMRF	0.05	1/D
	DOMCNT	0.3	—
	TSEDDK	0.05	1/D
RK	DOMT1	5.0	C
	DOMT2	30.0	C
	DOMK1	0.1	—
	DOMK2	0.98	—
RL	NH3T1	5.0	C
	NH3T2	30.0	C
	NH3K1	0.1	—
	NH3K2	0.98	—
RM	NO3T1	2.0	C
	NO3T2	25.0	C
	NO3K1	0.1	—
	NO3K2	0.98	—
RN	ADSRBP	30.0	M*M*M/G
	ADSRBN	2.0	M*M*M/G
	ADMAXP	0.001	G/G
	ADMAXN	0.0003	G/G
RO	O2NH3	4.57	—
	O2DET	1.4	—
	O2RESP	1.1	—
	O2FAC	1.4	—
	O2DOM	1.4	—
	OXYLIM	0.5	mg/L
RP	TXP4RE	0.01	G/M*M-D
	XPO4T1	1.0	C
	XPO4T2	5.0	C
	XPO4T3	35.0	C
	XPO4T4	0.0	C

DATA INDEX	PARA-METER	VALUE	UNITS
RQ	XPO4K1	0.1	—
	XPO4K2	0.98	—
	XPO4K3	0.98	—
	XPO4K4	0.1	—
RR	TCNREL	0.3	G/M*M-D
	CNT1	1.0	C
	CNT2	5.0	C
	CNT3	35.0	C
	CNT4	40.0	C
RS	CNK1	0.1	—
	CNK2	0.98	—
	CNK3	0.98	—
	CNK4	0.1	—
RT	TSODx	2.0	G/M*M-D
	ISODx	94.0	—
RU	SODT1	1.0	C
	SODT2	5.0	C
	SODT3	35.0	C
	SODT4	40.0	C
RV	SODK1	0.1	—
	SODK2	0.98	—
	SODK3	0.98	—
	SODK4	0.1	—
	SFCO2	1.4	—
RW	BIOP	0.005	—
	BIOC	0.45	—
	BION	0.08	—
RX	TFESET	0.3	M/D
	TFEREL	2.0	G/M*M-D
	FEFACT	1.5	—

NOTE: The abbreviations used in the above table are defined as follows: C - °C, D - Day, G - Gram, L - Liter, M - Meter, mg - Milligram, S - Second, SQRT - Square root, W - Watt

4.3. EVALUATION OF DESIGN OPTIONS TO IMPROVE WATER QUALITY

4.3.1. <u>Introduction.</u> The fully calibrated 2-D model can now be used to evaluate various alternatives to improve the water quality in the Ala Wai Canal. The range of options include the following:

- Injecting seawater into the Kapahulu end of the AWC, where the source of the seawater is the nearshore, coastal waters.
- Injecting water into the Kapahulu end of the AWC, where the source of the water is groundwater.
- Injecting seawater and withdrawing canal water at the Kapahulu end of the AWC, as a function of the tidal cycle.
- Withdrawing canal waters from the Kapahulu end of the AWC and discharging into nearshore waters.
- Connecting the Kapahulu end of the AWC to Waikiki Beach using a box culvert with a free surface.
- Dredging the AWC between the McCully Bridge and the confluence of the Manoa-Palolo Stream.
- Filling in the deep basin between the confluence of the Manoa-Palolo Stream and the Kapahulu end of the AWC.

Based on the recommendation in Chapter 3.0, the primary criteria to evaluate water quality in the AWC was the concentration of chlorophyll in the water column. Specifically, a chlorophyll concentration of between 5 to 10 μg/liter was selected as target values. Any option which exceeded 10 μg/l was considered unsatisfactory.

The following sections describe the 2-D model results for the above described options to improve the water quality in the Ala Wai Canal.

4.3.2. Base Case Conditions. For evaluation purposes, a "Base Case" has been defined in order to provide a relative standard for comparisons with improvement options. The Base Case is defined by the conditions shown in Tables 4.2, 4.4 and 4.5, except that zero wind speed conditions are imposed. Figures 4-19 to 4-26 show the standard output format from the 2-D model for chlorophyll, PO_4, NH_4, NO_3, O_2, horizontal velocity, salinity and water temperature, respectively. Due to the large volume of output figures available for each 2-D model run, in general the graphical output displays will be limited to chlorophyll concentrations and horizontal velocities, and these figures will be provided in Appendix F in order to provide reading continuity.

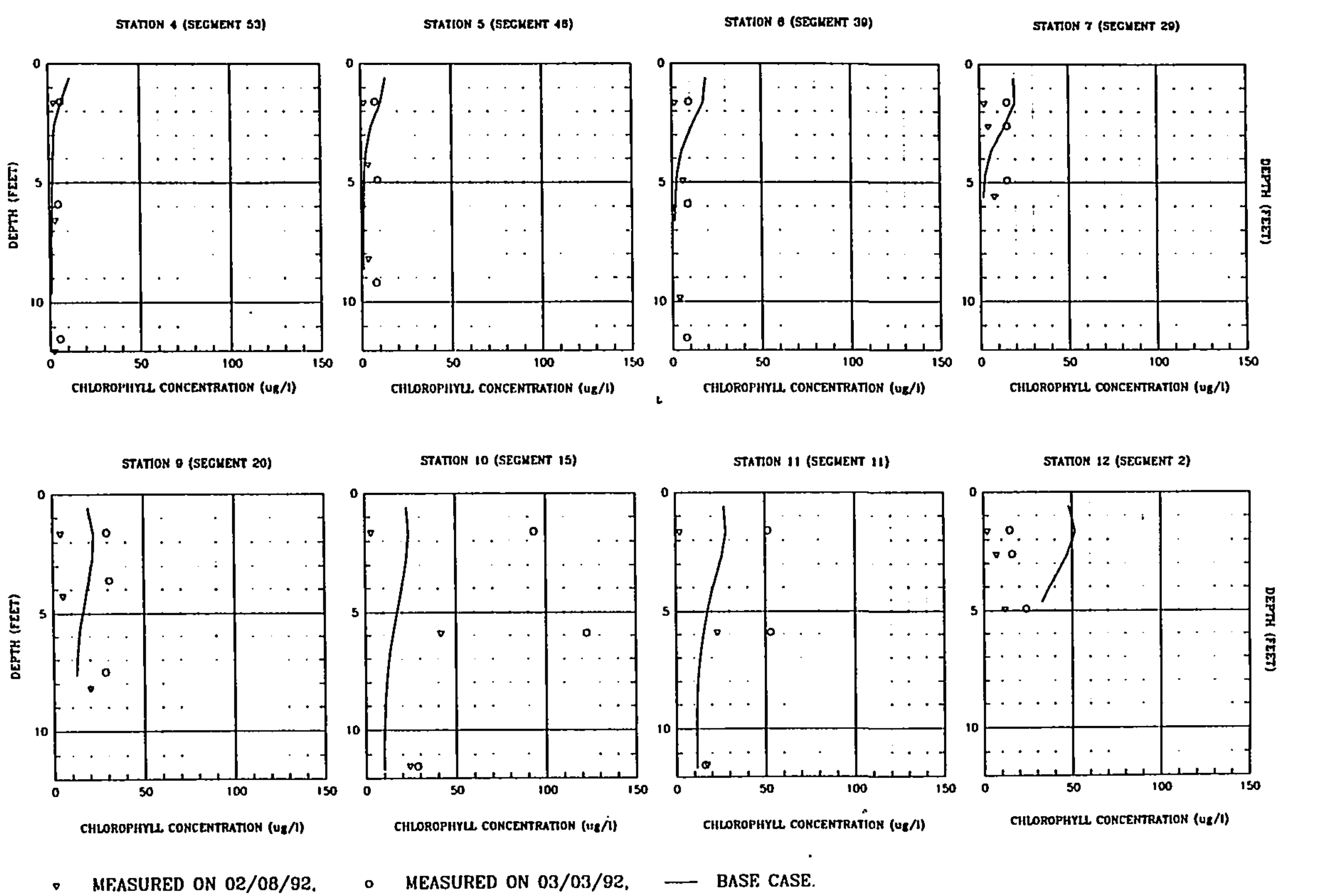
Table 4.6 shows the chlorophyll concentration ($\mu g/l$) results for the Base Case (BC), the BC with a 5 knot tradewind (from the East), and the BC with a 5 knot Kona wind (from the West-Southwest) at the 8 water quality station locations and a harbor location.

The harbor location that has been selected for the display of chlorophyll concentrations is segment number 90 ("Harbor Station") shown in Figure 4-1, which is located at about half-way between the ends of Branch 5, and provides a representative condition in this branch. Evaluations of the chlorophyll concentrations in Branches 3 and 4 indicate that Branch 5 yields higher concentration values. While the objectives of the present study are not focused on improving the water quality in the Ala Wai Boat Harbor, it is important that any recommended option does not significantly degrade the water quality in this marina complex. Consequently, the "Harbor Station" has been displayed to evaluate the water quality consequences in this important basin area.

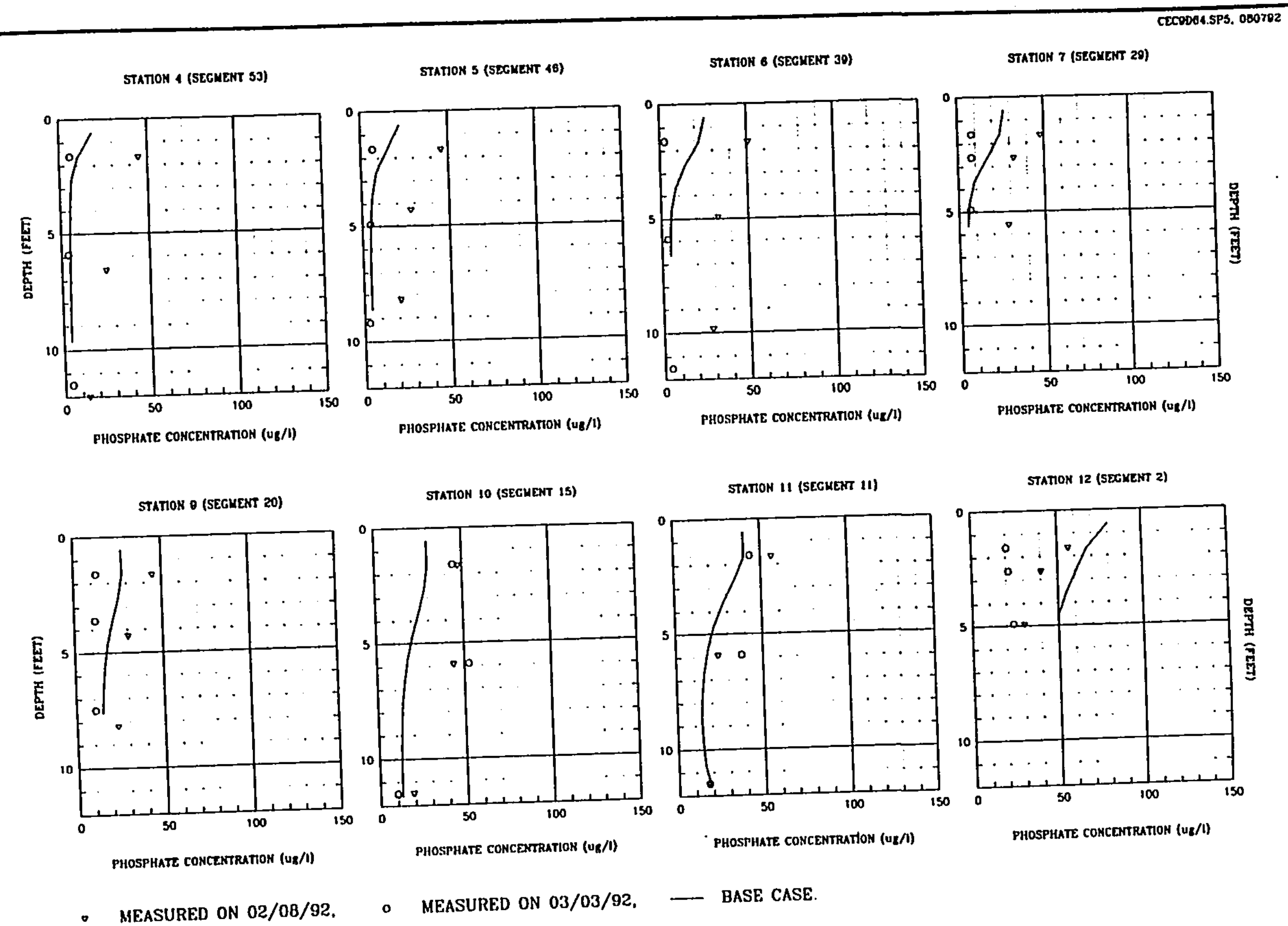
The vertical position descriptions shown in Table 4.6 represent the Top, Middle and Bottom layers in the model at the given station locations, while the maximum (Max) designation represents the maximum chlorophyll concentration in the water column.

The Base Case with the 5 knot tradewind conditions represent the calibration case and the results are shown in Figures 4-11 to 4-18. The results for the Base Case with a 5 knot Kona wind condition are shown in Figures F-1 and F-2 in Appendix F for the chlorophyll concentrations and horizontal velocities respectively.

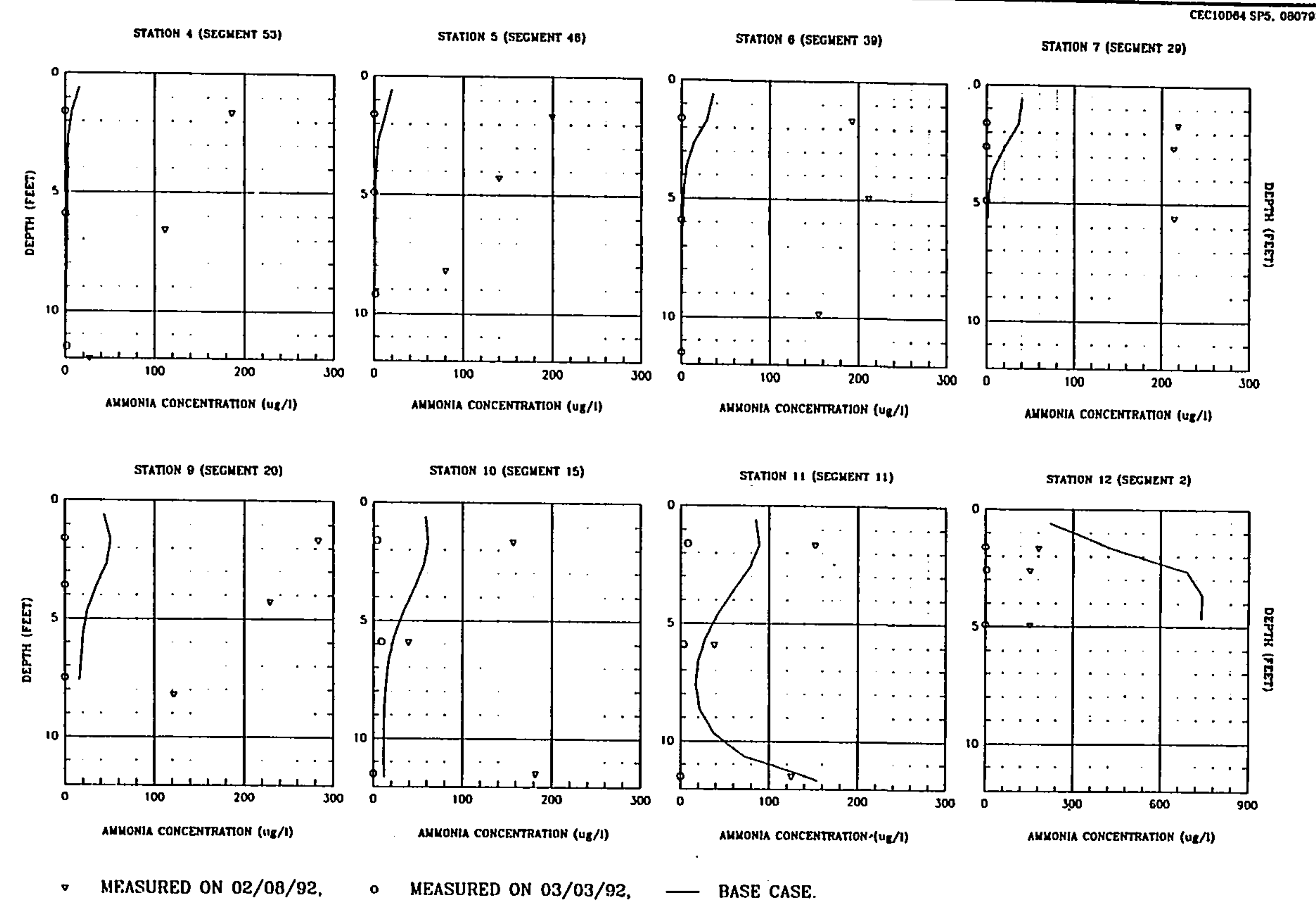
In general, the extensive calibration process has clearly shown that the dynamics of the AWC, both hydrodynamically and biologically, are very complex both in time and space (both vertically and longitudinally). The 2-D model calibration results provide reasonable agreement with the field-measured values, and provide a verification of the ability of the CE-QUAL-W2 model to represent the complicated processes in the Ala Wai Canal.



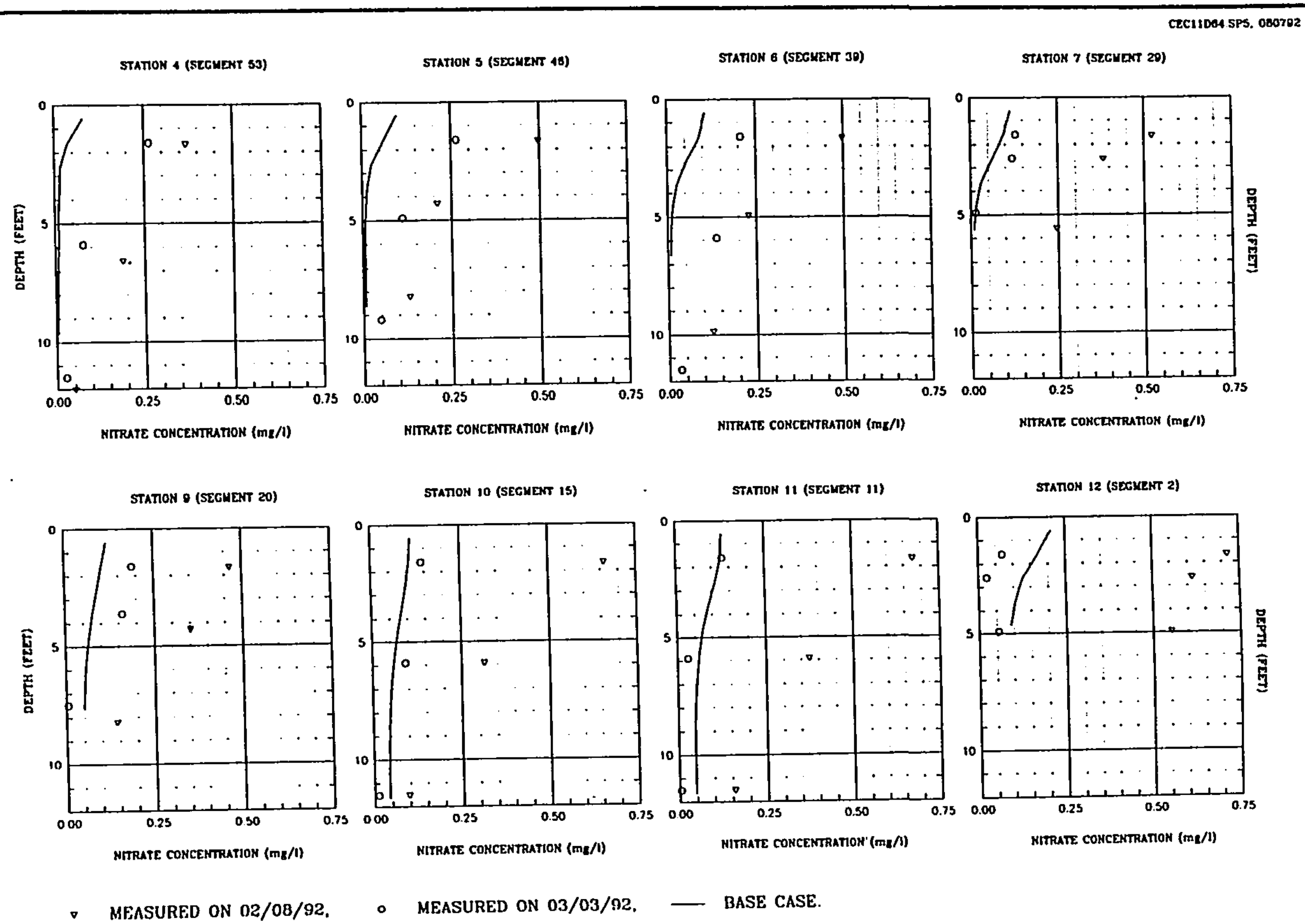
ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	Base Case Chlorophyll Concentrations	FIGURE 4-19



ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	Base Case Phosphate (PO_4) Concentrations	FIGURE 4-20



ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	Base Case Ammonia (NH_4) Concentrations	FIGURE 4-21

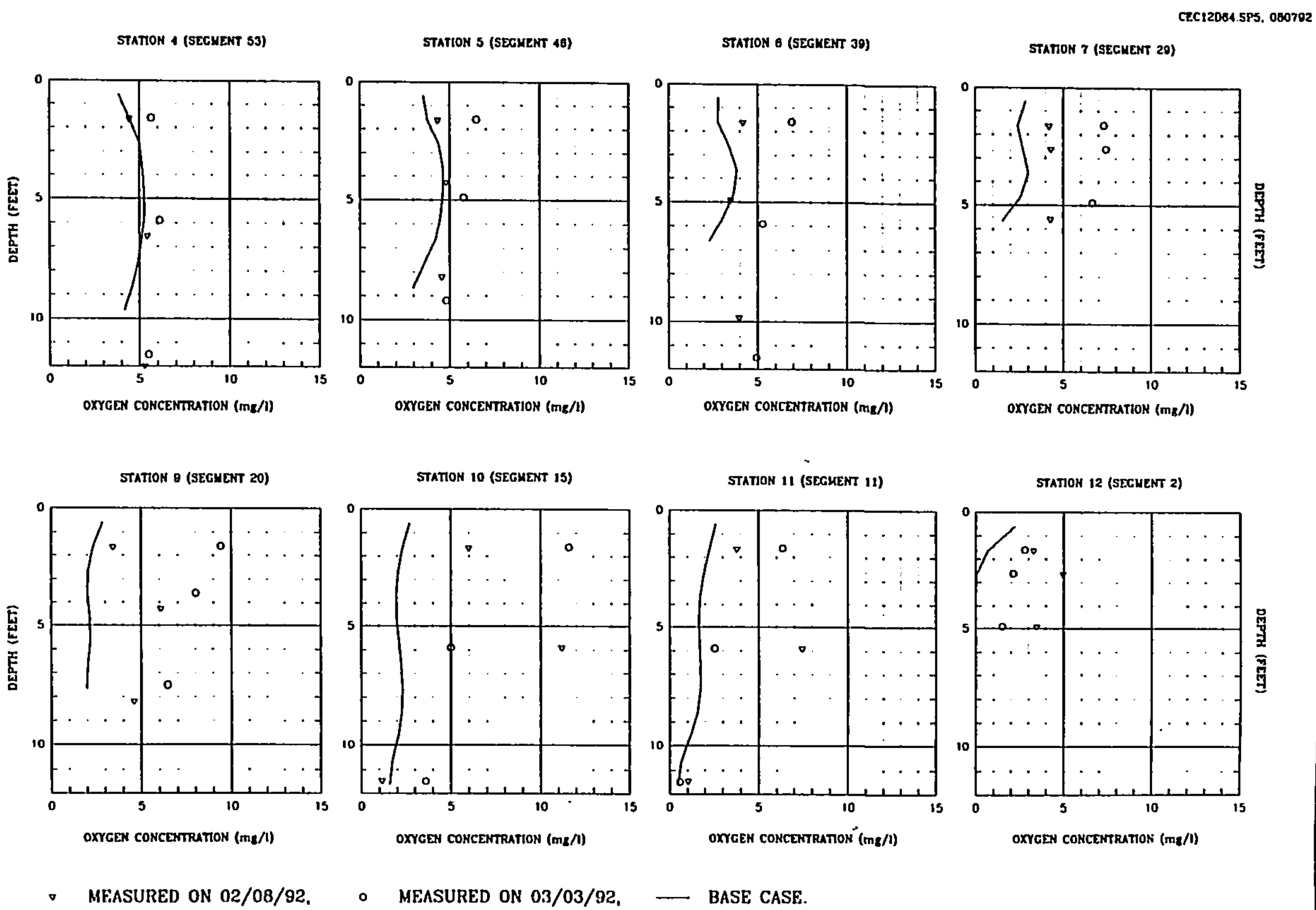


ALA WAI CANAL
IMPROVEMENT PROJECT

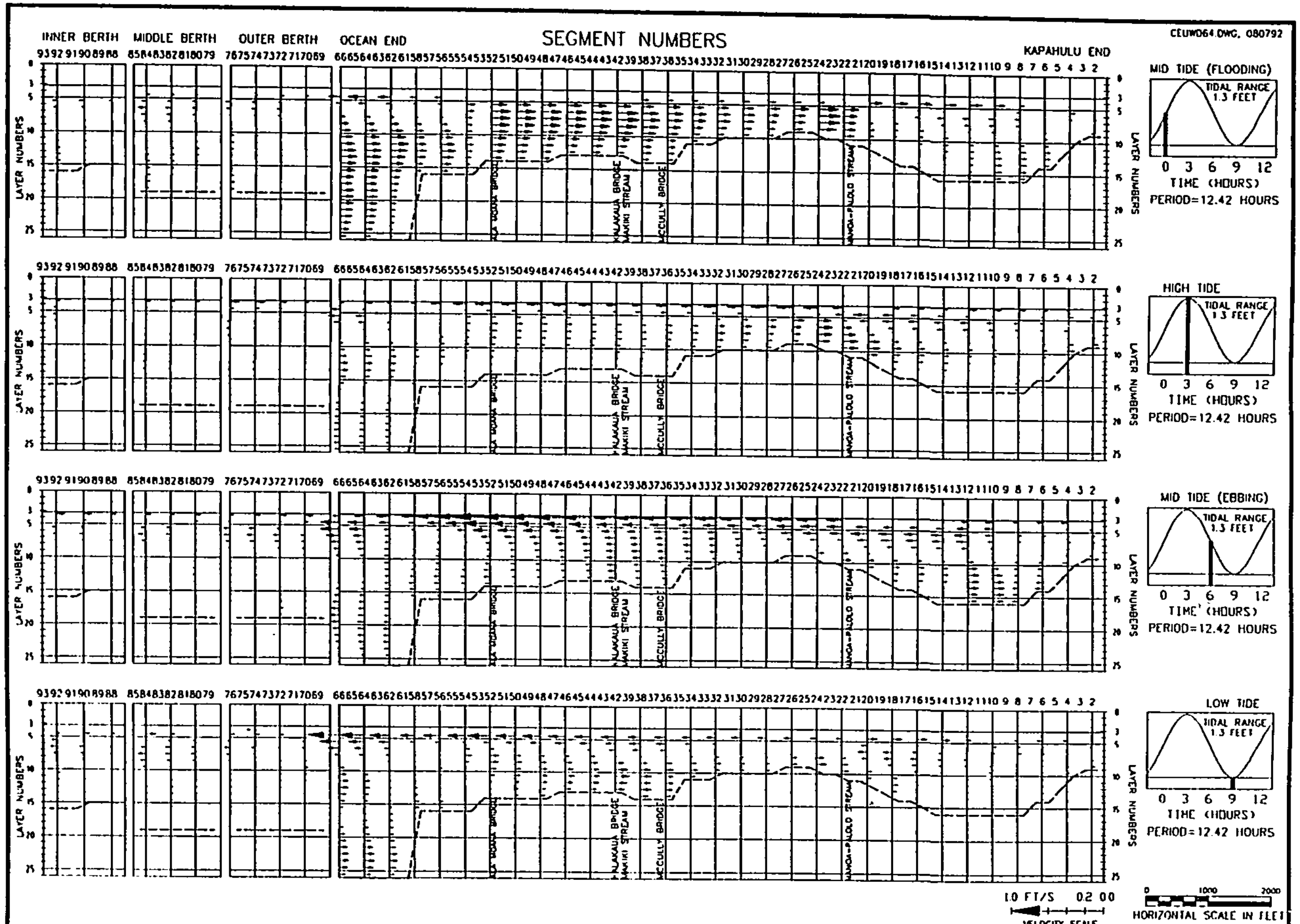
Edward K. Noda
and
Associates, Inc.

Base Case Nitrate (NO_3) Concentrations

FIGURE
4-22



ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	Base Case Dissolved Oxygen (O_2) Concentrations	FIGURE 4-23

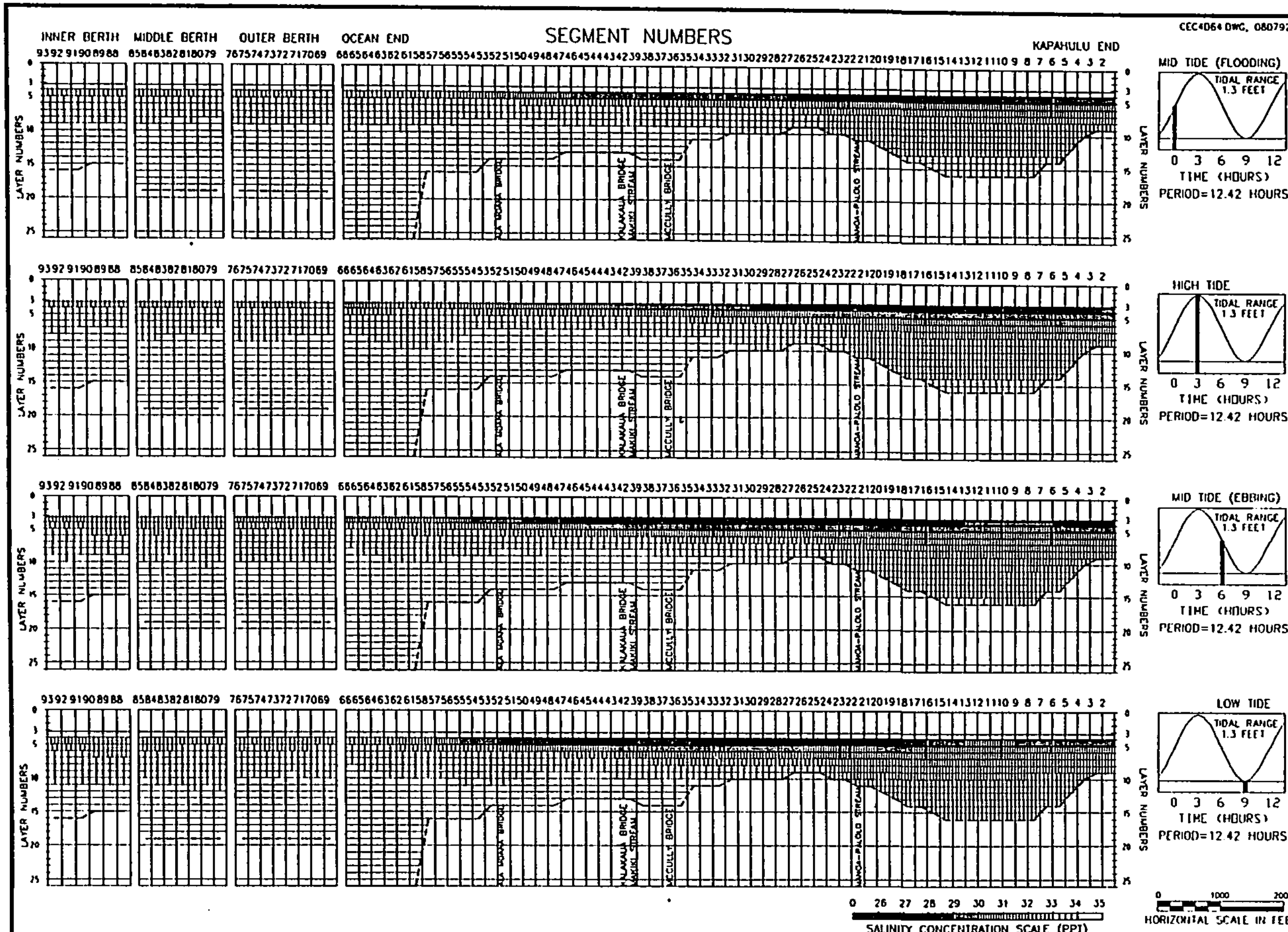


ALA WAI CANAL IMPROVEMENT PROJECT

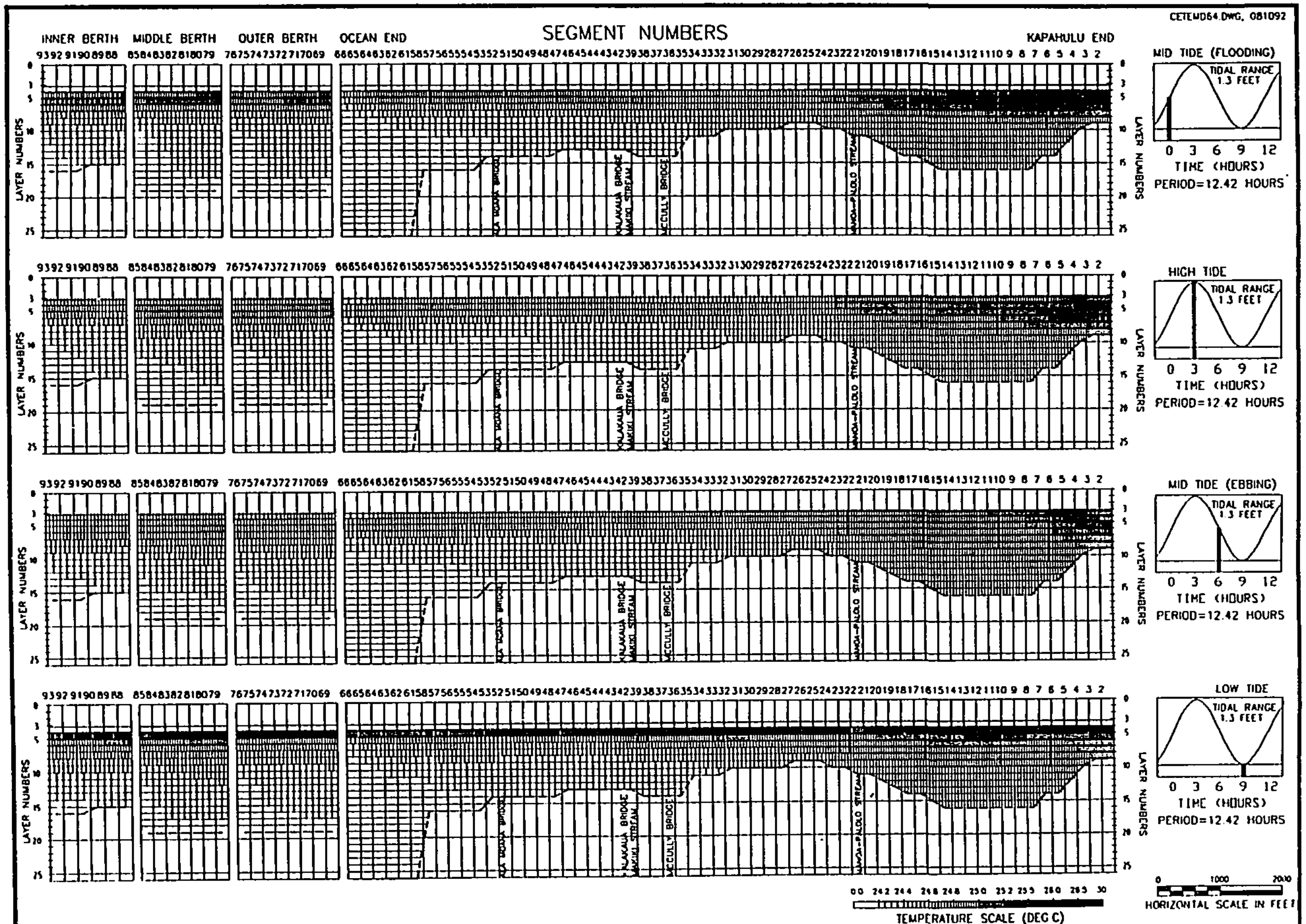
Edward K. Noda and Associates, Inc.

Base Case Horizontal Flow Velocity Distribution

FIGURE 4-24



ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	Base Case Salinity Concentration Distribution	FIGURE 4-25



ALA WAI CANAL
IMPROVEMENT PROJECT

Edward K. Noda
and
Associates, Inc.

Base Case Water Temperature Distribution

FIGURE
4-26

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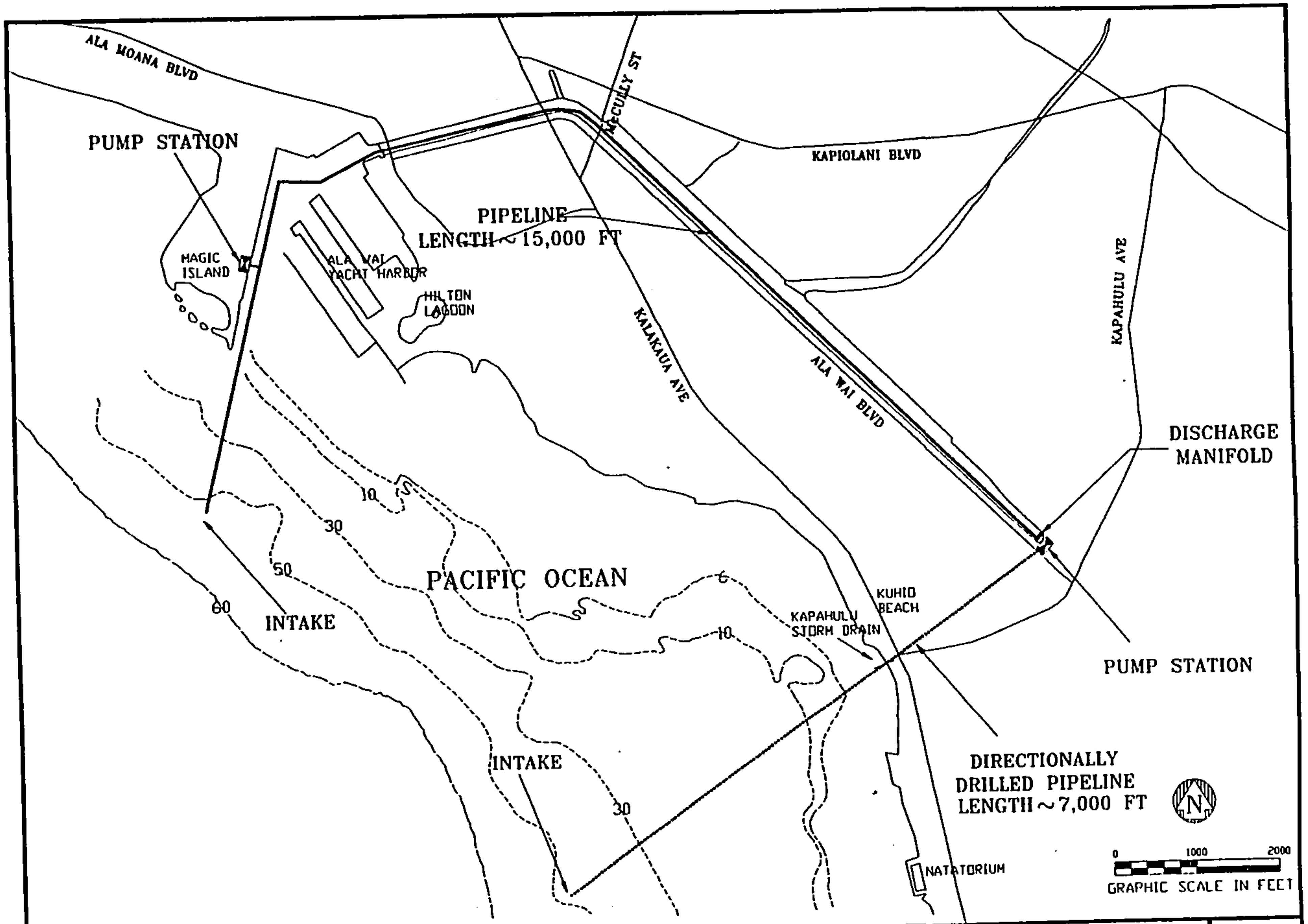
TABLE 4.6
Chlorophyll Concentrations for Base Case, and BC with 5 knot Tradewind and Kona Wind Conditions

Description	Station Number								
	4	5	6	7	9	10	11	12	Harbor
Base Case (BC)									
TOP	11.79	13.57	19.10	19.11	19.44	22.80	27.18	48.36	5.47
MIDDLE	1.85	1.66	5.59	14.00	19.64	15.85	16.05	46.98	1.74
BOTTOM	0.95	0.98	1.43	1.94	12.61	10.22	11.58	32.76	0.89
MAX	11.79	13.57	19.10	19.72	22.51	23.79	28.16	51.92	5.47
BC & 5 kt Tradewind									
TOP	7.63	9.15	16.88	17.66	24.56	39.34	41.80	43.81	4.22
MIDDLE	1.62	1.12	3.39	7.85	15.60	9.42	10.88	39.14	2.42
BOTTOM	0.83	0.89	1.14	1.39	5.45	6.09	9.60	31.68	1.09
MAX	7.63	9.15	16.88	17.66	27.95	39.34	41.80	43.81	4.22
BC & 5 kt Kona Wind									
TOP	9.87	12.38	15.96	15.70	15.34	17.29	17.81	25.92	5.29
MIDDLE	1.99	2.21	7.02	13.82	17.26	15.31	16.09	30.67	1.79
BOTTOM	0.90	0.97	1.88	2.96	13.29	11.52	12.32	25.06	0.88
MAX	9.87	12.38	15.96	16.99	17.96	18.32	19.41	30.67	5.29

The results shown in Table 4.6 indicate that the Base Case represents the worst case situation for chlorophyll concentrations. It is interesting to note the differences in the vertical structure and longitudinal variations in chlorophyll concentrations as a function of the direction of the wind velocity. The surface layer chlorophyll concentrations improved during light Kona wind conditions as compared to light tradewind conditions, but the opposite is true in the lower water column. The difference in circulation is evident in the display of the horizontal velocities.

4.3.3. Injecting Seawater into the Kapahulu End of the AWC. The design concepts which inject seawater into the Kapahulu end of the AWC include laying a submerged pipeline in the Ala Wai Canal with the intake located in the entrance channel of the Ala Wai Boat Harbor, and constructing a pipeline completely underground from the Kapahulu end of the AWC to a location off Waikiki Beach using a directional drilling methodology. Figure 4-27 provides a schematic description of these two seawater injection system concepts. While other design concepts could be envisioned, all these design concepts are essentially identical in the 2-D model results, since the source water characteristics are assumed to be identical.



ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	PROPOSED PIPELINE ROUTES	FIGURE 4-27

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Based on the water quality characteristics obtained at Station 1 (Appendix E) located outside of the Ala Wai Boat Harbor entrance channel, Table 4.7 shows the selected water quality characteristics for the source seawater to be used to flush the AWC.

TABLE 4.7

CE-QUAL-W2 Seawater Inflow Characteristics

Parameter	Seawater Characteristics	Parameter	Seawater Characteristics
Temperature °C	23.0	NH_4 kg/m^3	0.0
Salinity ppt	35.0	NO_3 kg/m^3	0.0013
Suspended Solids (SS) kg/m^3	0.0	O_2 kg/m^3	6.0
Coliform units/100 ml	0.0	Dissolved Organic Matter kg/m^3	0.0
Chlorophyll kg/m^3	0.00016	Detritus kg/m^3	0.0
PO_4 kg/m^3	0.004	Inorganic Carbon kg/m^3	0.171

A variety of seawater flow rates (10, 20, 30 and 40 cfs) were injected into the Kapahulu end of the AWC and the chlorophyll results are shown in Table 4.8. In Table 4.8, the 10 cfs seawater inflow at the Kapahulu end of the AWC yields a maximum chlorophyll concentration of 16.4 μg/l at Station 12, with maximum concentrations greater than 10 μg/l throughout most of the Canal. Thus, this flow rate is considered insufficient to develop satisfactory water quality in the AWC. Seawater injection flow rates of 20 - 40 cfs produce satisfactory water quality results, based on our requirement that the chlorophyll concentration be less than 10 μg/l.

To test the sensitivity of the chlorophyll concentration results to light tradewind and Kona wind conditions, the 5 knot tradewind and 5 knot Kona wind conditions were run for the 20, 30 and 40 cfs seawater injection cases and the results are shown in Table 4.9. The results in Table 4.9 indicate that while the overall concentrations of chlorophyll are slightly reduced when either of these light wind conditions are imposed, the reductions are not uniform throughout the canal, both longitudinally and vertically. In other words, at different depths and different locations in the AWC, the concentrations of chlorophyll could be either higher or lower than its no wind, Base Case condition. The important conclusion drawn from Table 4.9 is that the chlorophyll concentrations in the AWC, when there is a reasonable seawater injection at the Kapahulu terminus, is somewhat insensitive to light wind conditions.

TABLE 4.8

Chlorophyll Concentrations for Base Case with 10, 20, 30, 40 cfs Seawater Inflow

Description	Station Number								
	4	5	6	7	9	10	11	12	Harbor
BC & 10 cfs Seawater Inflow									
TOP	6.27	7.08	9.67	9.59	9.79	11.17	12.08	15.83	3.51
MIDDLE	1.52	1.47	3.98	8.57	9.45	7.98	10.48	14.42	1.43
BOTTOM	0.93	0.98	1.44	1.90	5.78	6.65	9.42	0.16	0.88
MAX	6.27	7.08	9.67	10.31	11.45	12.01	12.57	16.40	3.51
BC & 20 cfs Seawater Inflow									
TOP	3.47	3.66	4.24	4.09	4.24	4.71	4.95	6.26	2.37
MIDDLE	1.37	1.42	2.89	4.40	4.29	3.80	3.57	3.51	1.33
BOTTOM	0.94	1.00	1.50	1.93	3.81	3.25	2.90	0.16	0.89
MAX	3.47	3.66	4.32	4.59	4.77	5.03	5.21	6.56	2.37
BC & 30 cfs Seawater Inflow									
TOP	1.92	1.89	1.52	1.30	1.27	1.27	1.27	1.96	1.80
MIDDLE	1.30	1.50	2.25	1.72	1.31	1.15	0.94	0.45	1.28
BOTTOM	0.95	1.03	1.73	2.21	1.72	1.05	0.97	0.16	0.89
MAX	1.92	2.14	2.25	2.31	1.77	1.27	1.27	1.96	1.80
BC & 40 cfs Seawater Inflow									
TOP	1.27	1.14	0.87	0.73	0.77	0.77	0.73	1.03	1.45
MIDDLE	1.30	1.69	1.44	0.83	0.67	0.52	0.44	0.16	1.19
BOTTOM	0.96	1.08	2.07	1.36	0.92	0.81	0.44	0.16	0.90
MAX	1.61	1.87	2.09	1.36	0.92	0.81	0.73	1.03	1.48

Based on the Table 4.8 and 4-9 results, a seawater injection rate of 20 cfs would meet the proposed chlorophyll water quality criteria. For descriptive purposes, the 20 cfs seawater injection case will be designated as the 20 cfs Base Case in the following discussions. To further test the sensitivity of the 20 cfs seawater injection option, runs were calculated with a 2 foot tidal range (1 foot tidal amplitude), a 0.6 foot tidal range (0.3 foot tidal amplitude), a 20 knot tradewind condition, and a 10 knot Kona wind condition, with the results shown in Table 4.10.

TABLE 4.9

Chlorophyll Concentrations for Base Case with 10, 20, 30, 40 cfs Seawater Inflow and 5 knot Tradewind and Kona Wind Conditions

Description	Station Number							
	4	5	6	7	9	10	11	12	Harbor
BC & 20 cfs Seawater Inflow & 5 kt Tradewind									
TOP	2.30	2.41	3.69	3.86	4.46	4.92	4.92	5.25	2.63
MIDDLE	1.43	1.11	1.77	2.68	4.62	3.61	3.03	1.42	2.51
BOTTOM	0.87	0.95	1.15	1.38	4.12	3.01	2.47	0.16	1.16
MAX	2.30	2.41	3.69	3.86	4.79	4.92	4.92	5.25	3.07
BC & 20 cfs Seawater Inflow & 5 kt Kona wind									
TOP	4.00	4.21	4.17	3.97	3.88	4.07	3.79	5.14	2.69
MIDDLE	1.46	1.71	3.67	4.69	4.57	4.26	3.11	4.32	1.40
BOTTOM	0.92	1.00	1.70	2.25	4.58	3.65	2.73	0.16	0.87
MAX	4.00	4.30	4.45	4.69	4.86	4.76	3.79	5.18	2.69
BC & 30 cfs Seawater Inflow & 5 kt Tradewind									
TOP	1.50	1.49	1.65	1.55	1.73	1.78	1.71	1.65	2.42
MIDDLE	1.42	1.16	1.50	1.74	1.50	1.06	0.81	0.16	2.64
BOTTOM	0.93	0.99	1.23	1.57	1.35	1.04	0.71	0.16	1.17
MAX	1.50	1.55	1.67	1.76	1.79	1.78	1.71	1.65	3.11
BC & 30 cfs Seawater Inflow & 5 kt Kona Wind									
TOP	1.80	1.61	1.37	1.24	1.22	1.23	1.13	1.80	1.66
MIDDLE	1.24	1.52	1.96	1.51	1.30	1.09	0.91	0.69	1.13
BOTTOM	0.88	1.00	1.65	1.99	1.48	1.03	0.86	0.16	0.85
MAX	1.86	1.99	2.00	2.00	1.58	1.23	1.13	1.80	1.66
BC & 40 cfs Seawater Inflow & 5 kt Tradewind									
TOP	1.04	1.01	0.80	0.67	0.84	0.88	0.81	0.71	2.56
MIDDLE	1.38	1.21	1.13	0.80	0.52	0.36	0.29	0.16	2.70
BOTTOM	0.97	1.01	1.27	0.82	0.72	0.56	0.28	0.16	1.23
MAX	1.38	1.29	1.27	0.82	0.84	0.88	0.81	0.71	3.21
BC & 40 cfs Seawater Inflow & 5 kt Kona Wind									
TOP	1.06	0.98	0.79	0.70	0.69	0.69	0.65	1.01	1.15
MIDDLE	1.10	1.36	1.00	0.75	0.64	0.55	0.47	0.17	1.01
BOTTOM	0.87	1.00	1.52	1.32	0.77	0.55	0.47	0.16	0.84
MAX	1.29	1.38	1.52	1.32	0.78	0.69	0.65	1.01	1.17

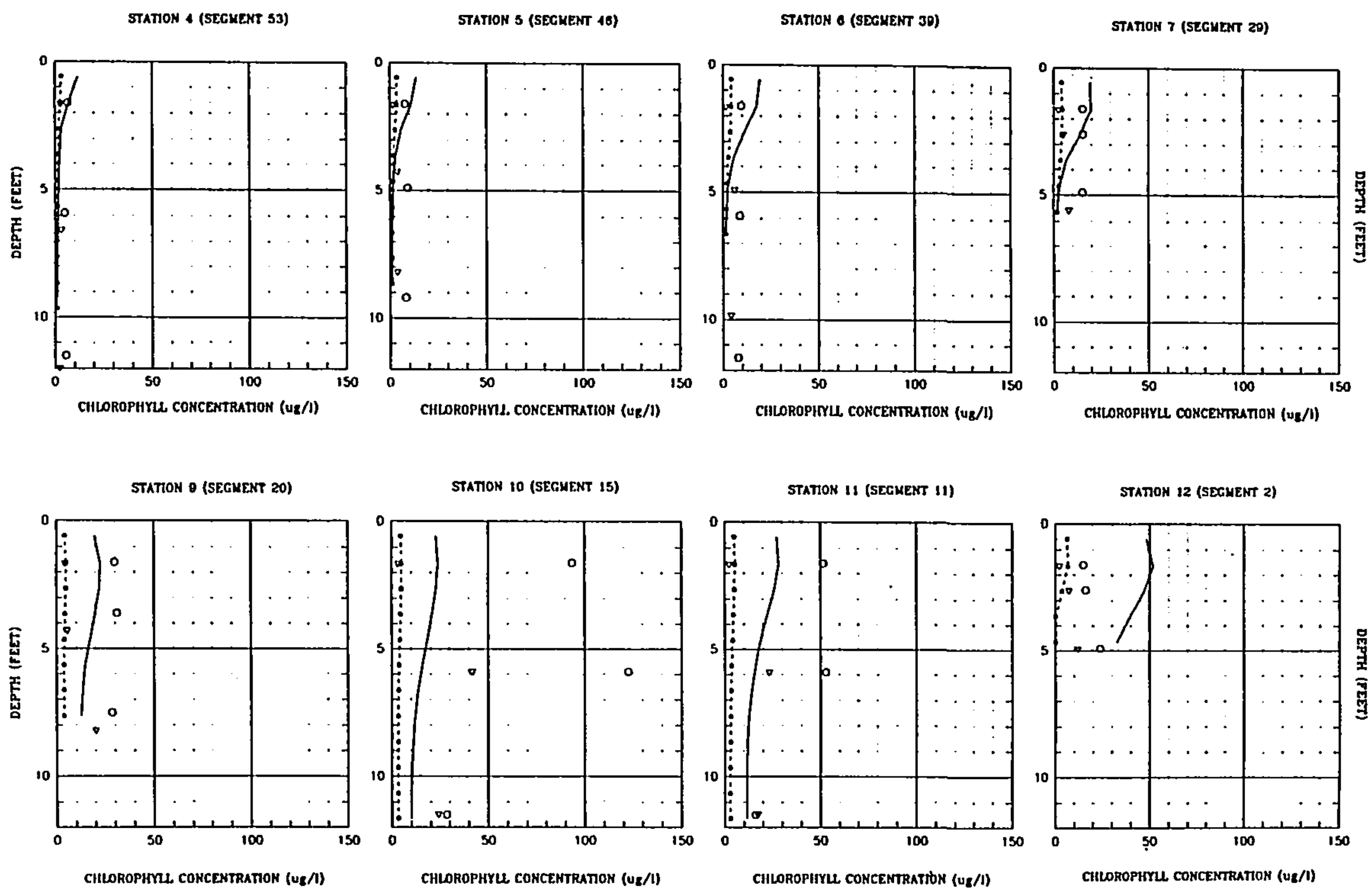
The results displayed in Table 4.10 show that while the 2 foot tide produces slightly better chlorophyll concentrations than the 20 cfs Base Case, and the 0.6 foot tide produces slightly worse chlorophyll concentrations than the 20 cfs Base Case, the differences are not significant. The 20 knot tradewind condition shows consistently better chlorophyll concentrations than its 20 cfs Base Case counterpart, with maximum concentrations of 1.2 to 3.3 μg/l between stations 4 to 12, compared to the 20 cfs Base Case concentrations of 3.5 to 6.5 μg/l (Table 4.8). Finally, the 10 knot Kona wind condition provides a slightly worse case than the 20 cfs BC, with maximum chlorophyll concentrations ranging from 4.3 to 7.6 μg/l between stations 4 to 12. The interesting aspect to the results shown in Table 4.10 is that the chlorophyll concentrations in the AWC are not adversely sensitive to typical changes in tides or wind velocity conditions.

Figures 4-28 to 4-35 show the standard outputs for chlorophyll, PO_4, NH_4, NO_3, O_2, horizontal velocity, salinity and water temperature respectively, for the 20 cfs Base Case run. For completeness, Figures F-3 to F-16 shown in Appendix F describe the chlorophyll concentrations and horizontal velocities for the 10, 30 and 40 cfs seawater inflows, and the 20 cfs seawater inflow with a 2 foot tidal range (1 foot tidal amplitude), a 0.6 foot tidal range (0.3 foot tidal amplitude), a 20 knot tradewind condition, and a 10 knot Kona wind condition.

An alternative to the injection of seawater into the Kapahulu end of the AWC is to split the inflow waters where part of the flow is also introduced into the Manoa-Palolo Stream as suggested by Miller and Chave (1976). To test this alternative, total seawater flow rates of 20 and 30 cfs were selected with 5 cfs of this flow injected into the Manoa-Palolo Stream at about 500 feet upstream from the confluence with the AWC. Table 4.11 shows the summary results of the 2-D model runs for these two alternatives. When the Table 4.11 results are compared with the 20 and 30 cfs seawater inflow at the Kapahulu end of the AWC as shown in Table 4.8, it is clear that for a given total seawater flow rate, better flushing results are obtained if the total flow was injection into the end of the AWC rather than split and partially injected into the Manoa-Palolo Stream. Figures F-17 to F-20 in Appendix F show the chlorophyll concentrations and horizontal velocities for the 20 cfs and 30 cfs total seawater inflow cases with 5 cfs diverted to the Manoa-Palolo Stream.

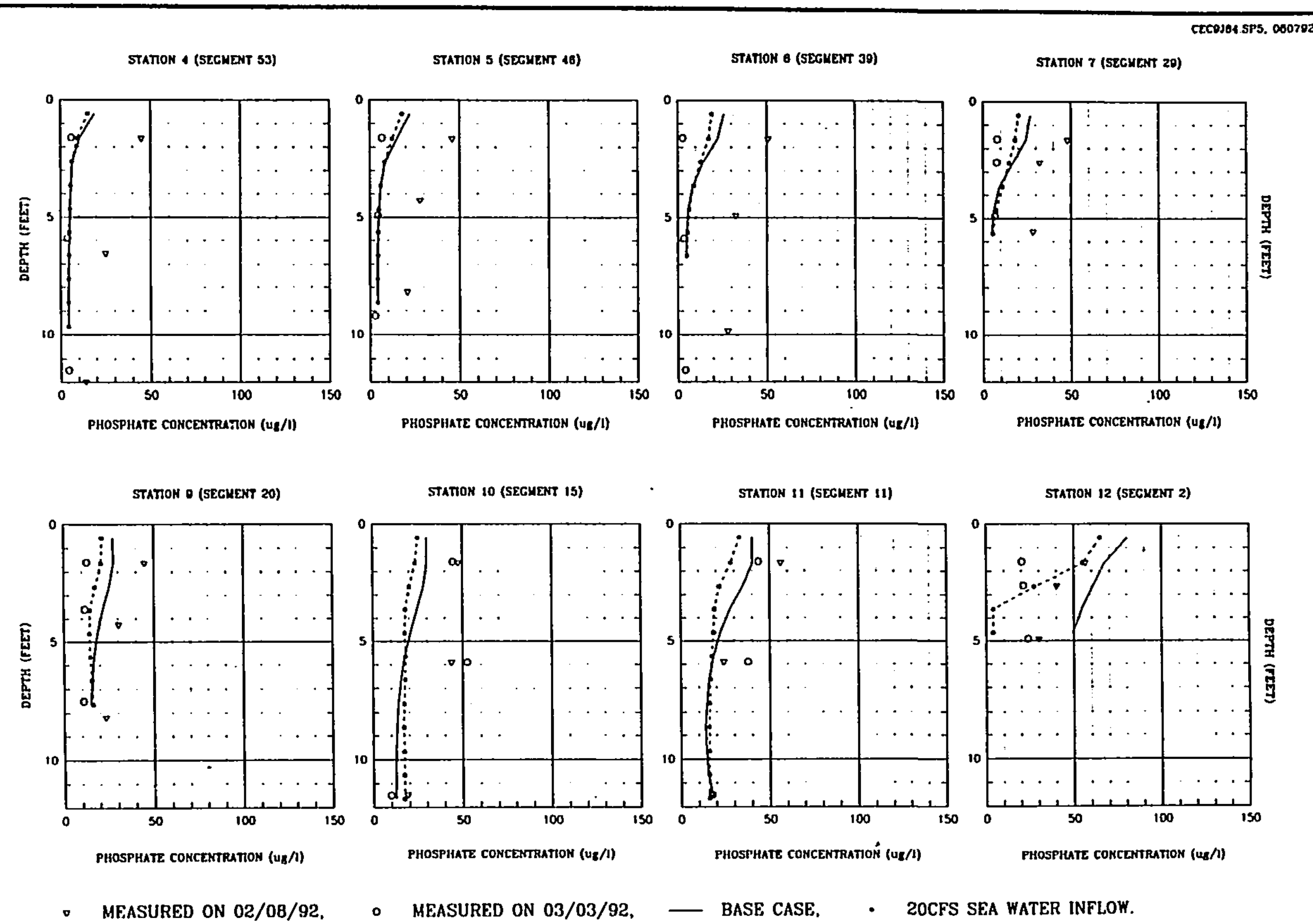
4.3.4. Injecting and Withdrawing Water from the Kapahulu End of the AWC. An interesting option to the injection of seawater into the Kapahulu end of the AWC, is the reversing of the flow direction by injecting water during the ebbing tide and withdrawing Canal waters during the flooding tide, in order to assist the tidal flow. Table 4.12

CEC7J64.SP5, 060792

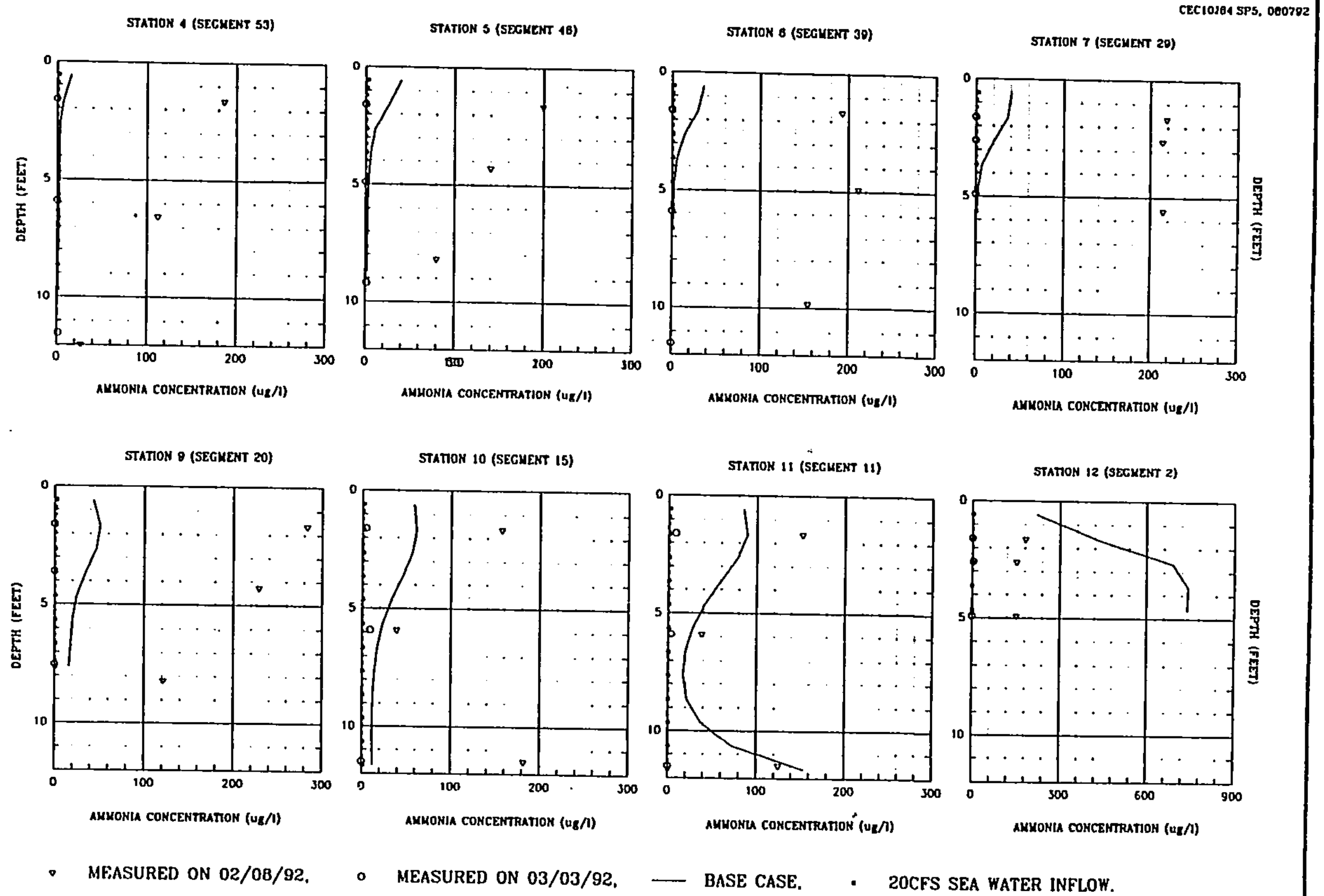


▿ MEASURED ON 02/08/92, ○ MEASURED ON 03/03/92, —— BASE CASE, • 20CFS SEA WATER INFLOW.

ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	**Base Case + 20 cfs Seawater Inflow Chlorophyll Concentrations**	FIGURE 4-28

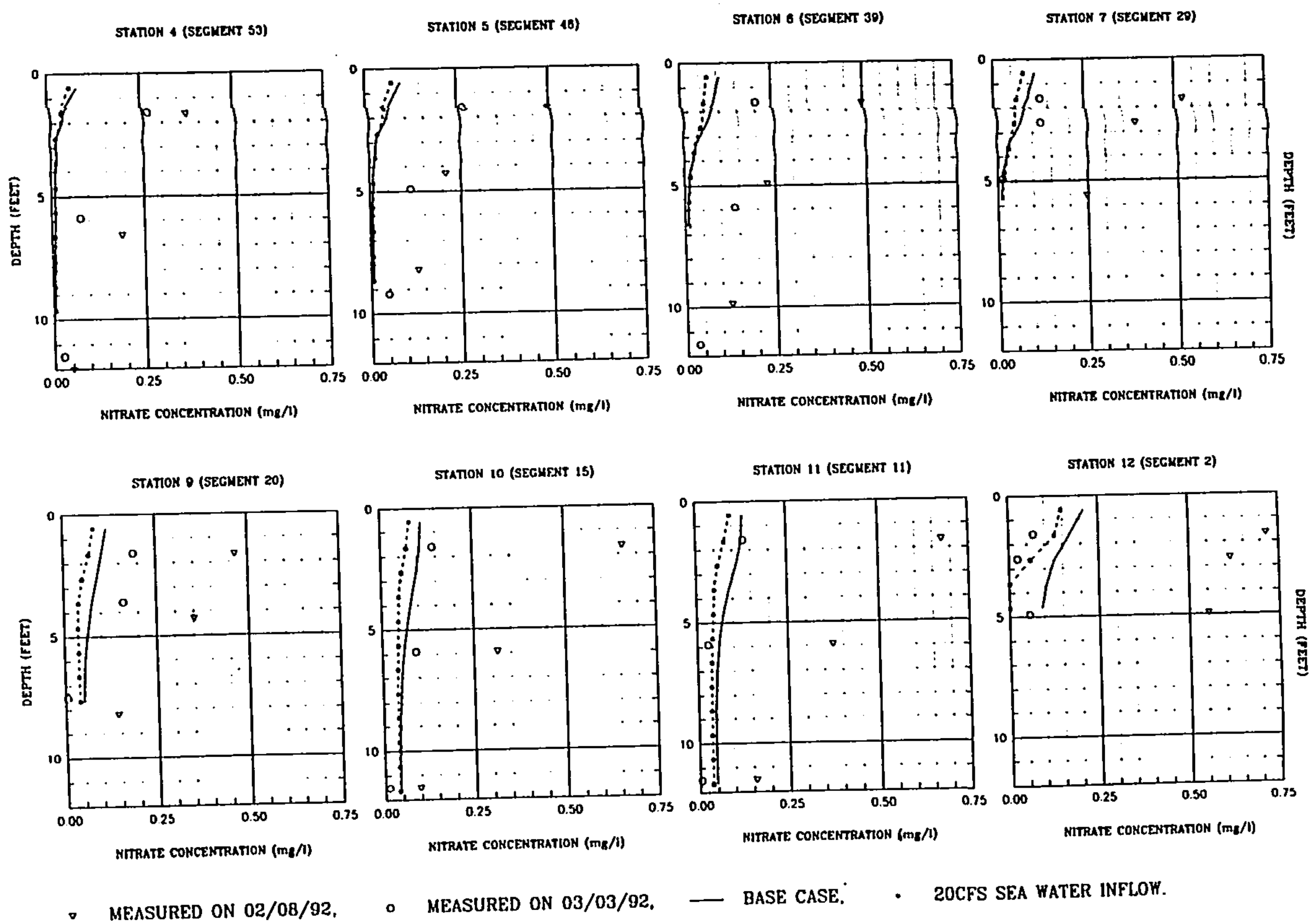


ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	Base Case + 20 cfs Seawater Inflow Phosphate (PO_4) Concentrations	FIGURE 4-29



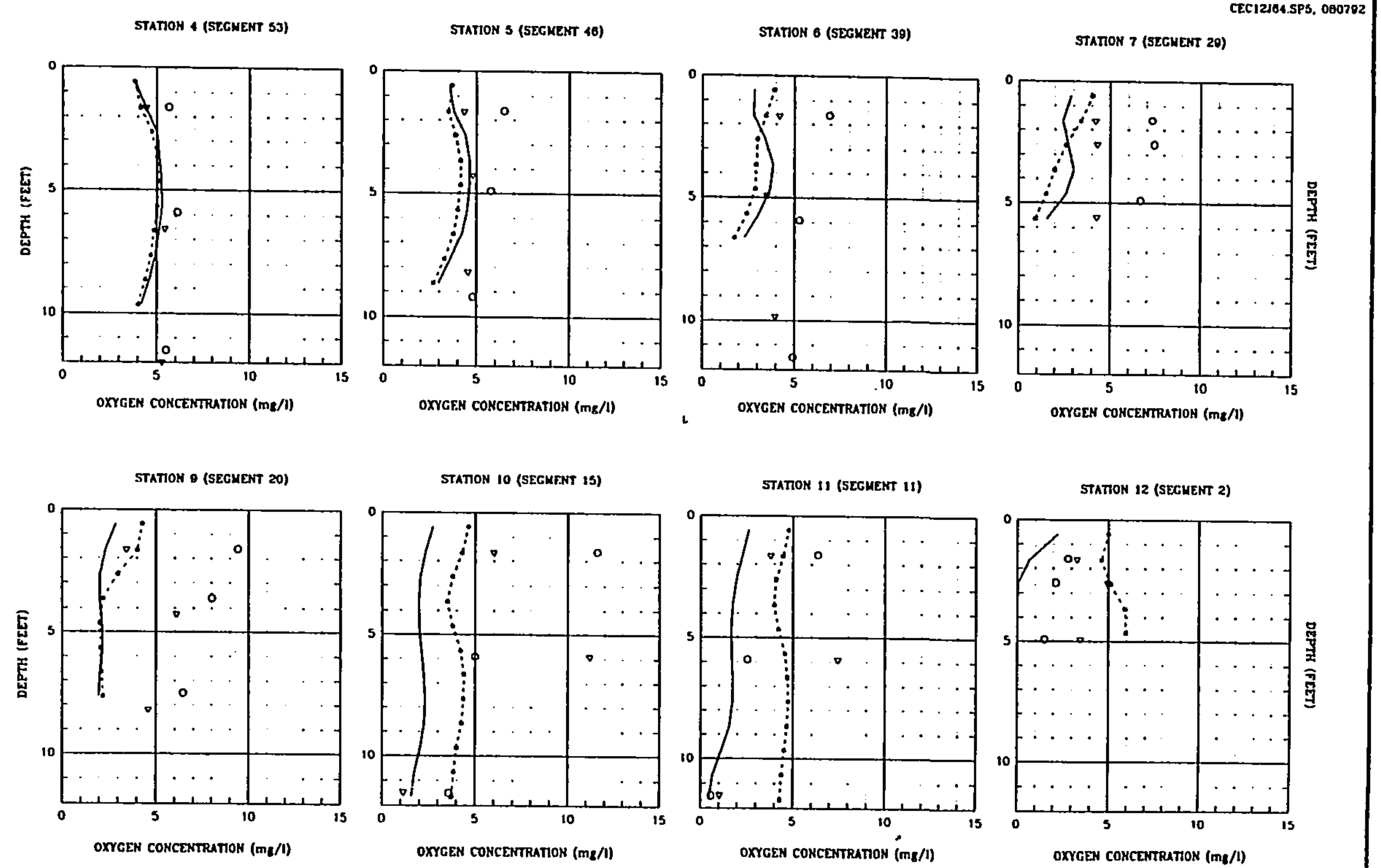
ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	Base Case + 20 cfs Seawater Inflow Ammonia (NH_4) Concentrations	FIGURE 4-30

CEC11J64.SP5, 080792



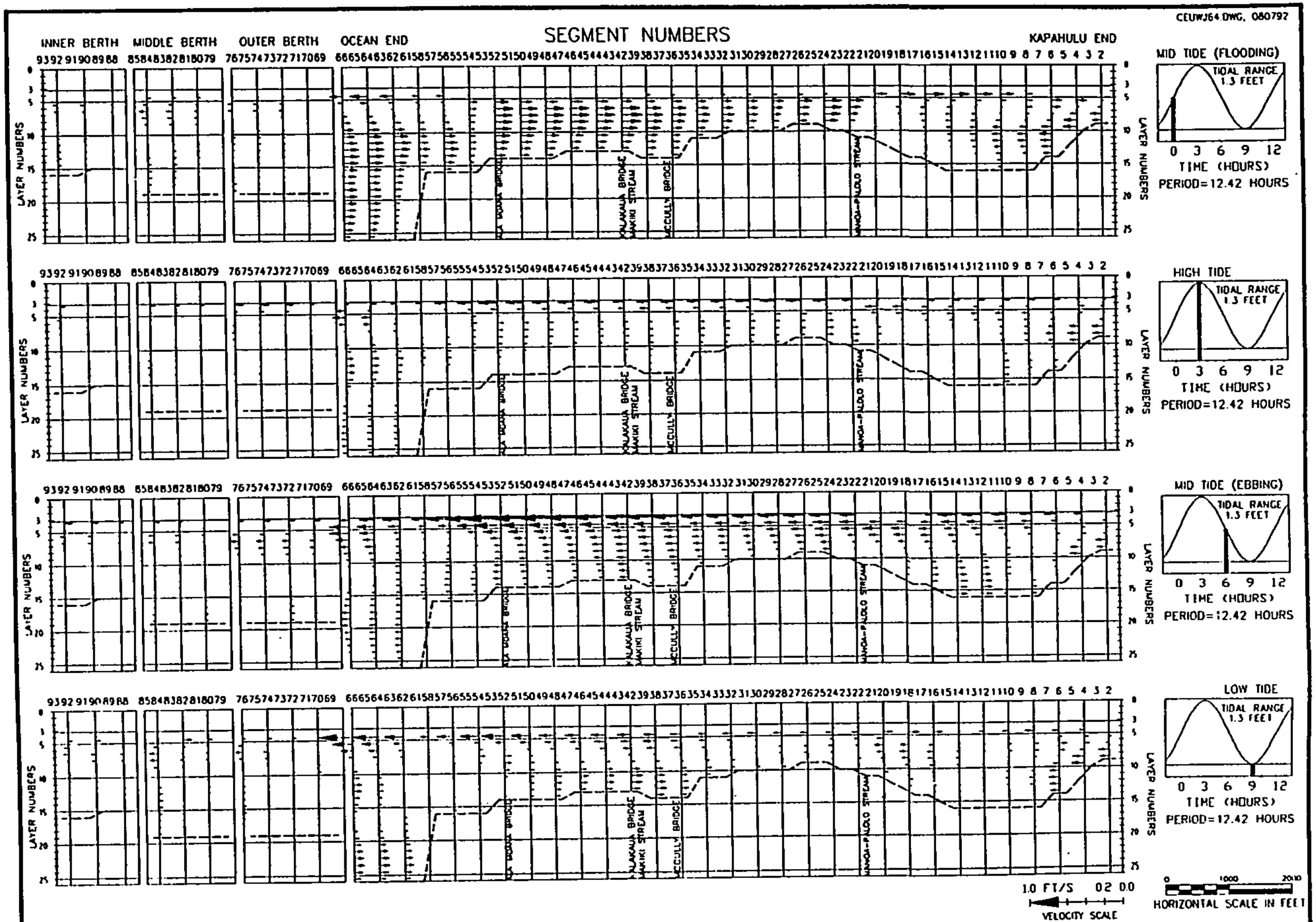
ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	Base Case + 20 cfs Seawater Inflow Nitrate (NO_3) Concentrations	FIGURE 4-31

CEC12J64.SP5, 080792



▿ MEASURED ON 02/08/92, ○ MEASURED ON 03/03/92, —— BASE CASE, • 20CFS SEA WATER INFLOW.

ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	Base Case + 20 cfs Seawater Inflow Dissolved Oxygen (O_2) Concentrations	FIGURE 4-32

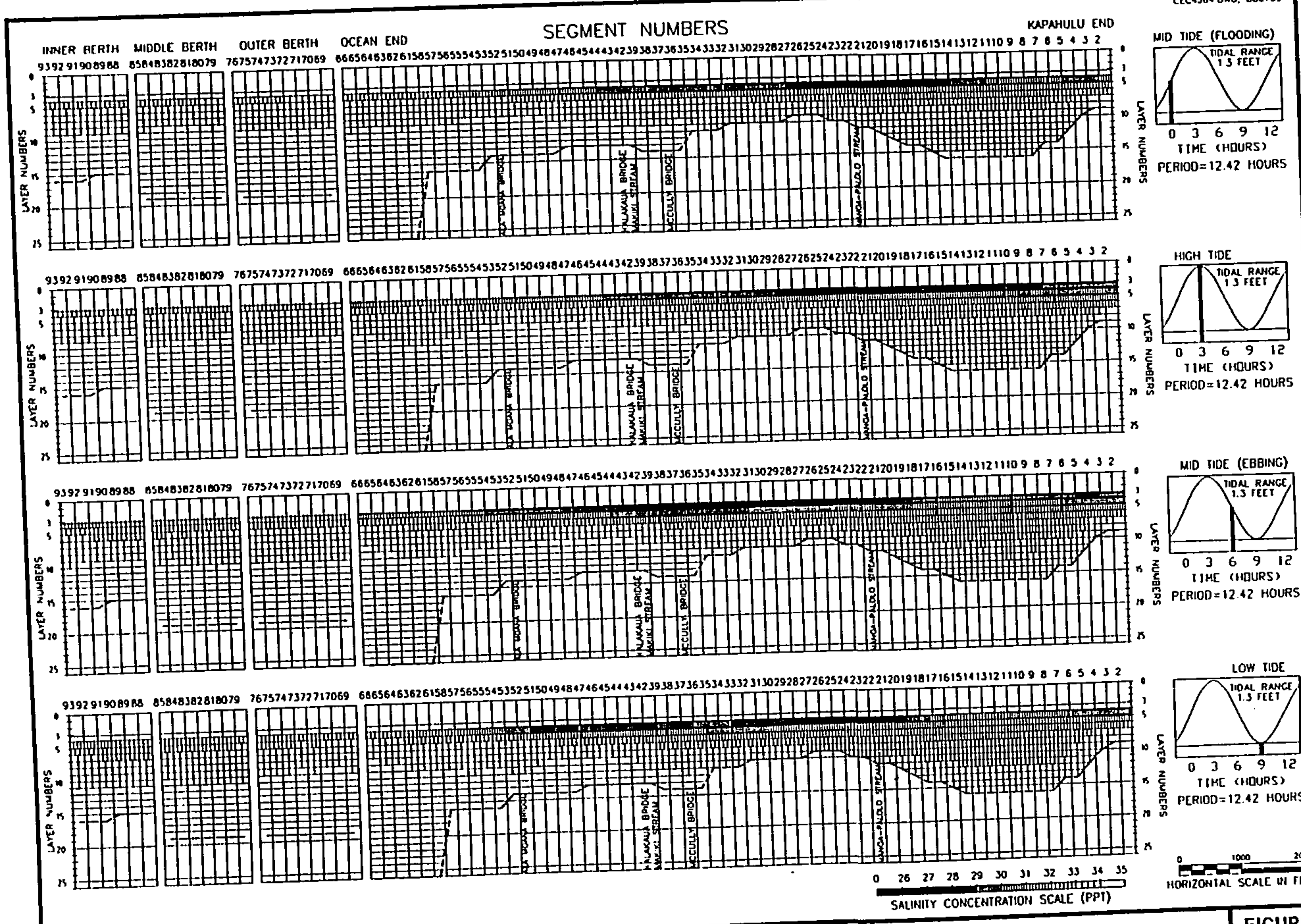


ALA WAI CANAL IMPROVEMENT PROJECT

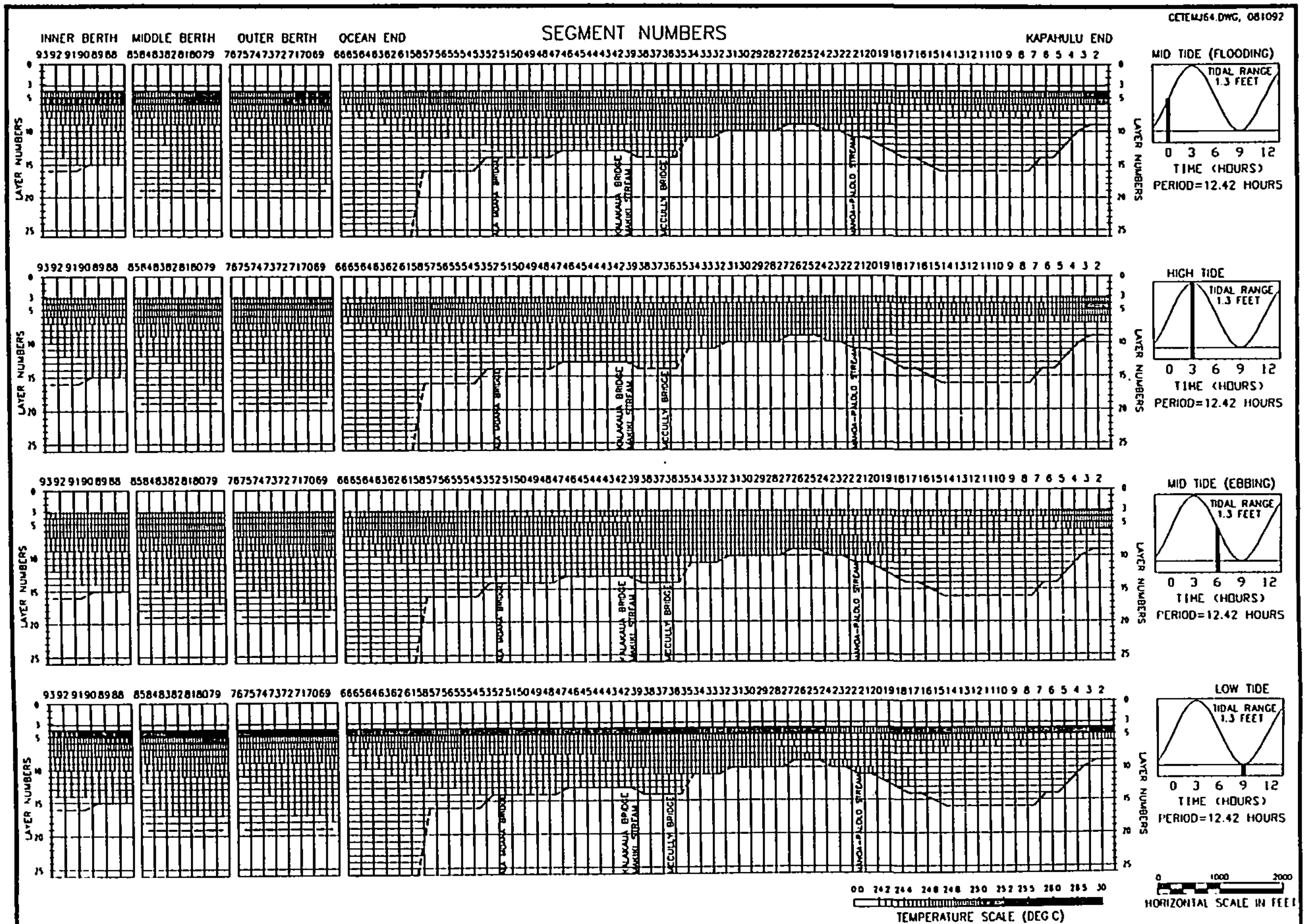
Edward K. Noda and Associates, Inc.

Base Case + 20 cfs Seawater Inflow Horizontal Flow Velocity Distribution

FIGURE 4-33



ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	Base Case + 20 cfs Seawater Inflow Salinity Concentration Distribution	FIGURE 4-34



ALA WAI CANAL
IMPROVEMENT PROJECT

Edward K. Noda
and
Associates, Inc.

Base Case + 20 cfs Seawater Inflow Water Temperature Distribution

FIGURE 4-35

describes the results of the simulation with 20 cfs of seawater inflow and 20 cfs of Canal water outflow. Comparing the Table 4.12 chlorophyll concentrations to the 20 cfs seawater inflow-only case shown in Table 4.8, it is evident that the inflow-outflow option yields a uniformly higher chlorophyll concentration throughout the AWC. Other options were then run consisting of injecting seawater during the flooding tide and withdrawing Canal waters during the ebbing tide, continually withdrawing Canal waters at the Kapahulu end, and continually withdrawing Canal waters at a location about 1,500 feet seaward of the Kapahulu end, in the deeper Inner Basin area. The results of these additional options are also shown in Table 4.12.

TABLE 4.10

Chlorophyll Concentrations for Base Case with 20 cfs Seawater Inflow and 2 ft Tide Range, 0.6 ft Tide Range, 20 knot Tradewind, and 10 knot Kona Wind Conditions

Description	Station Number								
	4	5	6	7	9	10	11	12	Harbor
BC with 2 ft Tide Range & 20 cfs Seawater Inflow									
TOP	2.97	3.21	3.68	3.50	3.92	4.23	4.39	4.54	2.24
MIDDLE	1.24	1.57	3.15	4.00	3.98	3.07	3.02	3.28	1.31
BOTTOM	0.93	0.98	1.58	2.35	3.48	2.63	2.36	0.16	0.87
MAX	2.97	3.23	3.89	4.00	4.35	4.50	4.52	4.82	2.24
BC with 0.6 ft Tide Range & 20 cfs Seawater Inflow									
TOP	4.40	4.59	5.03	5.04	4.90	5.22	5.29	7.06	3.35
MIDDLE	1.46	1.56	3.19	4.38	5.58	4.46	3.97	3.45	1.54
BOTTOM	0.90	1.01	1.81	2.54	4.87	4.04	3.13	0.16	1.00
MAX	4.40	4.59	5.11	5.23	5.68	5.59	5.39	7.06	3.35
BC with 20 cfs Seawater Inflow & 20 kt Tradewind									
TOP	1.25	1.45	1.79	2.10	3.26	3.20	3.05	0.29	0.93
MIDDLE	0.85	1.18	1.50	1.81	3.25	3.30	3.30	0.29	0.93
BOTTOM	0.77	0.86	1.02	1.09	3.17	3.29	3.33	0.24	0.91
MAX	1.25	1.45	1.79	2.10	3.26	3.30	3.33	0.29	0.93
BC with 20 cfs Seawater Inflow & 10 kt Kona Wind									
TOP	5.11	5.55	5.12	4.32	3.65	4.16	4.23	4.13	3.77
MIDDLE	2.33	4.07	4.91	4.33	4.53	4.50	3.37	4.26	2.71
BOTTOM	1.15	1.29	4.42	4.48	5.51	7.55	6.44	0.16	1.10
MAX	5.11	5.70	5.12	4.67	5.51	7.55	6.44	4.26	3.77

TABLE 4.11
Chlorophyll Concentrations for Base Case with 20 And 30 cfs Total Seawater Inflow, with 5 cfs Injected into the Manoa-Palolo Stream

Description	Station Number								
	4	5	6	7	9	10	11	12	15
BC & 20 cfs Total Seawater Inflow with 5 cfs Injected into Manoa-Palolo Stream									
TOP	4.92	5.22	6.14	6.46	6.16	6.89	7.44	10.76	2.29
MIDDLE	1.67	1.85	4.32	6.54	7.07	6.71	6.13	8.87	5.32
BOTTOM	0.98	1.05	1.96	2.73	5.29	5.71	5.80	0.16	0.24
MAX	4.92	5.22	6.34	6.82	7.15	7.05	7.44	10.76	5.52
BC & 30 cfs Total Seawater Inflow with 5 cfs Injected into Manoa-Palolo Stream									
TOP	2.53	2.48	2.31	2.21	2.13	2.08	2.00	2.79	0.98
MIDDLE	1.52	1.86	2.89	2.43	2.42	1.80	1.38	1.07	1.93
BOTTOM	0.98	1.12	2.15	2.76	2.28	2.09	1.25	0.16	0.19
MAX	2.53	2.75	2.89	2.82	2.61	2.09	2.00	2.79	1.93

From Table 4.12 it is interesting to note that the option of the inflow of seawater during the flooding tide and the withdrawal of Canal waters during ebb tide yields very similar results to its opposite counterpart. Moreover, the continuous withdrawal of 20 cfs of Canal waters at the Kapahulu end of the AWC produces significantly higher concentrations of chlorophyll than the 20 cfs seawater inflow-only case. Finally, the 20 cfs withdrawal of Canal waters in the deeper Inner Basin, about 1,500 feet from the canal terminus, yields much worse results than the same withdrawal at the Kapahulu end of the AWC. For reference, Figures F-21 to F-28 in Appendix F show the chlorophyll concentrations and horizontal velocities for the options cases described in Table 4.12 in the same order as listed.

The results of the 20 cfs options of inflow-outflow or continual outflow all indicate higher chlorophyll concentrations than the 20 cfs seawater inflow-only option.

TABLE 4.12

Chlorophyll Concentrations for Base Case with 20 cfs Total Flow with Various Inflow-Outflow Schedules

Description	Station Number								
	4	5	6	7	9	10	11	12	Harbor
BC & 20 cfs Outflow from Kapahulu End of Canal									
TOP	4.66	5.15	6.97	6.99	6.95	8.06	9.27	16.88	2.79
MIDDLE	1.44	1.27	2.41	4.23	7.23	6.37	6.14	11.54	1.44
BOTTOM	0.87	0.94	1.17	1.37	5.28	4.30	4.71	9.57	0.90
MAX	4.66	5.15	6.97	6.99	7.98	8.35	9.39	16.88	2.79
BC & 20 cfs Outflow at 1,500 ft Seaward from Kapahulu End of Canal									
TOP	8.01	9.31	14.83	15.55	15.80	19.10	20.54	32.62	4.01
MIDDLE	1.53	1.35	3.24	7.30	14.88	10.41	11.63	26.32	1.53
BOTTOM	0.84	0.93	1.16	1.44	9.67	7.06	7.34	16.00	0.89
MAX	8.01	9.31	14.83	15.55	19.00	21.60	23.52	33.51	4.01
BC & 20 cfs Inflow during Ebb Tide, Outflow during Flood Tide									
TOP	5.19	6.00	8.00	7.72	8.22	9.74	10.28	13.50	3.14
MIDDLE	1.46	1.50	3.71	7.32	7.53	7.25	8.74	10.16	1.48
BOTTOM	0.89	0.97	1.43	1.87	4.46	10.04	7.76	0.16	0.89
MAX	5.19	6.00	8.00	8.52	9.32	10.04	10.28	14.12	3.14
BC & 20 cfs Inflow during Flood Tide, Outflow during Ebb Tide									
TOP	5.44	5.88	7.78	8.02	7.97	9.48	10.11	13.40	3.00
MIDDLE	1.50	1.31	2.79	4.96	7.93	6.62	8.57	11.96	1.36
BOTTOM	0.90	0.97	1.26	1.54	5.23	5.36	7.89	10.84	0.89
MAX	5.44	5.88	7.78	8.02	9.28	9.70	10.49	13.73	3.00

4.3.5. Injecting Groundwater into the Kapahulu End of the AWC. Instead of constructing a pipeline from the Kapahulu end of the AWC to a nearshore location to obtain seawater for flushing purposes, the use of nearby groundwater as the flushing water source has been proposed by Miller and Chave (1976). The characteristics of groundwater varies as a function of the extraction depth below the existing ground level. Near the surface, the groundwater is expected to have very low salinity with relatively high nutrient levels. As the depth of extraction increases, both the salinity and nutrient levels are expected to approach coastal seawater concentrations. These conditions approaching coastal water characteristics are expected below about 150 - 200 feet. Thus, between the near-surface almost fresh water conditions and the near-seawater conditions at depth, the nutrient and salinity concentrations can be assumed to decay linearly.

Using near-surface groundwater as the flushing source water, flow rates of 20, 30 and 40 cfs were injected into the Kapahulu end of the AWC and the results are shown in Table 4.13, and Figures F-29 to F-37 presented in Appendix F provide the chlorophyll concentration, horizontal velocity and salinity distributions for the 20, 30 and 40 cfs runs respectively. The near-surface groundwater physical characteristics were identical to the Makiki Stream inflow characteristics shown in Tables 4.2 and 4.4.

The results in Table 4.13 are very interesting in that the 20 cfs near-surface groundwater inflow provides better flushing results in the deeper layer at the end section of the AWC, than the 30 cfs case, whereas the opposite is true throughout the rest of the AWC. Figures F-30 and F-33 show different vertical circulation structures in the Inner Basin, and the salinity distributions in Figures F-31 and F-34 show that the 20 cfs flow provides a greater vertical mixing signature than the 30 cfs flow rate, where the dark color indicates less salinity concentrations. The salinity distribution figures clearly show that the injection of less-dense groundwater tends to be confined to the near-surface layers.

The results for the 40 cfs near-surface groundwater inflow option are also shown in Table 4.13. The end section chlorophyll concentrations have improved relative to the 30 cfs results, with a general relative improvement throughout the AWC.

While near-surface groundwater could be used as a source of flushing flow, the flow rates required are much larger than for a seawater source as exemplified by a comparison with the results shown in Table 4.8. Thus, near-surface groundwater is not considered a viable source of flushing water.

On the other extreme, if deep groundwater were to be used as the flushing water source, with physical characteristics similar to seawater, the chlorophyll concentration results would be similar to the seawater injection results as shown in Table 4.8. Consequently, depending on the salinity and nutrient concentrations, which are dependent on the depth of groundwater extraction, the resulting chlorophyll concentrations would vary between the Table 4.8 and Table 4.13 results.

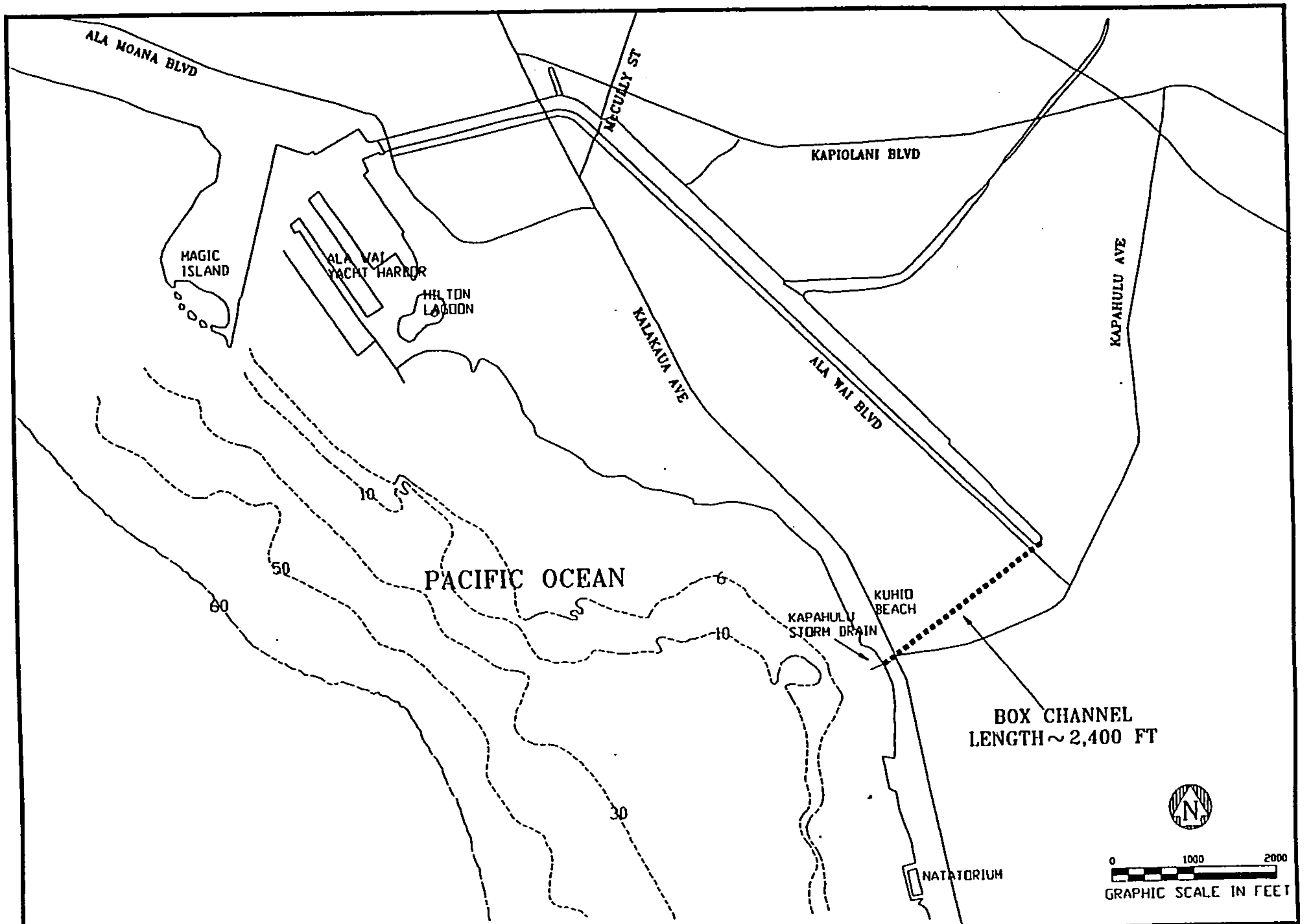
TABLE 4.13

Chlorophyll Concentrations for Base Case with 20, 30, 40 cfs Near-Surface Groundwater Inflow

Description	Station Number								
	4	5	6	7	9	10	11	12	Harbor
BC & 20 cfs Groundwater Inflow									
TOP	6.36	8.04	9.63	9.12	9.61	9.57	9.01	4.34	3.18
MIDDLE	1.33	1.61	4.11	6.43	9.26	9.05	9.07	12.10	4.65
BOTTOM	0.82	0.84	1.52	2.85	8.22	7.86	7.98	13.04	0.85
MAX	6.36	8.04	9.63	9.79	9.72	9.70	9.84	13.04	3.18
BC & 30 cfs Groundwater Inflow									
TOP	6.34	7.40	7.57	6.71	7.60	8.28	8.57	3.44	3.85
MIDDLE	1.17	0.99	2.12	5.45	6.16	4.60	5.11	23.04	1.06
BOTTOM	0.76	0.78	0.88	0.96	4.00	3.62	4.39	18.37	.0.96
MAX	6.34	7.40	7.57	7.16	7.76	8.57	9.44	23.68	3.85
BC & 40 cfs Groundwater Inflow									
TOP	4.76	5.43	5.66	5.22	6.28	7.00	6.17	0.57	3.08
MIDDLE	1.10	0.96	1.84	4.67	5.56	3.99	4.55	13.04	0.98
BOTTOM	0.76	0.77	0.86	0.93	3.49	3.09	3.30	9.41	0.79
MAX	4.76	5.43	5.67	5.79	6.72	7.56	8.22	13.04	3.08

NOTE: Groundwater salinity = 0, nutrients & other parameters are identical to Makiki Stream.

4.3.6. <u>Constructing a Channel Between the Kapahulu End of the AWC and Waikiki Beach.</u> The concept of extending the Ala Wai Canal to Waikiki Beach using a channel, was proposed during the initial development of the Canal in the 1920's. Due to budget limitations, the AWC was only constructed to its present inland terminus near Kapahulu Avenue. To evaluate the water quality impacts of the option of extending the AWC to Waikiki Beach, a box culvert, with a width of 20 feet and a depth of -6 feet MLLW, extending 2,400 feet directly from the Kapahulu end of the AWC to the Kapahulu Storm Drain as schematically shown in Figure 4-36, was envisioned. Note that the exact terminus of the channel at Waikiki Beach is not critical to the present analysis, and the proposed box culvert alignment shown in Figure 4-36 is provided for conceptual analysis purposes only.



ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	PROPOSED CHANNEL BETWEEN ALAWAI CANAL AND WAIKIKI BEACH	FIGURE 4-36

For analysis purposes, one of the most important factors which would determine the hydrodynamics of the flow within this two ocean-entrance Ala Wai Canal system is the phase difference between the new Waikiki ocean entrance and the existing Ala Wai Boat Harbor ocean entrance. For a recent study (Edward K. Noda and Associates, Inc., 1991) of proposed inland waterways for the Kakaako Makai Waterfront Project, simultaneous water level measurements were made in Kewalo Basin, at the ocean entrance to the existing drainage channel which is the extension of Keawe Street, and in Honolulu Harbor. The measurement system was identical to the tide measuring system described in Section 2.2. Based on the tidal phase lag results from the Kakaako Inland Waterways Study, the phase difference between the proposed Waikiki Beach ocean entrance location and the Ala Wai Boat Harbor entrance channel was estimated to be 175 seconds, with the tide wave approaching the Waikiki Beach location first.

The ocean water characteristics for the Waikiki Beach ocean entrance were assumed to be identical to the Station 1 water quality data as shown in Appendix E and summarized in Table 4.7. Since it is very important to minimize the discharge of AWC waters into the prime Waikiki Beach nearshore waters, it was envisioned that flow would only be allowed <u>into</u> the AWC through the proposed box culvert by using a one-way valve or tide gate was placed in the channel. Thus, during certain parts of the tidal cycle or during significant surface runoff discharge into the AWC, the tide gate would close. Such one-way valve designs exist, whose opening and closing operations are determined by the water flow direction.

The requirement to run the 2-D model with two ocean entrances, and with different tidal phase relationship, proved to be somewhat difficult. After a considerable effort, the program was modified to include the one-way valve system and the results are shown in Table 4.14. Figures F-38 and F-39 shown in Appendix F describe the chlorophyll concentrations and horizontal velocities, respectively. Note that the results shown in Table 4.14 are based on the natural flushing of the modified AWC system, with no seawater injection included. It is reasoned that the merits of this extension of the AWC to Waikiki Beach should be evaluated on its natural flushing abilities. The Table 4.14 and Figure F-38 results show a significant reduction in the chlorophyll concentrations versus the existing Base Case conditions shown in Table 4.6. While the chlorophyll concentrations are significantly lower than the Base Case counterparts, the maximum concentrations range to over 17 μg/l, and thus exceed the 10 μg/l maximum criterion.

Based on this analysis, the option of constructing a channel between the existing Kapahulu terminus of the AWC to Waikiki Beach does not provide the necessary flushing forces to develop acceptable water quality characteristics in the Canal. Moreover, it is believed that the expected large cost to construct this option, the significant impacts associated with the construction activities in this crowded area (traffic, noise, dust, etc.), the interference of the extensive underground utilities, land acquisition costs or easement negotiations, and the potential failure of the tide gate system which would allow Canal waters to discharge into Waikiki Beach waters, all lead to a discontinuance of this option to improve the water quality in the Ala Wai Canal.

TABLE 4.14
Chlorophyll Concentrations for Base Case with Channel from the Kapahulu End of the Ala Wai Canal to Waikiki Beach

Description	Station Number								
	4	5	6	7	9	10	11	12	Channel
BC With Channel From Kapahulu End of Canal to Waikiki Beach									
TOP	6.16	6.56	8.54	8.81	9.41	11.03	11.38	10.92	10.09
MIDDLE	1.62	1.59	3.61	6.89	13.28	7.07	4.80	5.99	6.02
BOTTOM	0.97	1.01	1.52	2.05	16.66	17.30	4.38	3.34	6.66
MAX	6.16	6.56	8.54	8.84	16.66	17.30	11.40	10.92	10.09

4.3.7. Dredging and Fill Options for the AWC. Besides the construction options described in the previous sections, this section describes dredging and fill options which may potentially improve the water quality in the AWC. The following provides a listing of the run options that were tested:

- Area between the McCully Bridge and the confluence of the Manoa-Palolo Stream, called the Sill, dredged to -10 feet MLLW.
- Sill dredged to -10 feet MLLW with 5 knot tradewind.
- Sill dredged to -10 feet MLLW with 20 cfs seawater inflow at the Kapahulu end of the AWC.
- Sill dredged to -10 feet MLLW with the area between the Manoa-Palolo Stream confluence and the Kapahulu end of the AWC, called the Inner Basin, filled to -6 feet MLLW.

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- o Inner Basin filled to -6 feet MLLW.
- o Inner Basin filled to -6 feet MLLW with 5 knot tradewind.
- o Inner Basin filled to -6 feet MLLW with 20 cfs seawater inflow at the Kapahulu end of the AWC.
- o Inner Basin filled to -6 feet MLLW with 20 cfs near-surface groundwater inflow at the Kapahulu end of the AWC.
- o Sill dredged to -6 feet MLLW.
- o Sill dredged to -6 feet MLLW with 20 cfs seawater inflow at the Kapahulu end of the AWC.
- o Entire AWC dredged to -12 feet MLLW.
- o Entire AWC dredged to -12 feet MLLW with 5 knot tradewind.

The 1978 maintenance dredging project dredged the area between the McCully Bridge and the confluence of the Manoa-Palolo Stream of the AWC to a depth of -10 feet MLLW. Based on this historic situation, one of the alternatives was to evaluate the response of the AWC to this dredging option. Since the bathymetry data is referenced to the MLLW tidal datum, it was decided to use this datum rather than MSL for the evaluation of the alternatives. Note that the MLLW datum is 0.8 foot below the MSL datum. Table 4.15 shows that under Base Case conditions with the Sill dredged to -10 feet MLLW, the chlorophyll maximum concentration ranging from 11 - 34 μg/l, which indicates an improvement as compared to the Base Case (Table 4.6) with maximum concentrations ranging from 10 - 34 μg/l, but the improvement is not satisfactory to significantly improve the AWC water quality. Figures F-40 and F-41 shown in Appendix F describe the chlorophyll concentrations and horizontal velocities for the BC with the Sill dredged to -10 feet MLLW.

With the Sill dredged to -10 feet MLLW and with a 5 knot tradewind condition, Table 4.15 indicates that the chlorophyll concentrations in the end section of the AWC increase as compared to the no-wind case, which causes a similar increase in the surface layer chlorophyll concentration due to the vertical circulation in the Inner Basin area. When a 20 cfs seawater inflow is injected into the Kapahulu end of the AWC together with the dredging of the Sill to -10 feet MLLW, the results are similar to the case with the Sill undredged as shown in Table 4.8. This indicates that when a 20 cfs or greater flow is injected into the Kapahulu terminus of the AWC, conditions improve significantly with or without the Sill. Figures F-42 to F-45 shown in Appendix F graphically describe the chlorophyll concentrations and horizontal velocities, respectively for the above two Sill options.

Another potential improvement is to dredge the Sill to -10 feet MLLW and to fill the Inner Basin to a depth of -6 feet MLLW. The deeper Inner Basin seems to trap the more dense waters leading to the potential of poor circulation. Thus, filling this Inner Basin would seem to present an opportunity to improve the water quality in the AWC. The results shown in Table 4.15 indicate that this notion of water quality improvement is *misleading*, as the chlorophyll concentrations increases in the end section of the Canal, which then degrades the upper layer water to the McCully Bridge. Figures F-46 to F-47 describe the chlorophyll concentrations and horizontal velocities for this option, respectively.

Since the filling of the Inner Basin to -6 feet MLLW combined with the dredging of the Sill to -10 feet MLLW did not yield good results, how would the filling of the Inner Basin only affect the AWC water quality? Table 4.16 shows a summary of the chlorophyll concentrations for 4 cases: the Inner Basin filled to -6 feet MLLW; the Inner Basin filled to -6 feet MLLW with a 5 knot tradewind; the Inner Basin filled to -6 feet MLLW with 20 cfs of seawater inflow at the Kapahulu end of the AWC; and the Inner Basin filled to -6 feet MLLW with 20 cfs near-surface groundwater inflow at the Kapahulu end of the AWC. Figures F-48 to F-55 as shown in Appendix F provide the chlorophyll concentrations and horizontal velocities for these 4 cases, respectively.

The results described in Table 4.16 show that filling the Inner Basin to a depth of -6 feet MLLW produces higher chlorophyll concentrations in the end section of the AWC, leading to a general degradation of water quality throughout the Canal as compared to the existing Base Case (Table 4.6). The reason for this degradation can be seen in the horizontal velocities in Figure F-49 as compared to the Base Case velocities in Figure 4-24. The water in the Inner Basin under Base Case conditions is not stagnant, but instead responds to the flow of the surface layer due to continuity requirements, thereby creating a circulation flow which brings near-bottom fluids to the surface. When the Inner Basin is filled, this vertical circulation process is significantly inhibited. Consequently the flow tends to be more uni-directional throughout the water column, behaving like a one-dimensional flow or "slug" flow, thereby reducing the flushing efficiency of the system.

TABLE 4.15

Chlorophyll Concentrations for Base Case with Sill Area Dredged to -10 ft MLLW, with 20 cfs Seawater Inflow, with 5 knot Tradewind Conditions, and with the Inner Basin Filled to -6 ft MLLW

Description	Station Number								
	4	5	6	7	9	10	11	12	Harbor
BC with Sill Area Dredged to -10 ft MLLW									
TOP	10.80	11.58	12.46	12.09	12.37	16.10	21.00	33.97	6.54
MIDDLE	2.30	3.22	9.34	9.86	9.82	10.07	10.69	30.74	2.31
BOTTOM	0.92	0.92	1.93	2.61	3.61	4.60	4.83	23.56	0.92
MAX	10.80	11.58	12.93	13.21	14.41	16.73	21.00	34.18	6.54
BC with Sill Area Dredged to -10 ft MLLW & 5 kt Tradewind									
TOP	9.38	9.90	12.79	13.51	27.26	40.23	42.05	55.24	4.95
MIDDLE	1.91	1.29	4.43	3.68	9.12	12.26	18.94	58.82	2.47
BOTTOM	0.87	0.88	1.25	1.44	2.08	3.56	4.51	55.42	1.08
MAX	9.38	9.90	12.79	13.51	28.63	40.23	42.05	58.82	4.95
BC with Sill Area Dredged to -10 ft MLLW & 20 cfs Seawater Inflow									
TOP	6.03	6.06	5.78	5.18	5.02	5.24	5.24	7.30	4.22
MIDDLE	1.89	2.96	5.82	5.73	5.26	4.97	4.19	4.64	1.72
BOTTOM	0.91	0.95	1.78	2.35	3.59	4.73	4.32	0.16	0.89
MAX	6.03	6.45	6.42	6.16	5.51	5.24	5.24	7.30	4.22
BC with Sill Area Dredged to -10 ft MLLW & Inner Basin Filled To -6 ft MLLW									
TOP	10.52	10.50	14.31	19.81	30.92	54.57	62.52	79.52	6.25
MIDDLE	1.98	2.97	7.23	7.75	9.62	42.09	47.93	70.52	1.79
BOTTOM	0.85	0.88	1.85	2.29	3.87	15.52	21.20	47.90	0.88
MAX	10.52	10.50	14.31	19.81	39.47	54.57	62.52	79.52	6.25

TABLE 4.16

Chlorophyll Concentrations for Base Case with Inner Basin Filled to -6 ft MLLW, with 20 cfs Seawater Inflow, with 20 cfs Near-Surface Groundwater Inflow, and with a 5 knot Tradewind Condition

Description	Station Numbers								
	4	5	6	7	9	10	11	12	Harbor
BC with Inner Basin Filled to -6 ft MLLW									
TOP	15.48	17.91	27.77	28.27	29.86	37.77	42.19	63.08	6.66
MIDDLE	2.03	1.73	6.52	18.39	30.12	36.48	39.81	50.02	1.91
BOTTOM	0.93	0.96	1.44	2.04	8.16	10.54	13.56	29.24	0.89
MAX	15.48	17.91	27.77	28.27	35.59	41.30	45.98	64.48	6.66
BC with Inner Basin Filled to -6 ft MLLW & 5 kt Tradewind									
TOP	7.92	9.45	18.00	19.03	28.76	41.61	41.76	39.43	4.25
MIDDLE	1.59	1.11	3.36	7.66	26.41	33.51	34.88	33.27	2.39
BOTTOM	0.82	0.89	1.14	1.39	3.97	5.52	7.82	25.02	1.09
MAX	7.92	9.45	18.00	19.03	32.01	41.61	42.71	39.43	4.25
BC with Inner Basin Filled to -6 ft MLLW & 20 cfs Seawater Inflow									
TOP	2.83	2.93	3.18	2.98	2.96	3.16	3.20	4.46	2.13
MIDDLE	1.29	1.34	2.49	3.32	3.15	2.94	2.83	2.32	1.26
BOTTOM	0.92	0.99	1.48	1.90	2.85	2.45	1.99	0.16	0.88
MAX	2.83	2.93	3.28	3.38	3.22	3.16	3.20	4.46	2.13
BC with Inner Basin Filled to -6 ft MLLW & 20 cfs Groundwater Inflow									
TOP	3.75	4.65	5.59	5.31	5.69	5.70	5.39	2.49	2.14
MIDDLE	1.09	1.30	2.70	4.08	5.23	5.63	5.77	7.24	1.16
BOTTOM	0.79	0.81	1.27	2.03	3.74	3.88	3.96	6.48	0.82
MAX	3.75	4.65	5.59	5.58	5.69	5.81	5.90	7.24	2.14

With the Inner Basin filled to -6 feet MLLW with a 5 knot tradewind condition, the chlorophyll concentrations improve significantly as shown in Table 4.16 and yield similar results to the Base Case with 5 knot tradewinds as shown in Table 4.6. The horizontal velocities in Figure F-51 show that a two-layer flow system is developed which enhances the flushing circulation.

The results shown in the previous two cases indicate that filling the Inner Basin would not be sufficient to create adequate water quality in the AWC. Table 4.16 shows the chlorophyll concentration results when either 20 cfs of seawater or 20 cfs near-surface groundwater is injected into the Kapahulu end of the AWC. Both sets of results indicate that satisfactory water quality would be obtained with either of these two options. The more-dense seawater injection with its lower nutrient levels produces significantly lower chlorophyll concentration, with maximum chlorophyll concentrations ranging from 2.8 to 4.5 μg/l, as compared to the less-dense, near-surface groundwater injection with its higher nutrient concentrations producing maximum chlorophyll concentrations of 3.8 to 7.2 μg/l.

When the Table 4.16, 20 cfs seawater injection chlorophyll concentration results are compared to the 20 cfs Base Case seawater injection (Table 4.8) with maximum chlorophyll concentrations of 3.5 - 6.6 μg/l, this evaluation *indicates that the filling of the* Inner Basin improves the flushing .of the AWC.The 1966 maintenance dredging operations dredged the Sill area to a water depth of -6 feet MLLW. To evaluate the consequences of this condition, the option of increasing the Sill depth to -6 feet MLLW with all other parameters set identical to the Base Case was modeled. The 2-D model chlorophyll concentration results of this option are provided in Table 4.17 and Figures F-56 and F-57 describe the chlorophyll concentration and horizontal velocity outputs, respectively. When these concentrations are compared to the Base Case values shown in Table 4.6, a reasonable improvement is noted. When the Table 4.17 results are compared to the option of dredging the Sill to -10 feet MLLW as shown in Table 4.15, the results are very similar, with the -10 feet dredged Sill providing a slight improvement. In a practical sense, this -6 feet MLLW dredged Sill can also be considered an intermediary point in the evolution of the Sill from a -10 feet MLLW initial dredged depth to its existing Base Case depth.

When a 20 cfs seawater inflow is provided at the Kapahulu end of the AWC, combined with a -6 feet MLLW dredged depth for the Sill area, the summary results are shown in Table 4.17, and Figures F-58 and F-59 provide the chlorophyll concentration and horizontal velocity outputs, respectively. Comparing the Table 4.17 results with both the Base Case 20 cfs seawater inflow (Table 4.8) and the -10 feet MLLW dredged Sill with 20 cfs seawater inflow (Table 4.15) shows that the chlorophyll concentration results are very similar. This indicates that the 20 cfs or greater forced-flushing options are insensitive to changes in the Sill area water depth.

Another option to possibly improve the water quality and to increase the rainfall-runoff carrying capacity in the AWC is to dredge the entire length of the AWC to a constant depth. For example, a constant dredged depth of -12 feet MLLW was selected as an option. Table 4.18 shows the 2-D model chlorophyll concentration results for this cases, as well a run which included a 5 knot tradewind condition, and Figures F-60 to F-63 describe the chlorophyll concentration and horizontal velocity outputs for these cases, respectively.

The Table 4.18 results show that dredging the entire AWC to a constant depth of -12 feet MLLW greatly improves the natural flushing action of the Canal system, producing relatively low concentrations of chlorophyll which meet the criterion for satisfactory water quality. When a 5 knot tradewind condition is also imposed, the Table 4.18 2-D model output results indicate a degradation of the flushing characteristics as implied by the chlorophyll concentration increases. Examining Figures F-61 and F-63, which describe the horizontal velocities for these two cases, it is noted that the circulation pattern in the end section of the Canal, in the area of the Inner Basin, is more aggressive for the case without wind as compared to the 5 knot tradewind case. The no wind case shows a well defined two-layer flow system at the end section of the AWC, where the dense ocean waters move into the Canal in the lower layer and the lighter surface waters move seaward, producing a vertical circulation system. When a 5 knot tradewind condition is applied, the increased surface flow inhibits some of the lower depth landward flow, causing a general reduction in the vertical circulation pattern in the end section of the Canal, and leading to increased chlorophyll concentrations.

TABLE 4.17

Chlorophyll Concentrations for Base Case with Sill Area Dredged to -6 ft MLLW, with 20 cfs Seawater Inflow

Description	Station Number								
	4	5	6	7	9	10	11	12	Harbor
BC with Sill Area Dredged to -6 ft MLLW									
TOP	10.61	11.81	13.67	13.62	13.66	16.26	21.58	37.97	6.00
MIDDLE	1.89	1.78	7.25	13.00	13.50	10.23	10.90	36.50	1.68
BOTTOM	0.93	0.98	1.56	2.62	5.99	6.19	7.16	26.41	0.89
MAX	10.61	11.81	14.13	14.62	15.84	16.81	21.58	39.12	6.00
BC with Sill Area Dredged to -10 ft MLLW & 20 cfs Seawater Inflow									
TOP	4.21	4.42	4.57	4.33	4.29	4.84	5.03	6.44	3.01
MIDDLE	1.58	1.64	3.97	4.80	4.64	3.84	3.59	3.35	1.48
BOTTOM	0.97	1.00	1.74	2.26	3.46	3.19	2.80	0.16	0.91
MAX	4.21	4.47	4.86	4.85	4.94	5.08	5.06	6.53	3.01

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TABLE 4.18

Chlorophyll Concentrations for Base Case with the Ala Wai Canal Dredged to -12 ft MLLW, with 5 knot Tradewind Conditions

Description	Station Number								
	4	5	6	7	9	10	11	12	Harbor
BC with Whole Canal Dredged to -12 ft MLLW									
TOP	7.08	7.08	6.82	6.03	5.75	6.66	6.59	6.70	5.49
MIDDLE	2.71	2.88	5.72	5.52	5.74	5.50	5.05	5.36	2.44
BOTTOM	0.78	0.85	1.04	1.12	1.45	1.73	2.04	4.07	0.94
MAX	7.08	7.72	7.42	7.00	6.54	6.66	6.59	6.89	5.49
BC with Whole Canal Dredged to -12 ft MLLW & 5 knot Tradewind									
TOP	5.53	5.88	8.51	8.92	10.78	14.33	13.87	17.25	5.38
MIDDLE	1.98	0.95	1.75	1.60	3.12	5.18	6.89	15.83	4.29
BOTTOM	0.77	0.85	1.00	1.00	1.17	1.66	2.23	11.38	1.17
MAX	5.53	5.88	8.51	8.92	12.86	14.52	13.87	17.69	5.77

4.4. SUMMARY

The following summarizes the highlights and results of the hydrodynamic and water quality modeling task efforts.

1) The CE-QUAL-W2 two-dimensional, laterally averaged hydrodynamic and water quality model has been verified by comparisons with a one-dimensional hydrodynamic and transport model, using idealized conditions where the flow characteristics can be analytically verified.

2) The CE-QUAL-W2 model was calibrated using the extensive physical, biological and water quality field measurements obtained in the Ala Wai Canal. The comparisons of the field measured data with the 2-D model predicted results show very good correlations and confirm the validity of the CE-QUAL-W2 two-dimensional model.

3) The calibrated 2-D CE-QUAL-W2 model was then used to evaluate design options to improve the water quality in the AWC. The water quality parameter that was selected to evaluate whether a design option produced satisfactory water quality

results was the chlorophyll concentrations in the Canal. The target chlorophyll concentrations were between 5 - 10 μg/l, and any option that exceeded 10 μg/l was considered to produce unsatisfactory water quality conditions. For reference purposes, a Base Case situation was established which essentially represented the calibration case with a zero (0) wind speed condition. The following summarizes the results of the design option evaluations.

- Injecting seawater into the Kapahulu end of the AWC at continuous flow rates of 10, 20, 30 and 40 cfs were evaluated. The 2-D model results indicated that 10 cfs was an unsatisfactory flow rate, and flow rates of 20 cfs or greater produced satisfactory chlorophyll conditions in the Canal. Light and strong tradewind and Kona wind conditions were applied together with the 20 cfs seawater inflow. While the chlorophyll concentrations vary in response to these meteorological conditions, the chlorophyll concentrations remain well below 10 μg/l. Simulation runs to test the sensitivity of the 20 cfs seawater inflow option with large (2.0 feet) and small (0.6 foot) tidal ranges show some improvement with the larger tidal range and some degradation with the smaller tidal range, but the chlorophyll concentrations remain well below 10 μg/l for both.

  An option associated with the injection of seawater into the Kapahulu end of the AWC, was to evaluate the diversion of some of the flow into the Manoa-Palolo Stream. The 2-D model was run with 5 cfs of seawater inflow injected into the Manoa-Palolo Stream and 15 and 25 cfs seawater simultaneously injected in the terminus of the Canal, for total seawater flow rates of 20 and 30 cfs. The 2-D model results indicated that chlorophyll concentrations in the AWC were much higher than for the runs where the total seawater flow was injected into the Kapahulu end of the Canal.

- A variant of the continuous seawater inflow option was to alternate the flow, where during part of the tidal cycle seawater was injected and during other periods Canal water was withdrawn. Other options in this class included continuous withdrawal of Canal waters both at the Kapahulu end and at 1,500 feet seaward of the terminus in the Inner Basin area. The 2-D model results uniformly showed that the continuous inflow of seawater produced more satisfactory water quality results than of the variants tested.

- The option of injecting near-surface (low salinity) ground water into the Kapahulu end of the AWC was evaluated for flow rates of 20, 30 and 40 cfs.

The 2-D model results clearly indicated that these groundwater inflow options produced much higher chlorophyll concentrations than their seawater flow counterparts. It should be noted that if deep groundwater were to be used as the flushing water source, it would have similar characteristics to seawater (e.g. high salinity and low nutrient concentrations), and consequently the chlorophyll concentration response would be essentially identical to the seawater inflow options that were discussed previously.

- o The option of constructing a channel from the Kapahulu end of the AWC to Waikiki Beach was evaluated. In order to protect the Waikiki Beach coastal waters from discharges from the AWC, a "one-way valve" or tide gate was simulated in the channel, such that water could only enter the channel from the Waikiki Beach area. The 2-D model results indicated that while the chlorophyll concentrations improved significantly from the Base Case conditions, the improvement was not satisfactory to meet the criterion of < 10 μg/l.

- o Various options associated with dredging the Sill area between the McCully Bridge and the confluence of the Manoa-Palolo Stream were evaluated, including an additional combination of filling the Inner Basin. The 2-D model results indicated that while the Sill dredging options change the values and distribution of the chlorophyll concentrations, it does not uniformly provide better water quality conditions than the non-dredged Sill condition, particularly in the Inner Basin area. When a 20 cfs seawater inflow is also superimposed on the dredged-Sill option, the chlorophyll concentrations become very similar to the 20 cfs seawater inflow with the existing Sill condition. This indicates that with a 20 cfs seawater inflow, the water quality conditions in the Ala Wai Canal are relatively insensitive to depth conditions in the Sill area.

All the dredging and fill options tested do not of themselves provide satisfactory water quality conditions in the Ala Wai Canal.

Based on the above option evaluations for improving the water quality in the Ala Wai Canal, the following options are considered technically feasible to warrant further feasibility analysis and conceptual design evaluations:

1) Injection of 20 to 30 cfs seawater inflow into the Kapahulu end of the Ala Wai Canal. For this option, two design concepts are suggested:

- o A submerged pipeline would be constructed in the Ala Wai Canal, with an intake located in the entrance channel to the Ala Wai Boat Harbor, a pump station located adjacent to Magic Island, and an outlet manifold located across the Canal at the Kapahulu end.

- o A "non-trenched" buried pipeline would be constructed from a pump station located at the Kapahulu end of the AWC to an intake location offshore of Waikiki Beach in a water depth of about 40 feet. A similar outlet manifold would be provided across the Canal to distribute the injected seawater.

2) Injection of 20 - 30 cfs deep groundwater into the Kapahulu end of the Ala Wai Canal using groundwater wells located on the Ala Wai Golf Course. An outlet manifold would be provided across the Canal to distribute the injected groundwater. The deep groundwater wells must produce salinity and nutrient concentrations similar to coastal seawater.

CHAPTER 5.0

CONCEPTUAL ENGINEERING DESIGN AND COST ESTIMATES

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CHAPTER 5
CONCEPTUAL ENGINEERING DESIGN AND COST ESTIMATES

5.1. INTRODUCTION

Based on the CE-QUAL-W2 two-dimensional model output results of the water quality characteristics in the Ala Wai Canal due to various alternative design options, three options were selected for the development of conceptual design and construction cost estimates. The three options were designed to provide injection of 20 cfs (9,000 gpm) to 30 cfs (13,500 gpm) seawater into the Kapahulu end of the Ala Wai Canal, where the flow would be discharged through a diffuser across the width of the canal. The source waters would be obtained from one of the following systems:

- o A submerged pipeline system which would intake ocean seawater in the entrance channel of the Ala Wai Boat Harbor about 40 feet below the surface, with a submerged pump station located adjacent to Magic Island.

- o A "non-trenched" buried pipeline which would be constructed using existing directional drilling technology to drill and install an underground pipe from the Kapahulu end of the AWC to a location off Waikiki Beach, with the intake point located in a water depth of about 40 feet.

- o A deep groundwater well system, located on the Ala Wai Golf Course, which would extract groundwater of approximately seawater salinity.

The conceptual designs and costs estimates for the first two options (the ocean water source options consisting of the submerged pipeline system with the intake in the entrance channel of the Ala Wai Boat Harbor, and the directionally drilled underground pipeline system with an intake off Waikiki Beach), were carried out by Makai Ocean Engineering, Inc. (MOE) and their report is provided in Appendix G.

The evaluation of the deep groundwater well system was performed by Tom Nance Water Resources Engineering (TNWRE). This concept first required an evaluation of the available historic data on the sub-surface geologic structure, in order to determine the feasibility of the Ala Wai Golf Course site to produce the required flow rate of deep, ocean-salinity water. If this feasibility assessment yielded positive results, the subsequent task effort was to develop a conceptual design of the groundwater well system and from this design provide a construction cost estimate. TNWRE's report is provided in Appendix H.

In the following sections, information from the MOE and TNWRE reports are summarized and a concluding section provides recommendations on the selected option.

5.2. OCEAN WATER SOURCE SYSTEMS

Figure 5-1 schematically describes the two ocean water source alternatives that were evaluated by MOE. Alternative No. 1 represents the submerged pipeline with an intake in the Ala Wai Boat Harbor entrance channel, and Alternative No. 2 represents the directionally drilled pipeline with an intake off Waikiki Beach.

5.2.1. Alternative No. 1: Laying a Pipeline along the Ala Wai Canal. The proposed system consists of a pipeline which intakes seawater from the Ala Wai Boat Harbor entrance channel, at a depth of about 40 feet below the surface, and discharges the flow at the Kapahulu end of the Ala Wai Canal. In addition to the suction and discharge pipelines and the required intake and discharge manifolds, a submerged pump station with a minimum pumping capacity of 20 cfs (9,000 gpm) and a maximum pumping capacity of 30 cfs (13,000 gpm) is located near the entrance of the Ala Wai Canal adjacent to Magic Island. Figure 5-1 schematically shows the proposed location of the pipeline and pump station.

A preliminary optimization analysis was performed to determine the optimum size of the suction and discharge pipelines and components. The optimum sizes have been defined as those which would produce the smallest total costs (capital plus operational) over the life of the pipeline (assumed 30 years in this preliminary analysis). It was found that large diameter pipes and small pumps provide the best combination to minimize total costs over the lifetime of the system. As the size of the pipe diameter decreases, capital costs decrease due to the fact that the cost of the pipe, weights needed to hold the pipe down, and dredging requirements decrease. However, a smaller pipe diameter means that, for a given operational flow, the friction losses during operation will be larger. Larger friction losses increase capital costs since larger pumps and motors are required, but primarily increase operational costs since more electricity is needed to drive the pumps to achieve the desired flow rates. At this conceptual design level, a 40 inch, 4,000 foot long suction pipe and a 42 inch, 12,500 foot long discharge pipe have been selected, together with a submersible, three pump system (2 main and 1 back-up).

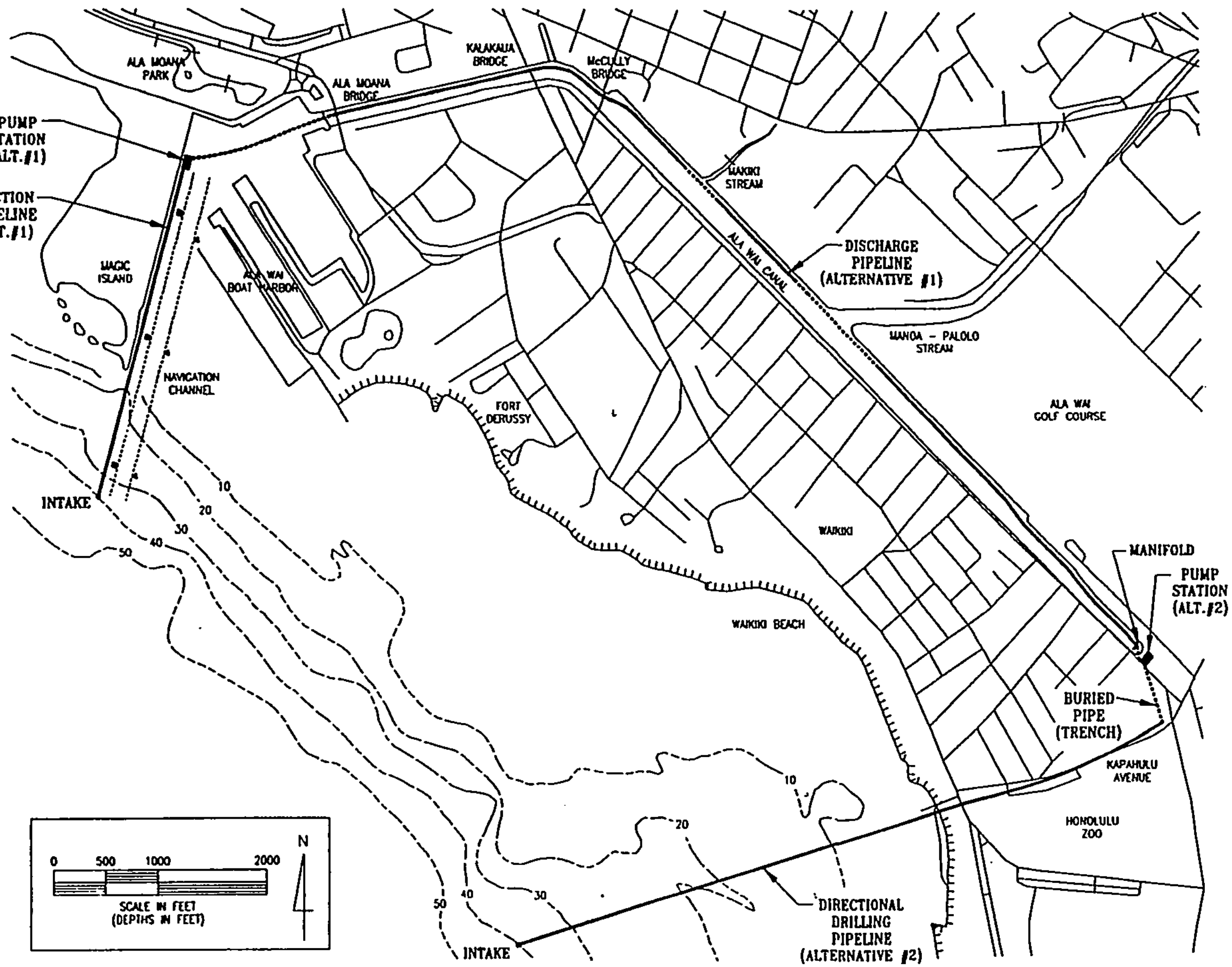


FIGURE 5-1 GENERAL SITE LOCATION SHOWING ALTERNATIVES ANALYZED

Polyethylene pipes have been selected for this alternative. Polyethylene is a very rugged and cost effective material with a long life in marine applications. In addition, polyethylene is an inert material which does not corrode and does not promote growth of marine organisms.

The pipeline route inside the Ala Wai Canal has been selected to be on the mauka side of the canal, 15 to 35 feet from the side wall, in water depths of approximately 5 feet. The main advantages of laying the discharge pipe on the mauka side of the canal are:

- On the mauka side of the canal between the McCully Bridge and the Kapahulu end of the canal are a golf course, a public park and a school. Large public spaces are available is this area to store, assemble and deploy the pipeline. On the makai side are a high density of apartments, commercial and resort areas, which make the construction, deployment and maintenance operations more difficult.

- Noise during construction would be minimal for the residents of Waikiki.

- Access is easier for large construction equipment.

- Minimize visual impact during construction and traffic congestion that would be created if the pipeline is assembled and deployed on the makai side. The same is applicable for maintenance operations.

- While the pipeline may be partly visible underwater in some areas when viewed directly overhead, the visual impact from the Waikiki area would be non-existent.

It has been assumed that the pipeline will be laid after maintenance dredging of the Ala Wai Canal is completed. With the exception of the crossing of the existing streams along the mauka side of the Ala Wai Canal and the crossing of the Ala Wai Boat Harbor, where the pipe is completely buried underground, the pipeline is laid partially above the canal bottom. This approach minimizes the capital cost associated with the required dredging, facilitates maintenance and re-deployment of the pipe in another location (if ever needed), and does not considerably affect boating and other recreational activities in the Ala Wai Canal. At the same time, boats of the size now in use in the Ala Wai Boat Harbor would not represent a threat to the integrity of the pipeline. A minimum clearance of about three feet has been established between the top of the pipeline and the water surface in the canal.

The suction pipe will lay on the bottom along the wall of Magic Island, parallel to the existing navigation channel of the Ala Wai Boat Harbor and will extend from the end of the navigation channel offshore to a water depth of approximately 50-60 feet. The last portion of this pipe will be properly protected and weighted/anchored against the action of waves and currents.

The implementation of this alternative is technically feasible and simple. Construction and deployment of the pipe and installation of the pump station involve minimum risks. During operations, the pumps are the only component in the system that can break down, and the addition of a back-up pump minimizes chances of interrupting operations.

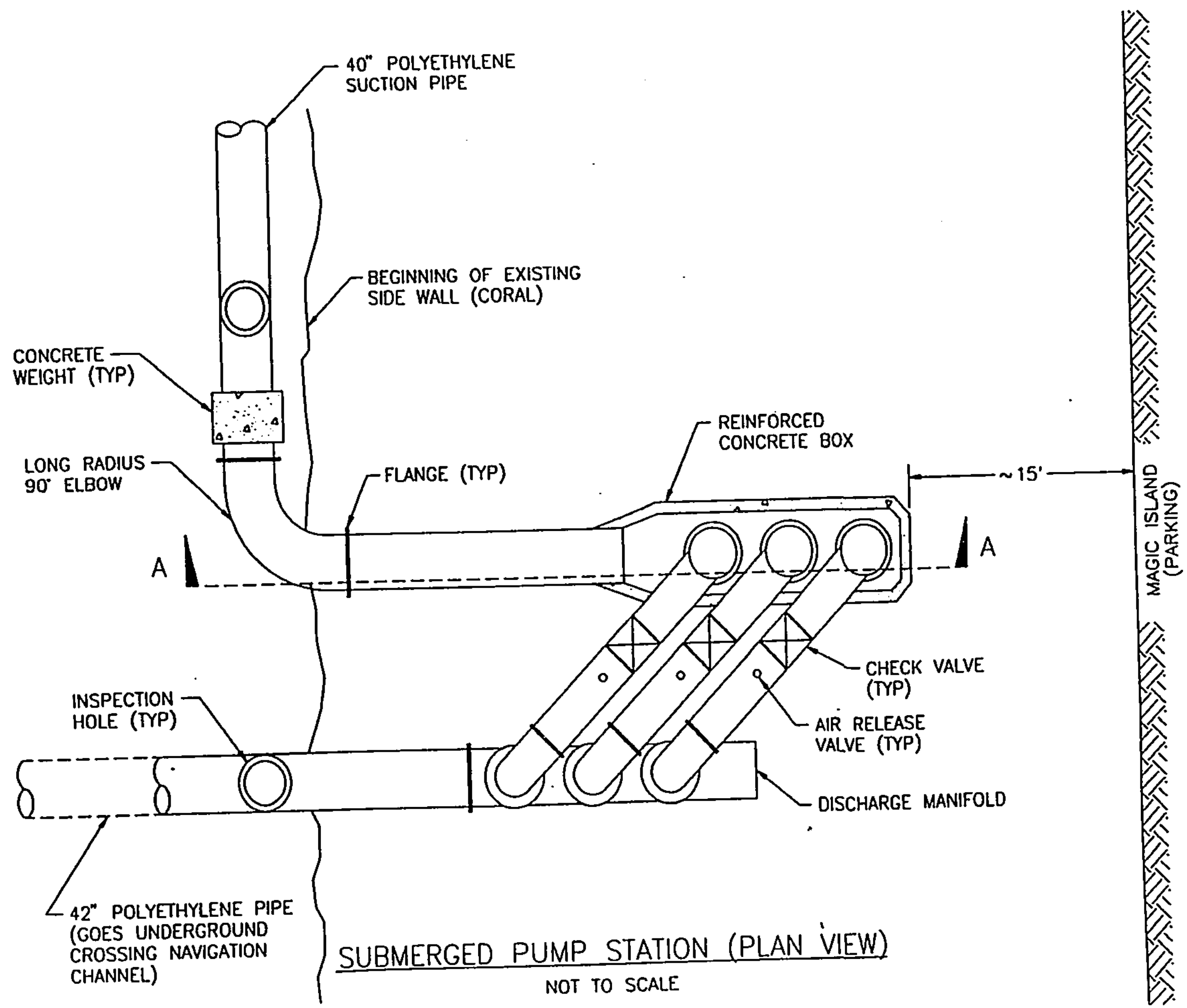
The following listing summarizes the conceptual design for Alternative No. 1.

- Operational flow of 20 cfs (9,000 gpm) with a maximum flow rate of 30 cfs (13,500 gpm). Three submersible pumps (Figures 5-2 and 5-3) located at a submerged pump station adjacent to Magic Island are proposed, with one pump capable of producing 20 cfs, two pumps producing about 30 cfs and the third pump used as a back-up.

- 40 inch diameter, 4,000 foot long suction pipeline extending from the intake structure to the submerged pump station. A 12,500 foot long. 42 inch diameter discharge pipeline extending from the submerged pump station to the Kapahulu end of the Canal. High density polyethylene (HDPE) material has been selected for both suction and discharge pipelines. To minimize interference with future dredging programs, the discharge pipeline would be constructed within 15 to 35 feet from the mauka wall of the AWC and the pipeline would not be deeply buried to minimize the risk of undermining the existing wall structure as shown in Figure 5-4.

- The discharge pipeline will be buried across the Makiki and Manoa-Palolo Stream outlets with the top of the pipe at -13 feet MSL, and from the Ala Moana Bridge to the pump station, where the top of the pipe would be 3 feet below the existing bottom. Figures 5-5 and 5-6 schematically illustrate the stream crossing conceptual design.

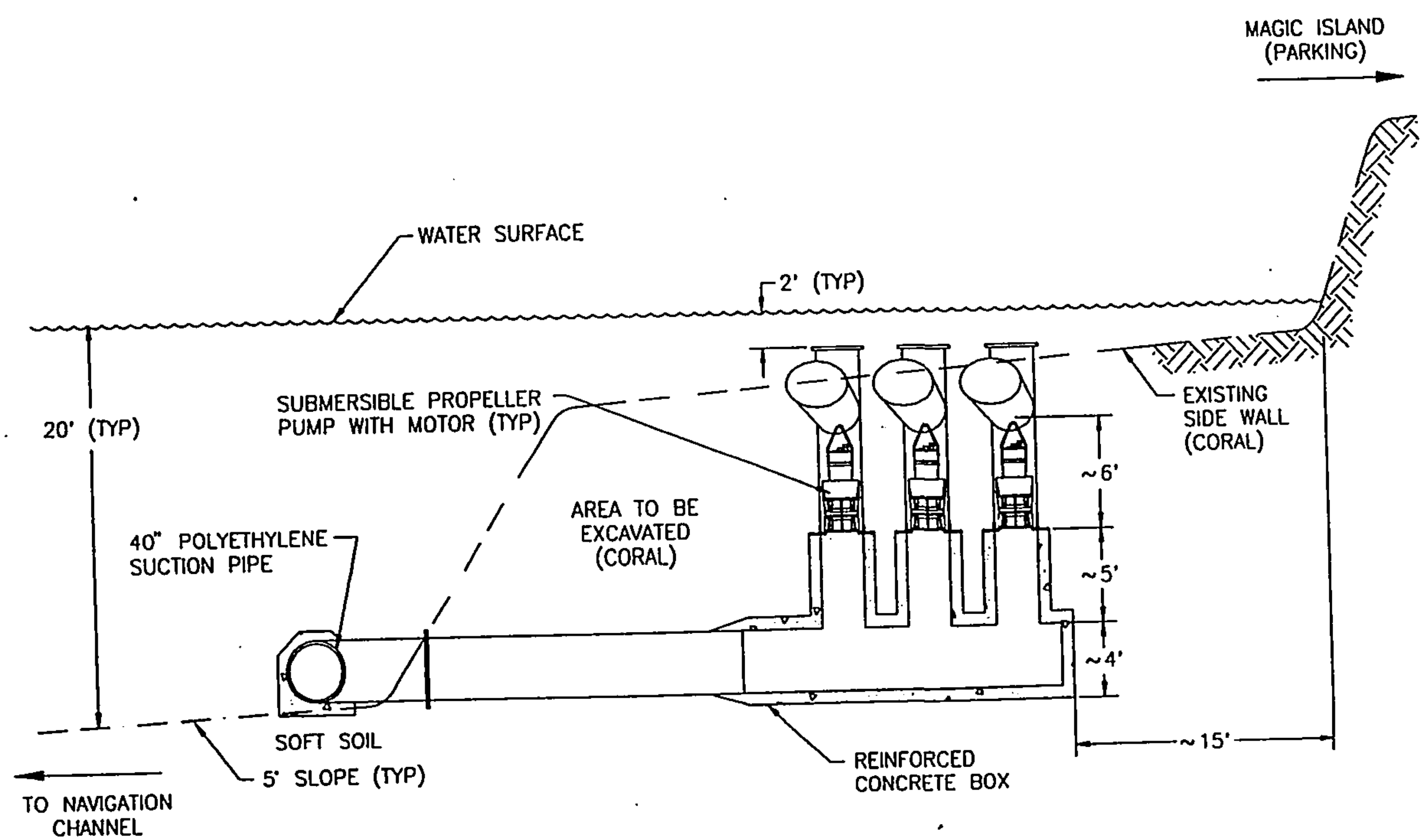
- An intake manifold (Figure 5-7) will be located in a bottom depth of about 50-60 feet with the top of the manifold about 40 feet below the water surface. Two inlet heads are proposed, consisting of 360 3-inch diameter



SUBMERGED PUMP STATION (PLAN VIEW)

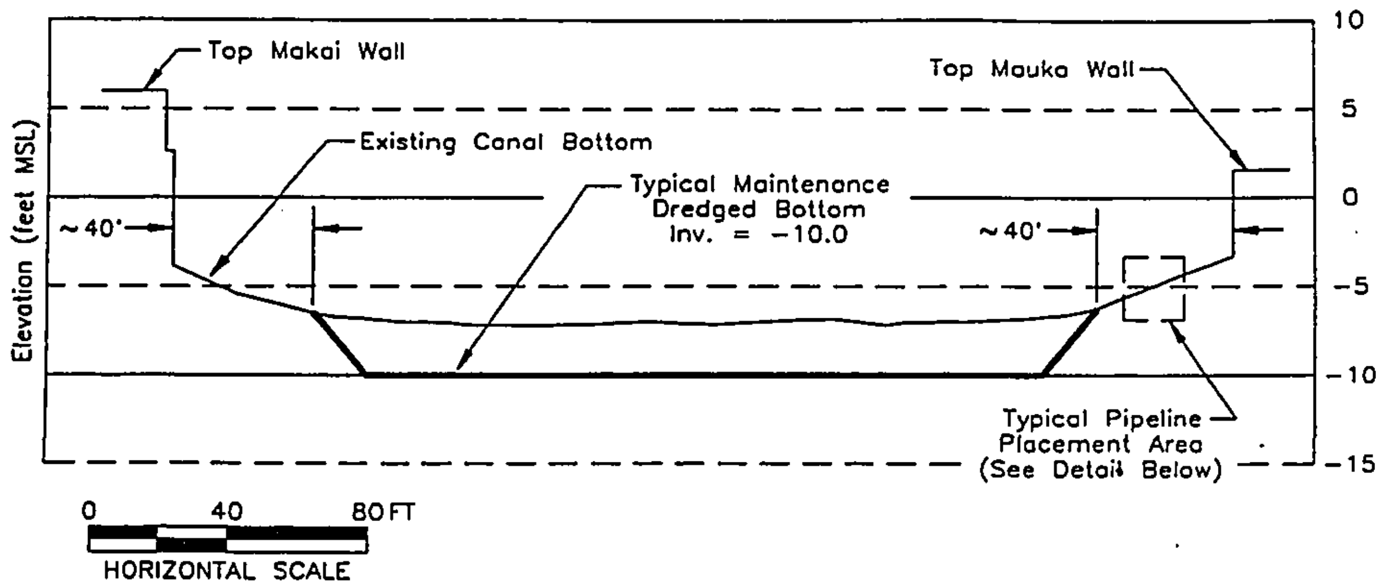
NOT TO SCALE

FIGURE 5-2

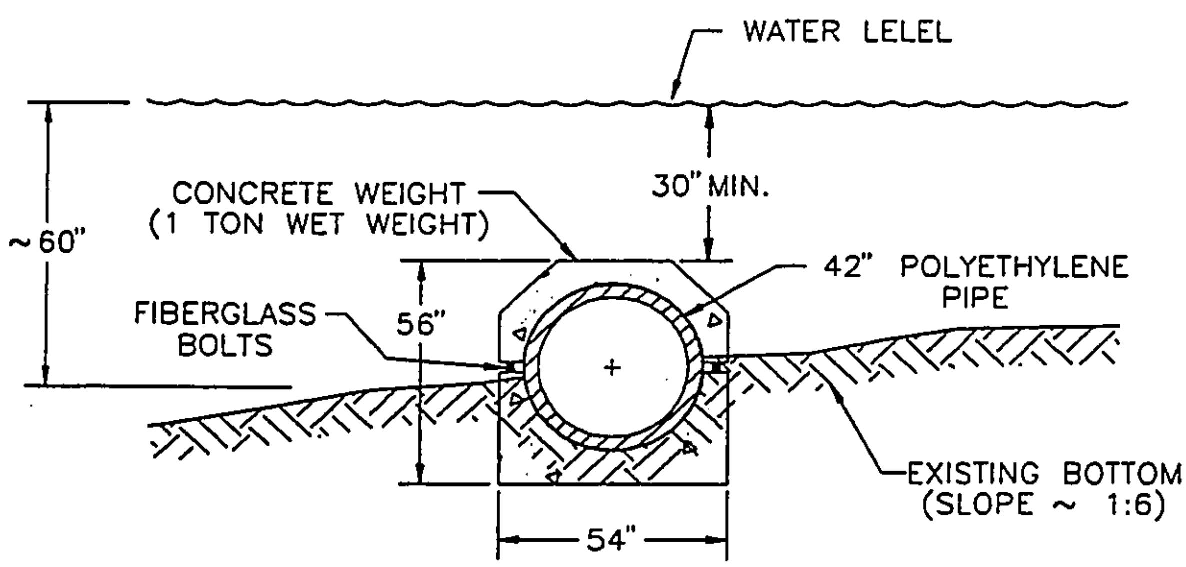


SUBMERGED PUMP STATION
SECTION A–A
NOT TO SCALE

FIGURE 5-3



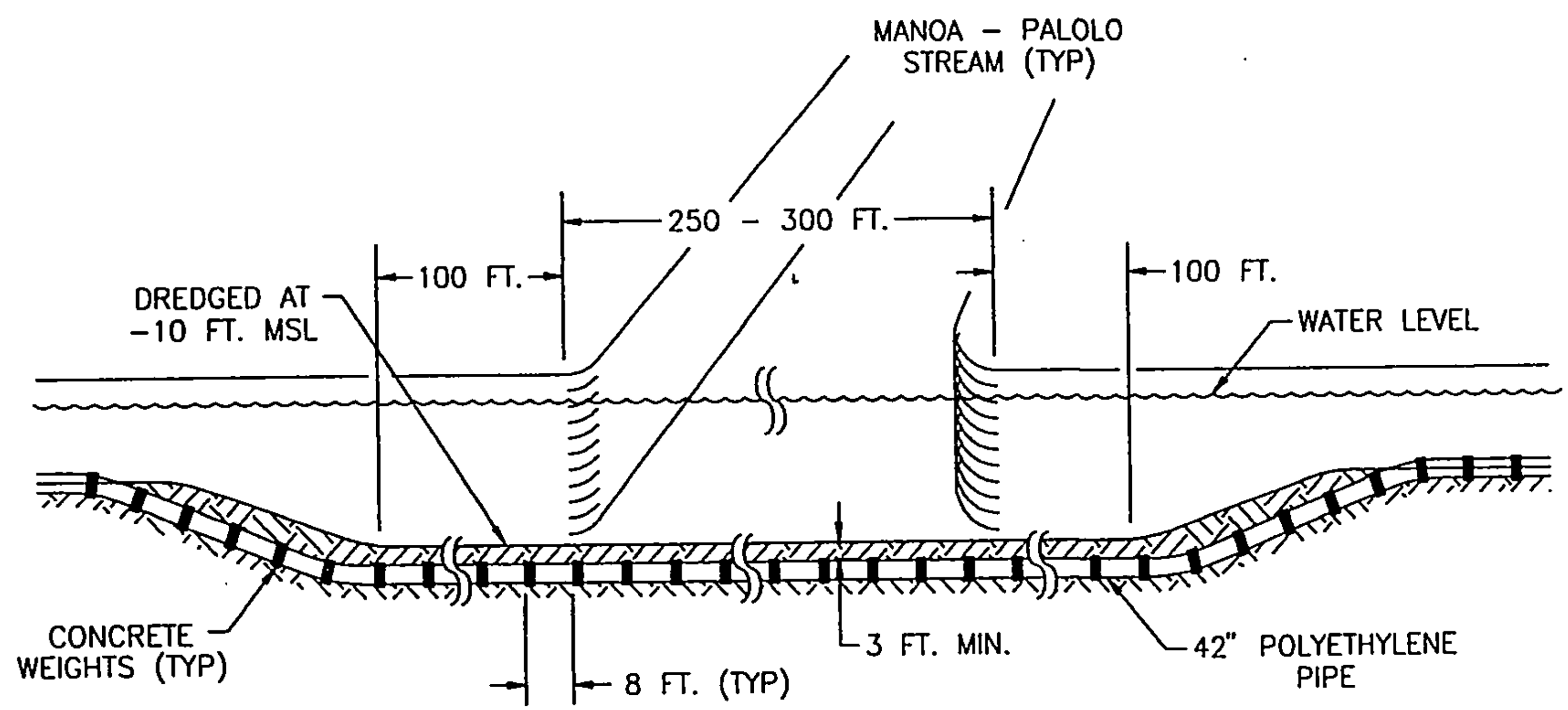
TYPICAL ALA WAI CROSS SECTION



CROSS SECTION
NOT TO SCALE

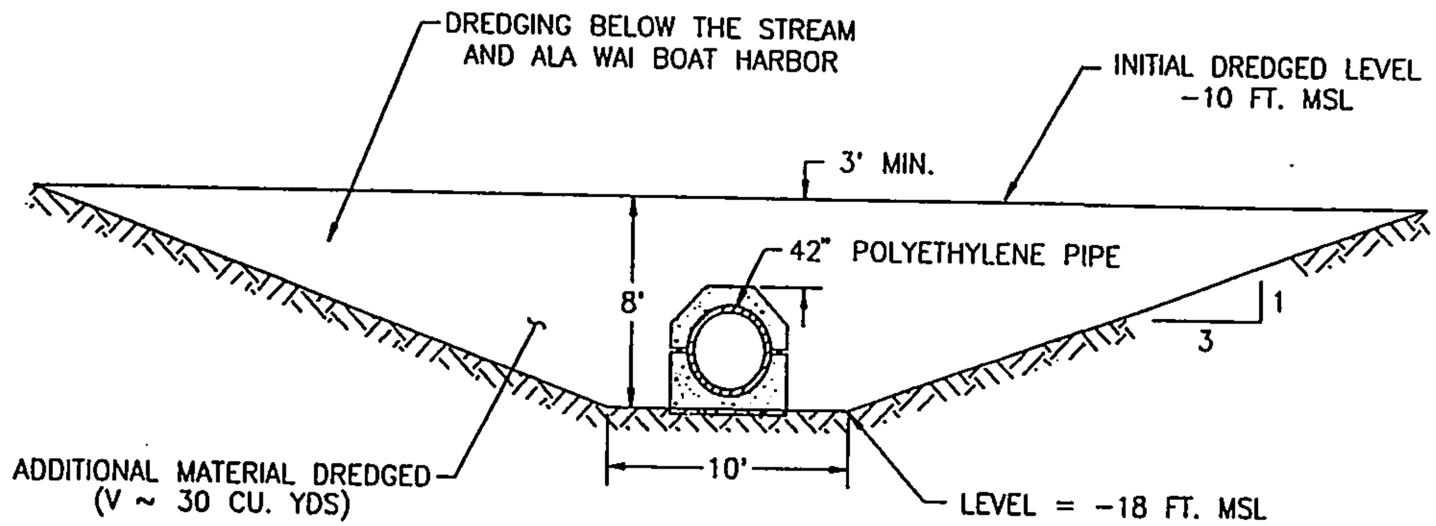
TYPICAL PIPE BOTTOM PLACEMENT
ALONG THE ALA WAI CANAL
NOT TO SCALE

Figure 5-4



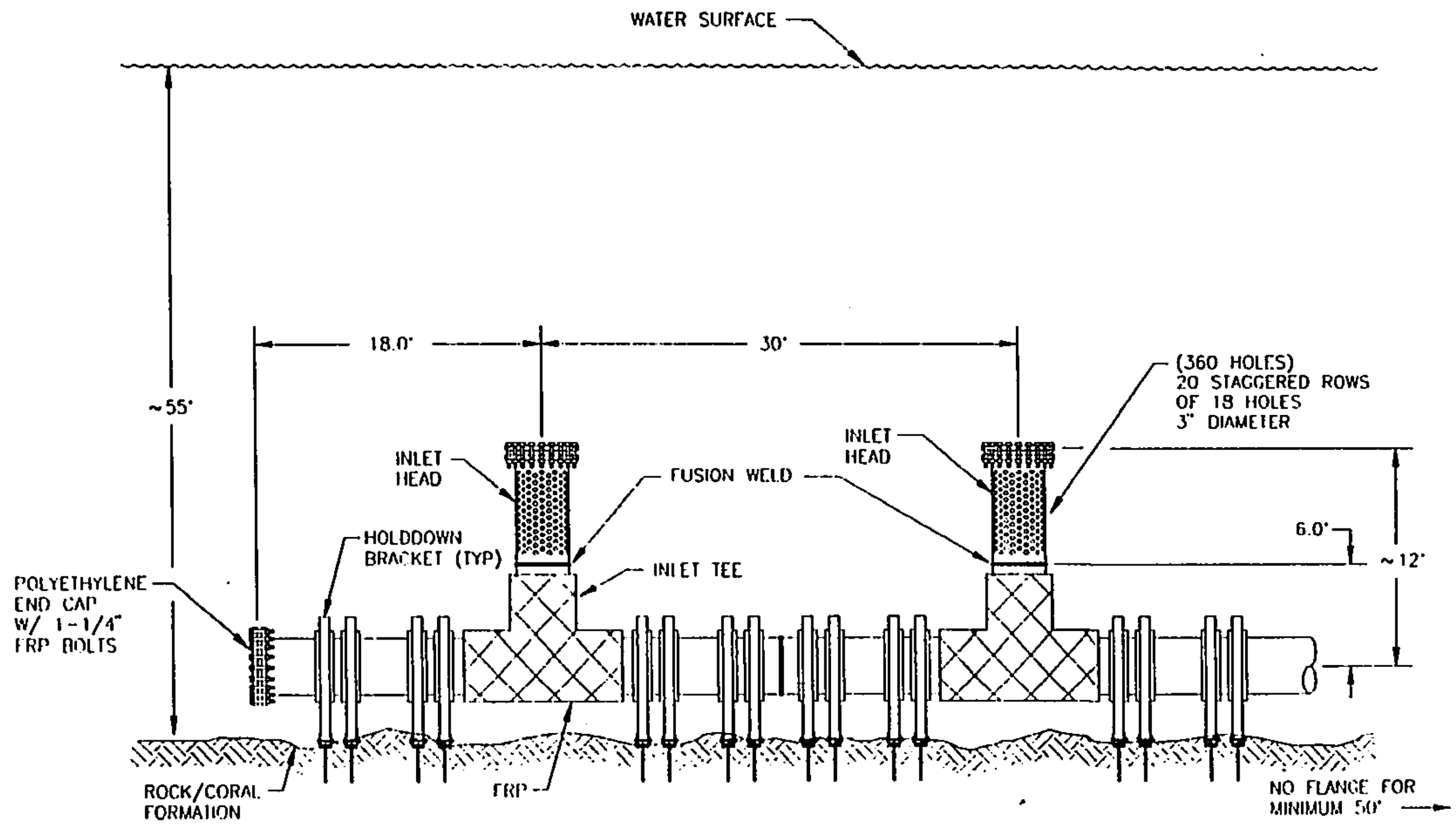
PIPELINE CROSSING STREAM ENTRANCE
NOT TO SCALE

Figure 5-5



CROSS SECTION OF PIPELINE CROSSING
STREAM ENTRANCE
NOT TO SCALE

Figure 5-6



ALA WAI FLUSH INLET CONCEPT

NOT TO SCALE

Figure 5-7

holes each, which would diffuse the intake flow and provide horizontal inflow circulation in order to minimize ingestion of marine life and to minimize danger to divers. For the maximum 30 cfs flow rate, the inlet velocities are less than 1 ft/sec (0.6 knots).

- A discharge manifold, comprised of a 28 inch diameter HDPE pipeline, will distribute and diffuse the outflow waters laterally across the Kapahulu end of the AWC. A total of 32 equally spaced holes, 5.5 inches in diameter oriented at 60° from the horizontal will distribute water uniformly across the Canal width, with a discharge velocity of about 4 ft/sec for the operational flow of 20 cfs. Figure 5-8 shows a plan view of the proposed manifold and Figure 5-9 shows a side view and detailed cross-section.

The capital and operational costs of the Alternative No. 1 pipeline system are shown below where all costs are in 1992 dollars. Note that the cost of dredging the estimated 5,000 yd^3 of bottom sediments from the Kapahulu end of the Canal for the placement of the discharge manifold and to provide a smooth transition for the outflow waters, which was included in the MOE construction cost estimate has been deleted. It is recommended that this dredging of the Kapahulu end of the AWC be performed as part of the next maintenance dredging project. Should this dredging not be performed, then this dredging costs must be added to the selected flushing system construction costs.

Engineering Design And Permitting Costs	$490,500
Construction Costs	$6,876,000
Less 5,000 yd^3 Of Dredging @ $34/$yd^3$	<$170,000>
Subtotal	$7,196,500
Contingency 15%	$1,079,500
TOTAL ESTIMATED ENGINEERING & CONSTRUCTION COST	$8,276,000
ESTIMATED ANNUAL OPERATING AND MAINTENANCE COST	$71,500

5.2.2. Alternative No. 2: Directional Drilling Pipeline Installation. This alternative evaluates the feasibility of using earth boring-trenchless technology to install an underground pipeline from a pump station at the Kapahulu end of the Ala Wai Canal to a location off Waikiki Beach, with the ground breaking point and intake located at a water depth of about 40 feet. The drilled hole would be about 7,000 feet long and the installed suction pipeline would be about 40 to 42 inches in diameter.

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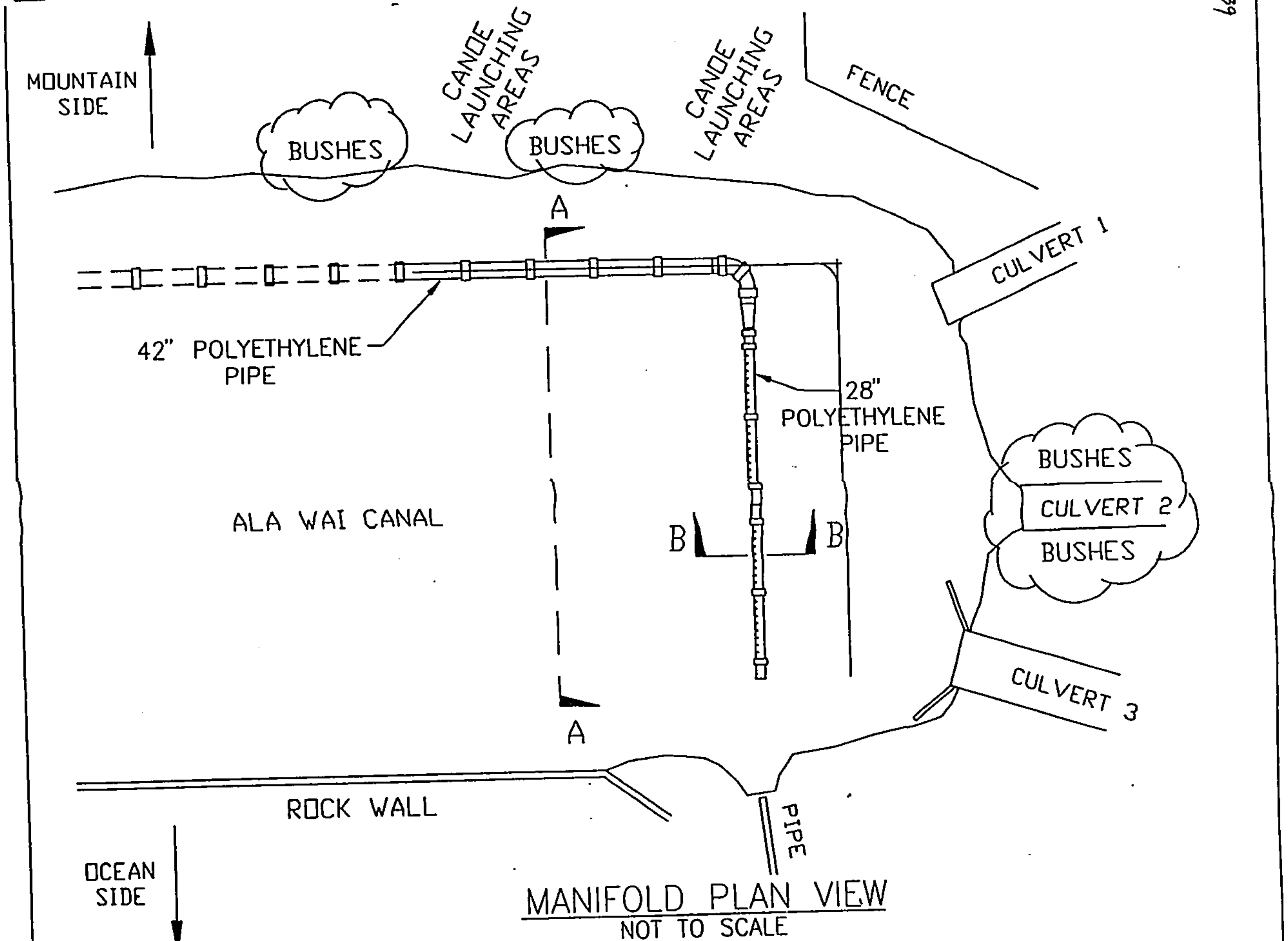
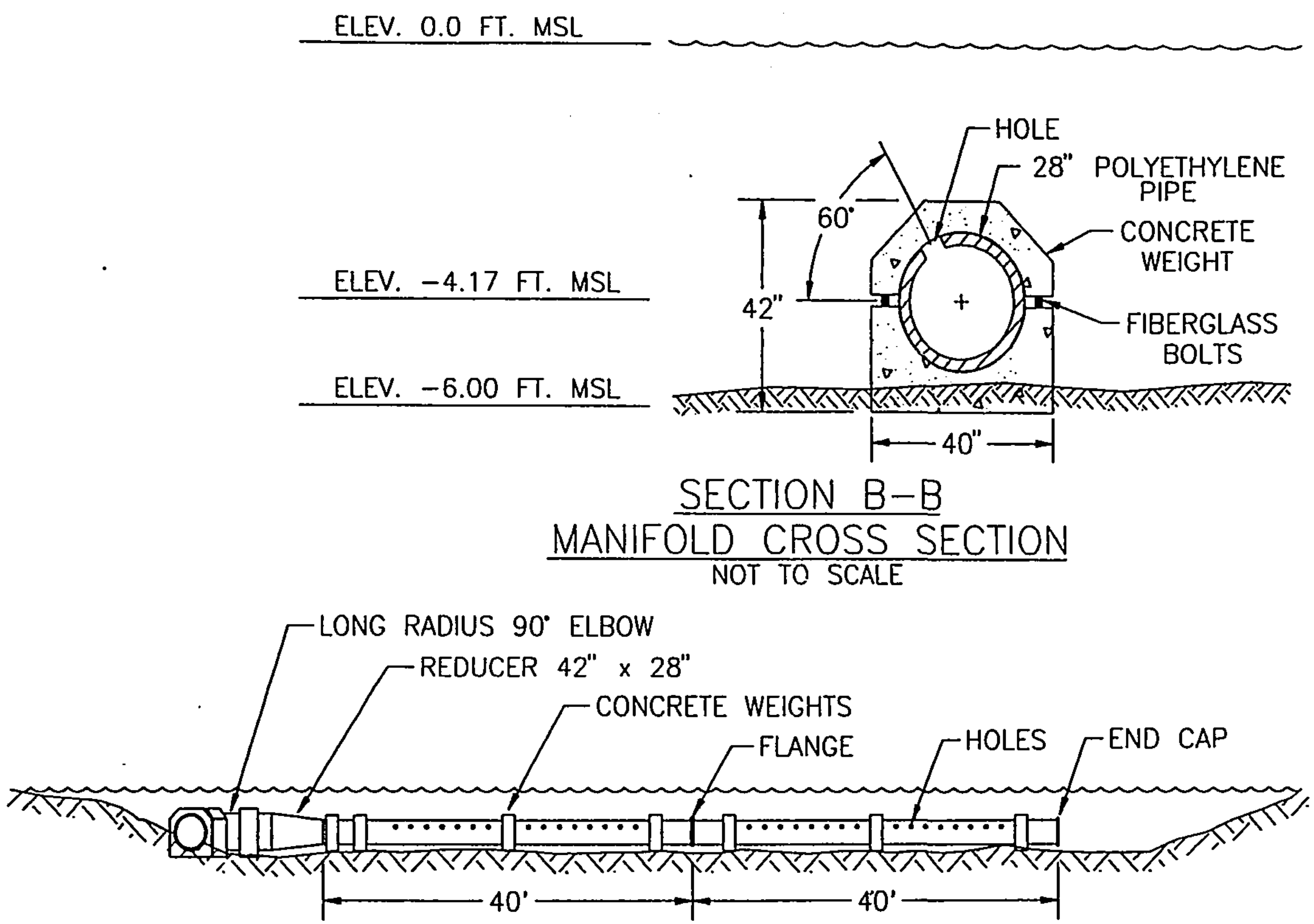


Figure 5-8



SECTION B–B
MANIFOLD CROSS SECTION
NOT TO SCALE

SECTION A–A
MANIFOLD SIDE VIEW
NOT TO SCALE

FIGURE 5-9

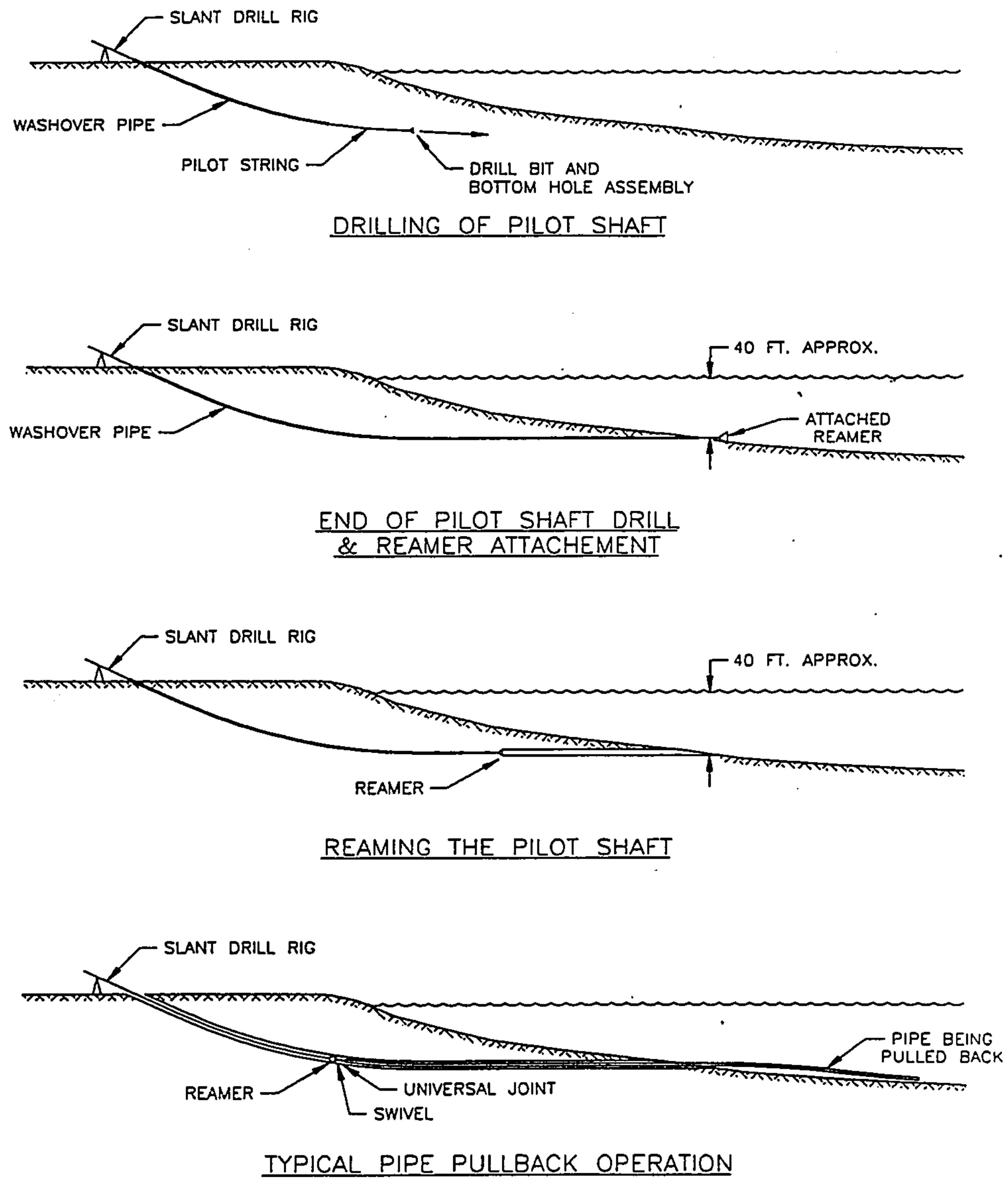
The earth boring technology that offers the best opportunity to construct the trenchless underground pipeline is Directionally Controlled Horizontal Drilling (commonly referred to as directional slant drilling). This methodology is a two step process first involving the drilling of a directionally controlled pilot hole, approximately 3 inches in diameter, with the second phase involving the enlargement of the pilot hole to the desired diameter by reaming. The required pipeline is then installed in the hole using a "pull back" operation. Figure 5-10 schematically illustrates the directional drilling methodology.

Directionally controlled horizontal drilling uses slanted rigs with shafts which typically start at a depression angle of 10° to 20° from the horizontal. The shaft is guided in both azimuth and tilt angles, runs horizontally, and finally curves upward to break through the ground. The directional drilling method was originally developed in the U.S. in the early 1970's and uses mainly technology developed in the oil industry for vertical drills. This method is now commonly used for crossing under natural or manmade obstacles, especially river crossings. This method has revolutionized complicated river crossings for pipelines which were initially done by conventional dredging methods or were rerouted through long distances and crossed over at a bridge location.

The progress and location of the pilot hole is monitored by a specially designed sensor system. An instrumentation system located near the cutting head records the exact position, inclination and orientation of the drill head by measuring compass heading, tilt and relative rotational angle. This information is then transmitted through a wire to the surface where a computer collects and interprets the data. The direction of the cutting head can be continually adjusted to follow the designed underground route.

A total of 10 construction companies in the field of directional horizontal drilling were contacted to assess the feasibility of using slant drilling technology to construct a pipeline to flush the Ala Wai Canal. A brief summary of the information collected as well as advantages and disadvantages of using directional drilling methodology are provided below:

a. All the companies but one agreed that a 6,000 to 7,000 foot long hole for a 42 inch pipe was beyond the current state-of-the-art.. Currently, the longest hole ever drilled was 5,400 foot long, but this was done for a 16 inch pipeline. Recently, a 4,500 foot long hole for a 42 inch pipe was successfully completed. This job was completed in well consolidated and relatively soft soils (sand, silt and clay) which are optimum for slant drilling. The company which completed this job, Cherrington Corporation, was the only company who felt that they could drill up to a 7,000 foot long hole for a 42 inch pipe if the soil conditions were appropriate.



SLANT DRILL RIG
WASHOVER PIPE
PILOT STRING
DRILL BIT AND
BOTTOM HOLE ASSEMBLY
DRILLING OF PILOT SHAFT
SLANT DRILL RIG
40 FT. APPROX.
WASHOVER PIPE
ATTACHED
REAMER
END OF PILOT SHAFT DRILL
& REAMER ATTACHEMENT
SLANT DRILL RIG
40 FT. APPROX.
REAMER
REAMING THE PILOT SHAFT
SLANT DRILL RIG
PIPE BEING
PULLED BACK
REAMER
UNIVERSAL JOINT
SWIVEL
TYPICAL PIPE PULLBACK OPERATION

FIGURE 5-10

Although information on the geology of the Waikiki area (Ferrall, 1976) was provided to a total of five drilling companies that initially showed interest in drilling a 6,000 to 7,000 foot long hole, only Cherrington Corporation submitted a preliminary budget for the Ala Wai Project (Appendix G).

b. All the companies agreed that the main risk associated with drilling a long hole is related to the quality of the subsurface soil along the drilling path. If pockets of unconsolidated materials are found along the drilled path, it is possible that soil may fall and clog the already drilled hole ("cave in" phenomenon). One solution to this problem is to pump concrete into these pockets of unconsolidated materials to minimize the risk of cave in. The presence of pockets of non self-supporting soils would increase substantially the cost of the operation. Given the geological data published for the area of Waikiki (Ferrall, 1976), it is not unreasonable to expect that some of these pockets would be encountered along the drilling path, and therefore, increase the risk and price of the drilling operation.

c. A second concern expressed by the drilling companies was the fact that bentonite drilling mud might not be allowed in this operation due to environmental concerns that the fluid may leak into the ocean waters. Recent experience with horizontal drilling at Keahole, Hawaii (Wilkins et al., 1992) revealed that the use of bentonite was prohibited by the U.S. Army Corp of Engineers since the coastal waters at Keahole were classified as Class AA. Although the waters off Waikiki are classified as Class A, and therefore have less environmental restrictions than the waters off Keahole, it is not known at this point if the use of bentonite drilling mud would be allowed. If bentonite were not allowed in Waikiki, the risks and cost of the drilling project would increase even further since friction resistance would build up considerably faster with other drilling fluids than with the use of bentonite.

d. In terms of the land area required for the drilling operation to take place, it varies with the type of rig and the size of the job. Land area between 1/4 acre (for small rigs) up to 1 acre (for larger rigs) were requested by the contractor companies. For the length and size of the hole desired, an area close to one acre would be required. Currently, there is no such area available at the end of the Ala Wai Canal. An alternative would be to use part of the Jefferson School grounds or one end of the Honolulu Zoo (Figure 5-11) to set up the rig. Then, an open trench excavation would be required to connect the drilled hole with the Ala Wai Canal. An additional constraint in the location of the drilling rig is that it is difficult to drill on a horizontal curve with this large diameter pipe, therefore, the drilling path must be as close as possible to a straight line.

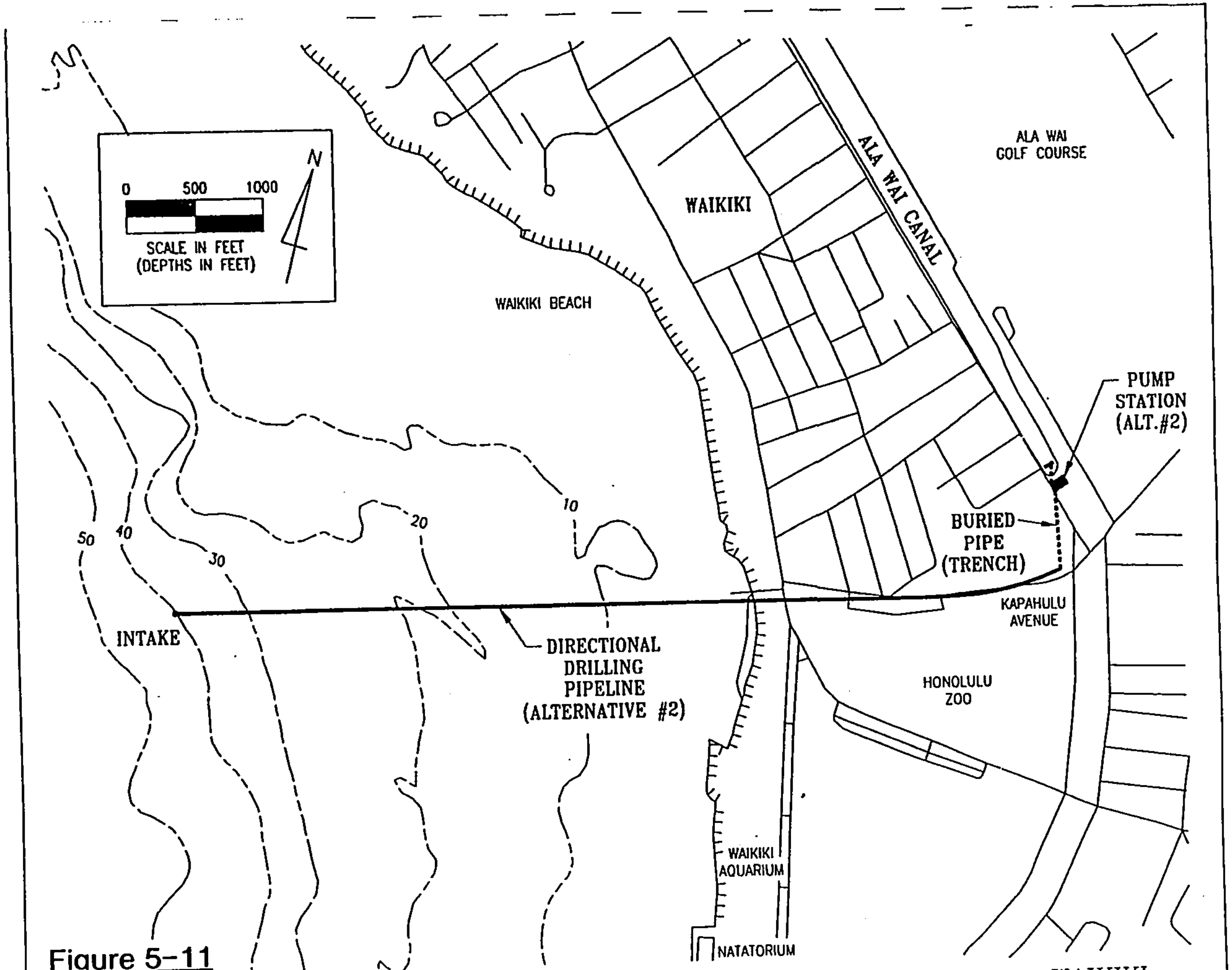


Figure 5-11

POTENTIAL LOCATION AND TRAJECTORY OF DRILLED HOLE UNDER WAIKIKI

e. Due to the length of the pipeline proposed for the Ala Wai Project, a heavy steel pipe is the most likely candidate to be used as the pipeline material. This pipe would have to be protected against corrosion to extend its life.

The following provides a summary of the capital and operational costs of Alternative No. 2, the directionally drilled pipeline system based on 1992 dollars.

Engineering Design And Permitting Costs	$486,000
Construction Costs	$22,913,000
Subtotal	$23,399,000
Contingency 20%	$4,680,000
TOTAL ESTIMATED ENGINEERING & CONSTRUCTION COST	$28,079,000
ESTIMATED ANNUAL OPERATING AND MAINTENANCE COST	$55,000

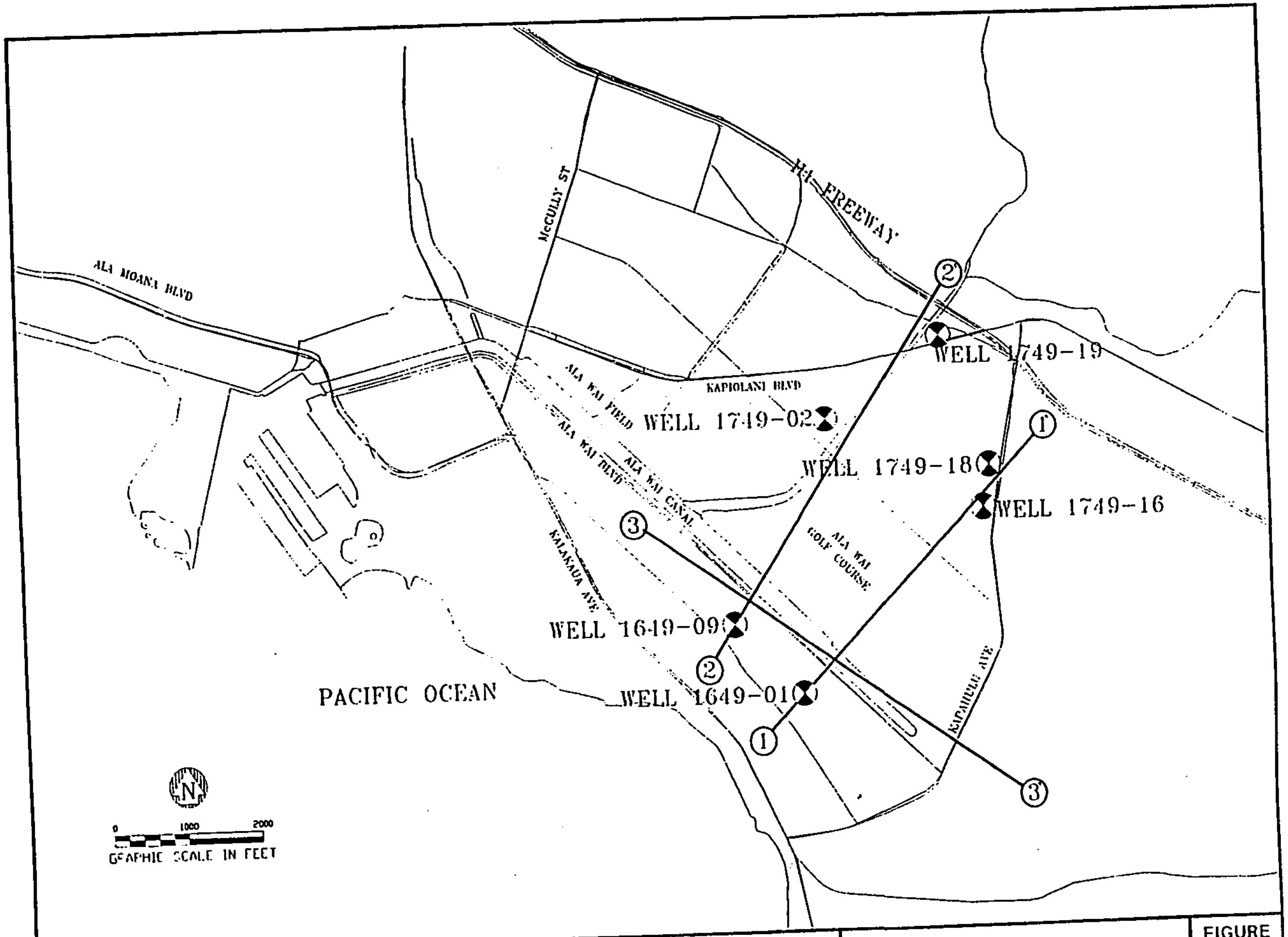
The above estimated construction cost for the directionally drilled pipeline indicates that even under favorable soil conditions and assuming that bentonite can be used as a drilling fluid, this alternative is much more expensive than the alternative involving laying a pipe along the Ala Wai Canal.

5.3. DEEP GROUNDWATER SOURCE SYSTEM

The initial task evaluation performed by TNWRE was to acquire and evaluate available historic data on the subsurface hydrogeology of the eastern end of the Ala Wai Canal in order to assess the feasibility of providing between 20 to 30 cfs deep groundwater flow rates. Figure 5-12 shows the locations of deep wells for which boring logs are available. Three geologic cross-sections, 1-1', 2-2, and 3-3' whose locations are shown in Figure 5-12 are provided in Figures 5-13, 5-14 and 5-15, respectively, and represent the present interpretation of the data.

In general, Figures 5-13 to 5-15 indicate that the first 20 to 30 feet of caprock sequence is comprised of lagoonal deposits, coralline debris, terrestrial alluvium, and/or imported fill. This layer is generally poorly permeable and can be very compressible if subject to dewatering. A pervasive, 10 to 30 foot thick coral ledge lies immediately below this first caprock layer, and is underlain by layers of coral and sand, in some places interrupted by a lens of coralline mud or alluvium of limited thickness and aerial extent.

At depths of 80 to 120 feet below the surface, a layer of later stage volcanics occurs which is typically 50 to 80 feet thick. This layer apparently underlies the entire east end



ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	WELL LOCATIONS, EAST END OF THE ALA WAI CANAL	FIGURE 5-12

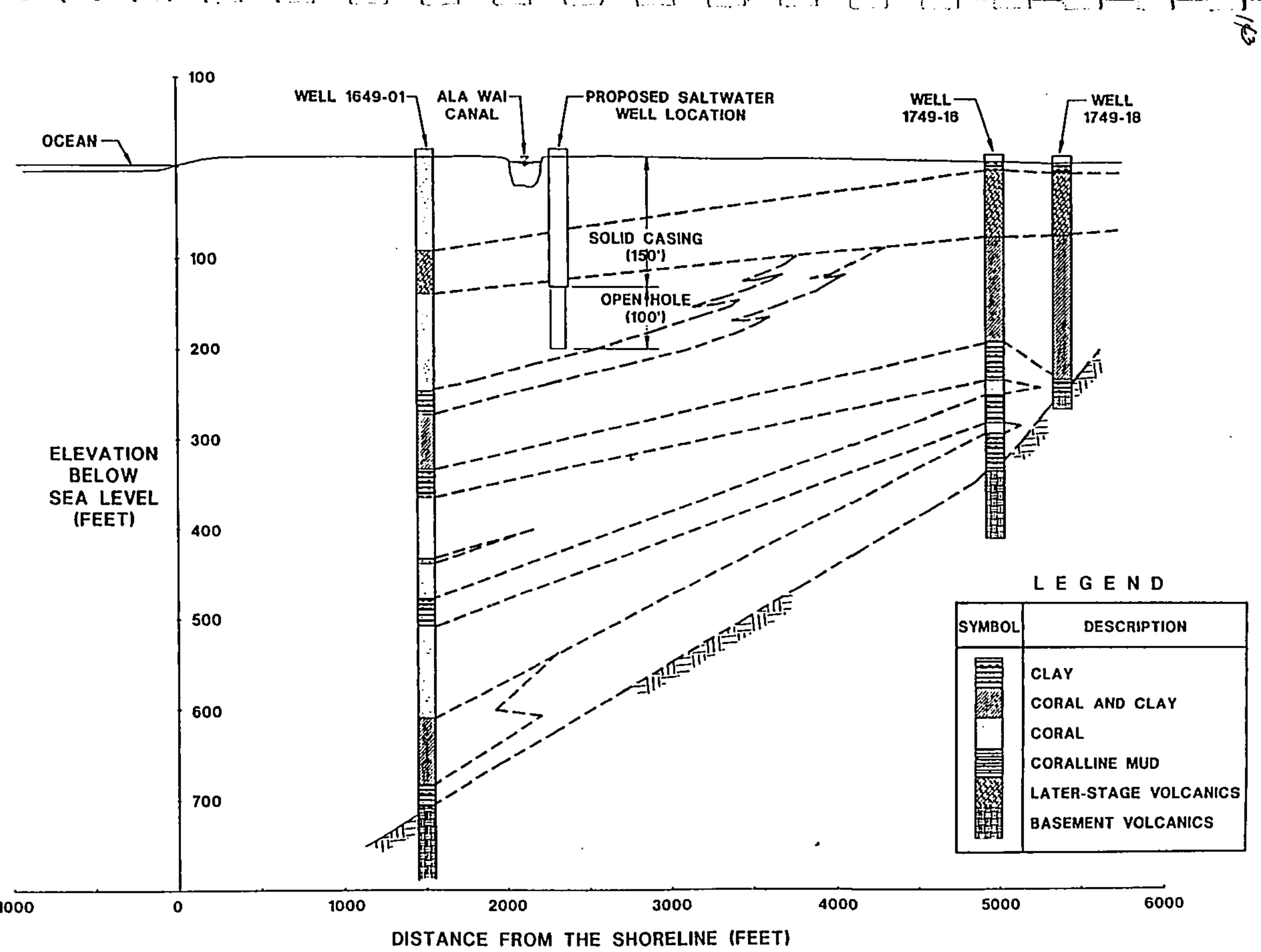


FIGURE 5-13

MAUKA-MAKAI GEOLOGIC SECTION 1 - 1'

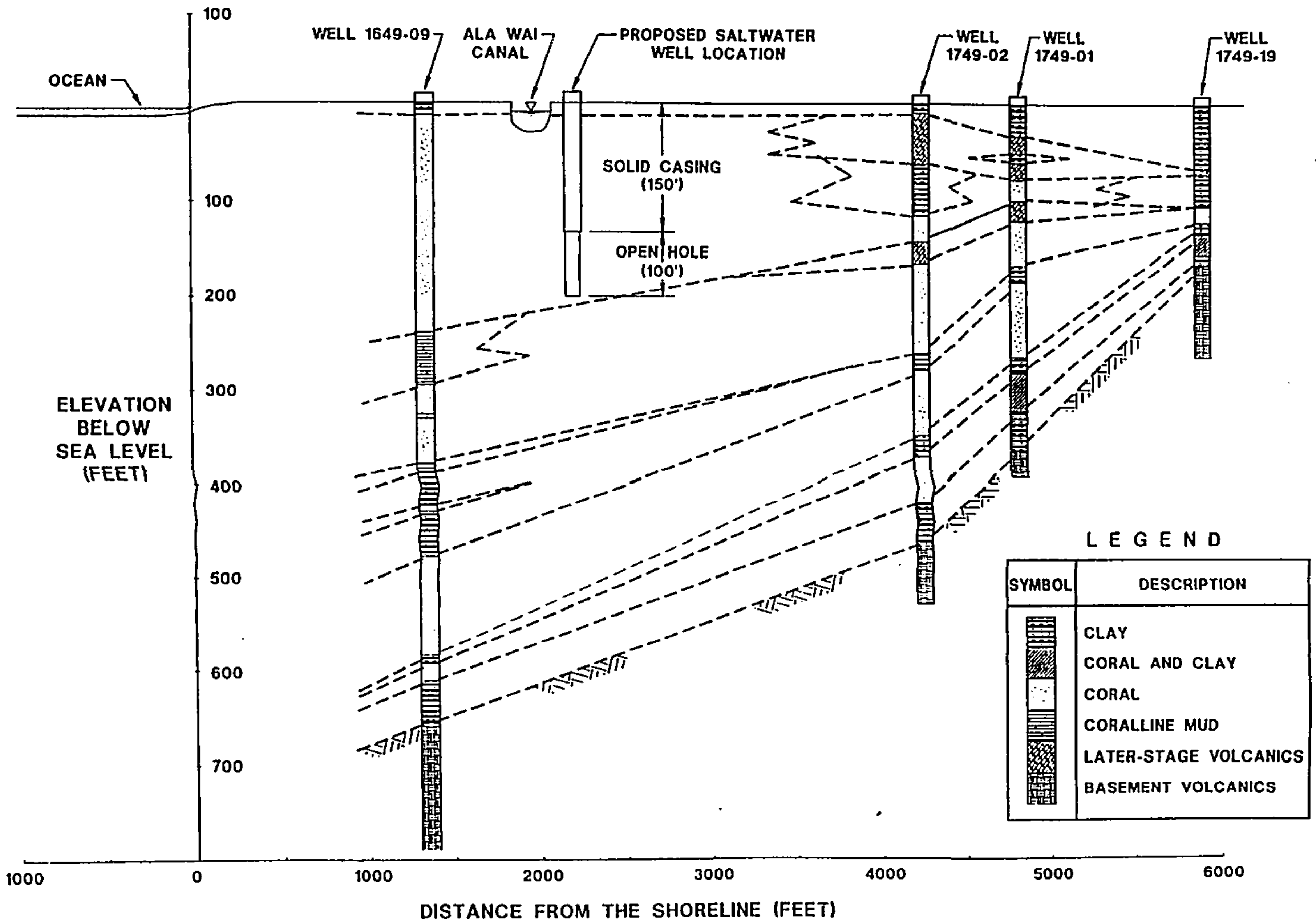
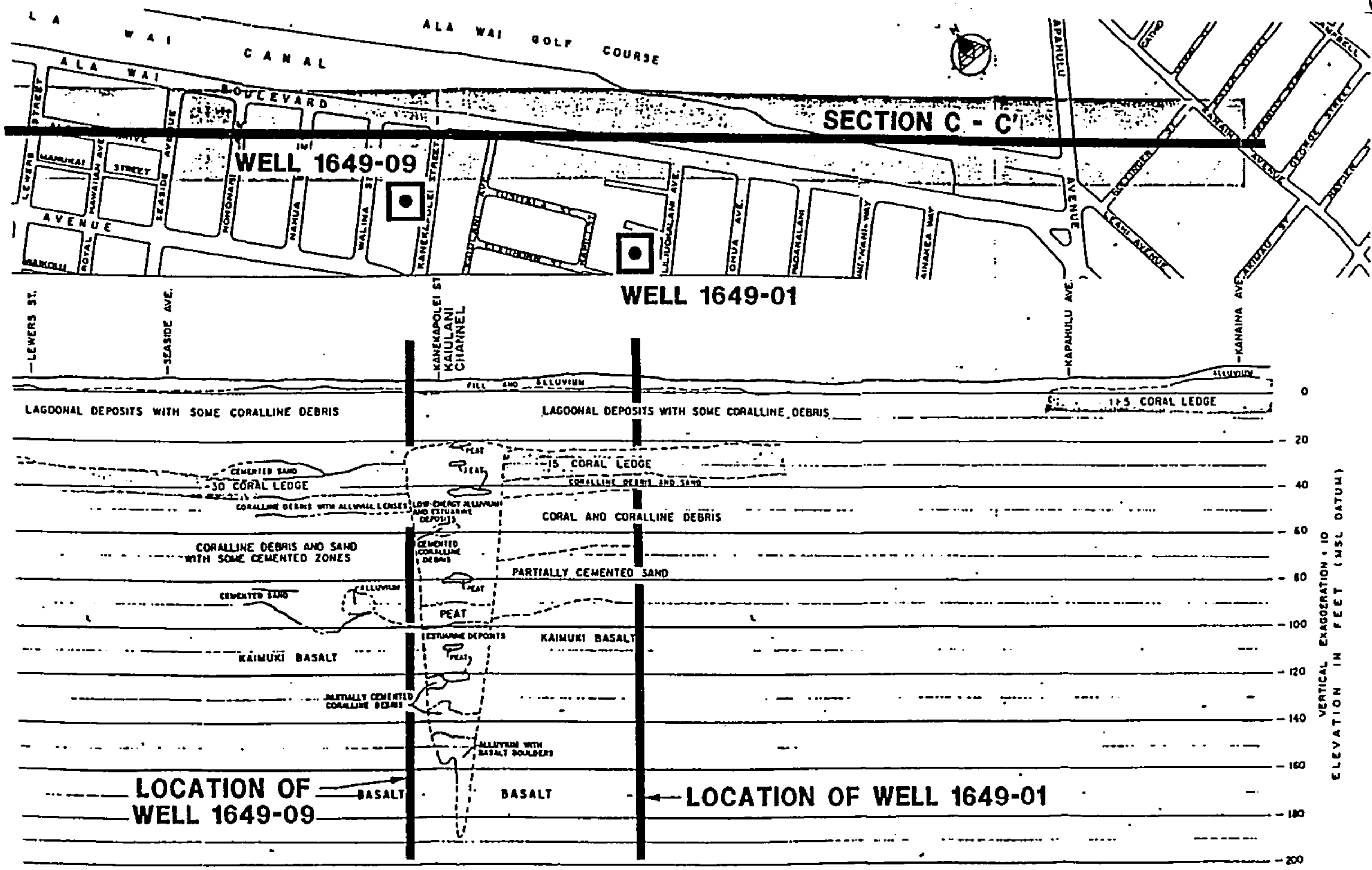


FIGURE 5-14

MAUKA-MAKAI GEOLOGIC SECTION 2 - 2'



MODIFIED FROM SECTION C - C', PLATE V, OF FERRALL (1976)

FIGURE 5-15
GEOLOGIC SECTION 3 - 3'
PARALLEL TO THE SHORELINE

of the Canal and pinches out toward the west. Although there are only a few drill logs available for borings which have penetrated through this volcanic layer into the formations below, these logs suggest that a layered sequence of corals, sands, calcareous muds, and "clays" (of unidentified origin) exists below the later-stage volcanics. The volcanic basement is likely to be 600 to 700 feet below the surface on the mauka side of the Canal, which means that the sequence of corals, sands, and clays between the two volcanic layers is about 400 to 500 feet thick.

From a technical view point, while it may be possible to withdraw groundwater at the flow rates required from the uppermost coral ledge, it is likely that dewatering of the overlying lagoonal deposits would occur, causing subsidence problems as has occurred during various construction projects in the Waikiki area. Moreover, the groundwater from this uppermost coral ledge would not have the high salinity and low nutrient levels as required by the water quality modeling results.

An option that looks optimistic is to withdraw water from the lower coral layers below the later stage volcanic layer, at withdrawal depths between 130 to 200 feet below the surface. The later stage volcanics, particularly the Diamond Head tuff formation at the east end of the Canal, may function as an aquitard, which is a layer that is relatively impermeable and resists the through-flow of groundwater. In this situation, the aquitard layer would provide an effective hydraulic separation from the uppermost coral layer and its overlying lagoonal deposits, thereby greatly minimizing the potential for dewatering of the uppermost lagoonal deposits with its attendant subsidence problems. A calcareous mud layer below the later-stage volcanics may also function as an aquitard. Figures 5-13 and 5-14 schematically show the proposed deep groundwater wells.

The deep groundwater well is likely to produce water with a salinity of 32 to 35 parts per thousand (ppt), little or no dissolved oxygen, and major ions differing from seawater only by the ion exchange which occurs in passage through the coral formation. There is some risk of organic contamination from lagoonal deposits, possibly resulting in high ammonia and sulfides concentrations, but this can probably be avoided through proper well design.

Very little use is presently made of water from this aquifer and none of it occurs at the depth of plumage of the proposed deep groundwater well. Thus, the proposed deep, groundwater well supply proposed above would have no adverse effects on either existing potable water supplies or the existing groundwater supply used for irrigation of the Ala Wai Golf Course.

The TNWRE report analyzed two pumping schemes: high volume, low head propeller pumps together with an aeration system; and an air lift pumping system. The propeller pumping system offers greater flexibility and is considered a more realistic concept than the air lift system. Thus, the following evaluation focuses on the propeller pumping system which has a larger estimated construction cost than the air lift system. Appendix H provides the details of the air lift system. Figure 5-16 shows a schematic description of the propeller pumps, mechanical aeration to increase the dissolved oxygen from 0 to 5.0 mg/liter, and the across-canal diffuser system. Figure 5-17 provides a conceptual design layout of the proposed seawater supply wells at the Ala Wai Golf Course.

In order to provide a basis of comparison with the direct seawater source systems, the seawater well option has been evaluated based on five 200 foot deep wells (130 feet of 18-inch solid casing grouted in-place and 70 feet of open hole), each well delivering 2,500 gpm, spaced nominally 200 feet apart. The following describes the estimated construction and operation and maintenance costs for the proposed seawater supply wells where all costs are in 1992 dollars.

Engineering Design And Permitting Costs	$475,000
Construction Costs	$2,125,000
Subtotal	$2,770,000
Contingency 20%	$554,000
TOTAL ESTIMATED ENGINEERING & CONSTRUCTION COST	$3,324,000
ESTIMATED ANNUAL OPERATING AND MAINTENANCE COSTS	$190,000

While the prospects for obtaining the required seawater supply from deep groundwater wells located at the Ala Wai Golf Course appear optimistic, in order to proceed with this concept, a prototype production well drilling and testing program would be necessary to confirm the expected subsurface geologic strata and water quality, estimate the potential yield from coral layers at depth, demonstrate that such high capacity pumping can be accomplished without adverse effect, and to develop other design parameters.

Figure 5-18 shows a schematic design of the prototype production well. A pilot borehole would be drilled, using rotary drilling equipment, to a depth of approximately 250 feet (or deeper if required by the strata encountered). Based on the geologic strata results, the casing depth would be selected, and the open hole completed as described in Figure 5-18. Full scale pumping tests would then be conducted. Placement of sounding tubes to various depths in the annular space would enable the effects of pumping on overlying

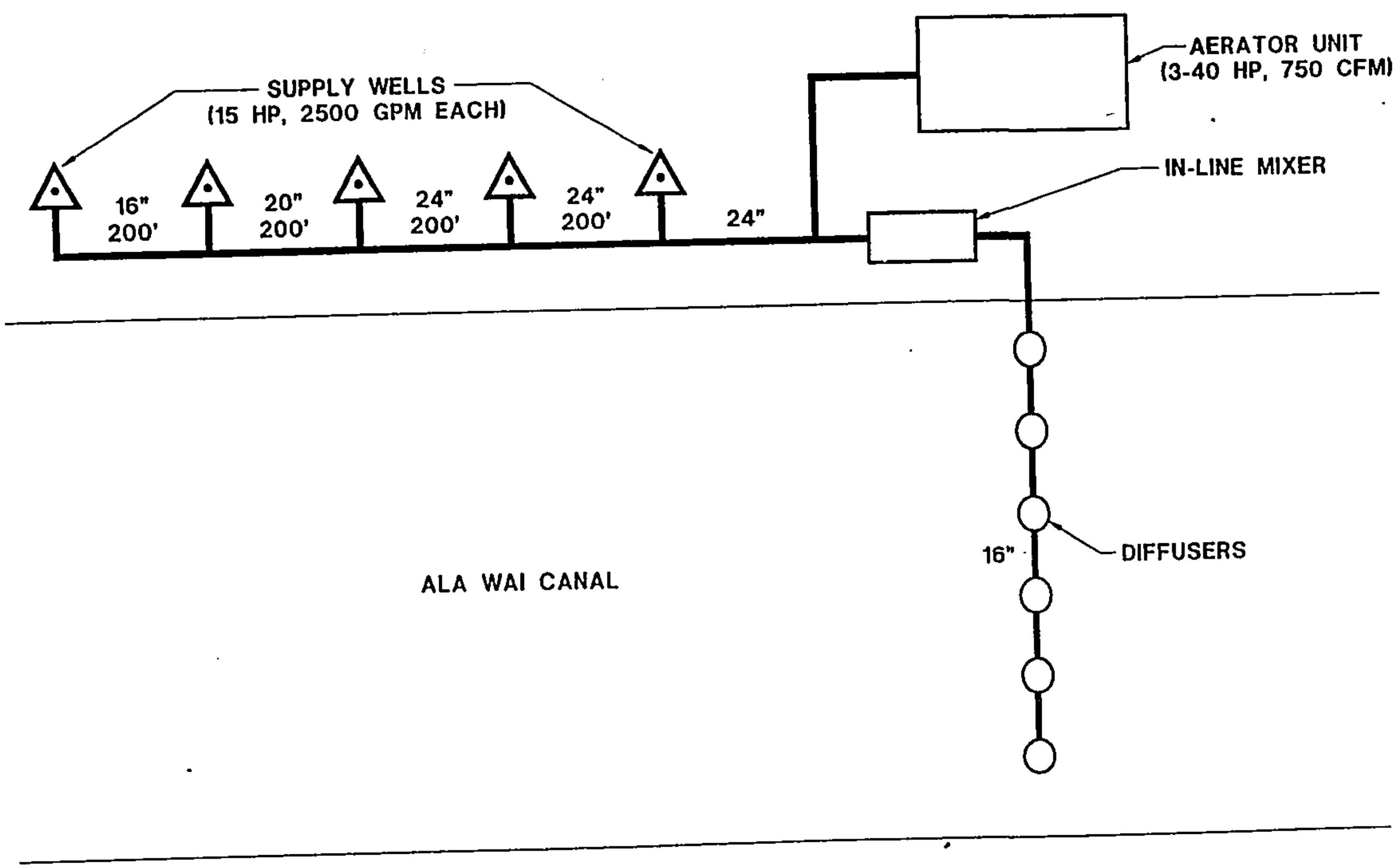
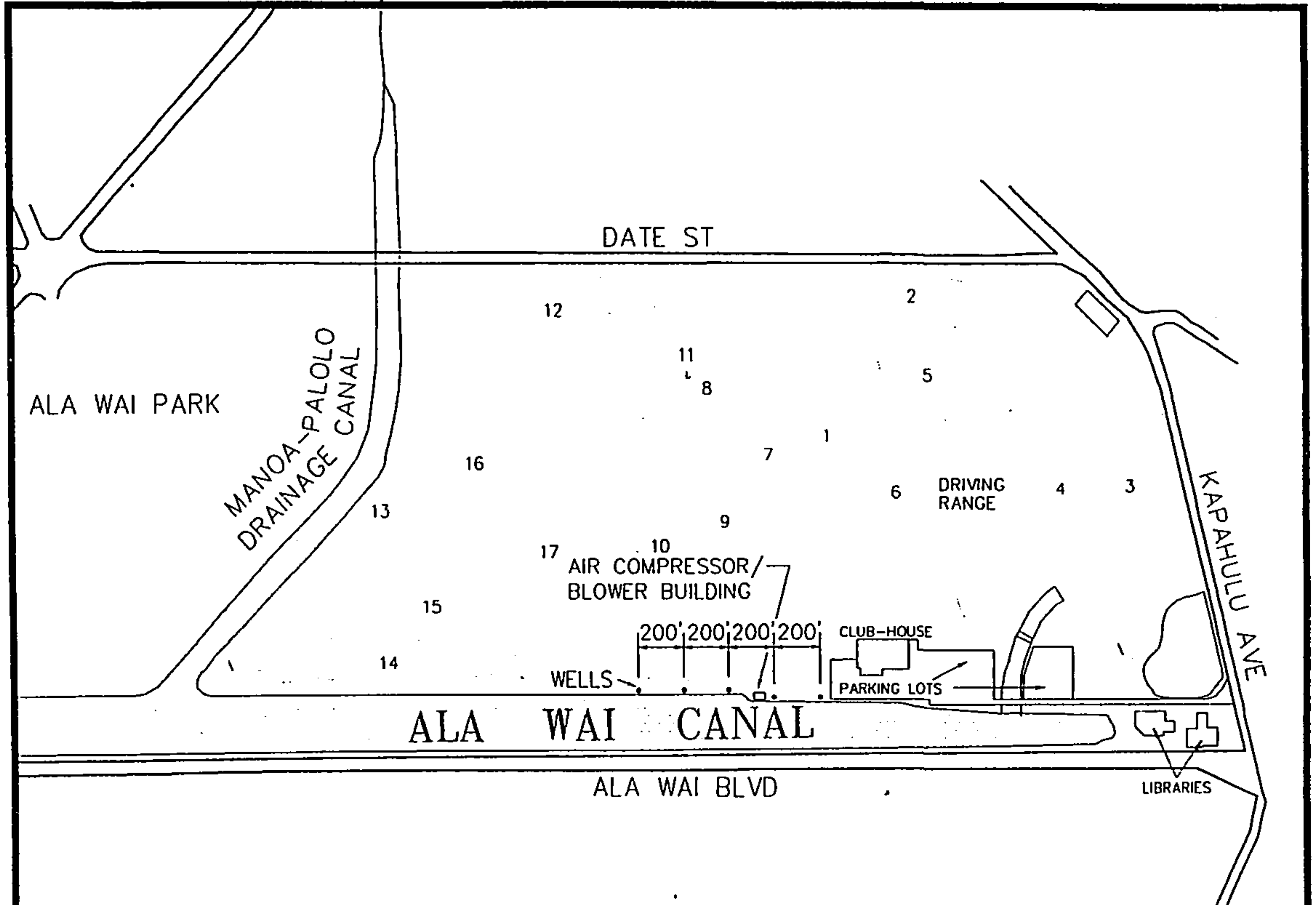


FIGURE 5-16

PROPELLER PUMPS, MECHANICAL AERATION, AND DIFFUSER DISCHARGE



ALA WAI CANAL IMPROVEMENT PROJECT	Edward K. Noda and Associates, Inc.	PROPOSED LOCATIONS OF THE FIVE 2500 GPM SALTWATER SUPPLY WELLS	FIGURE 5-17

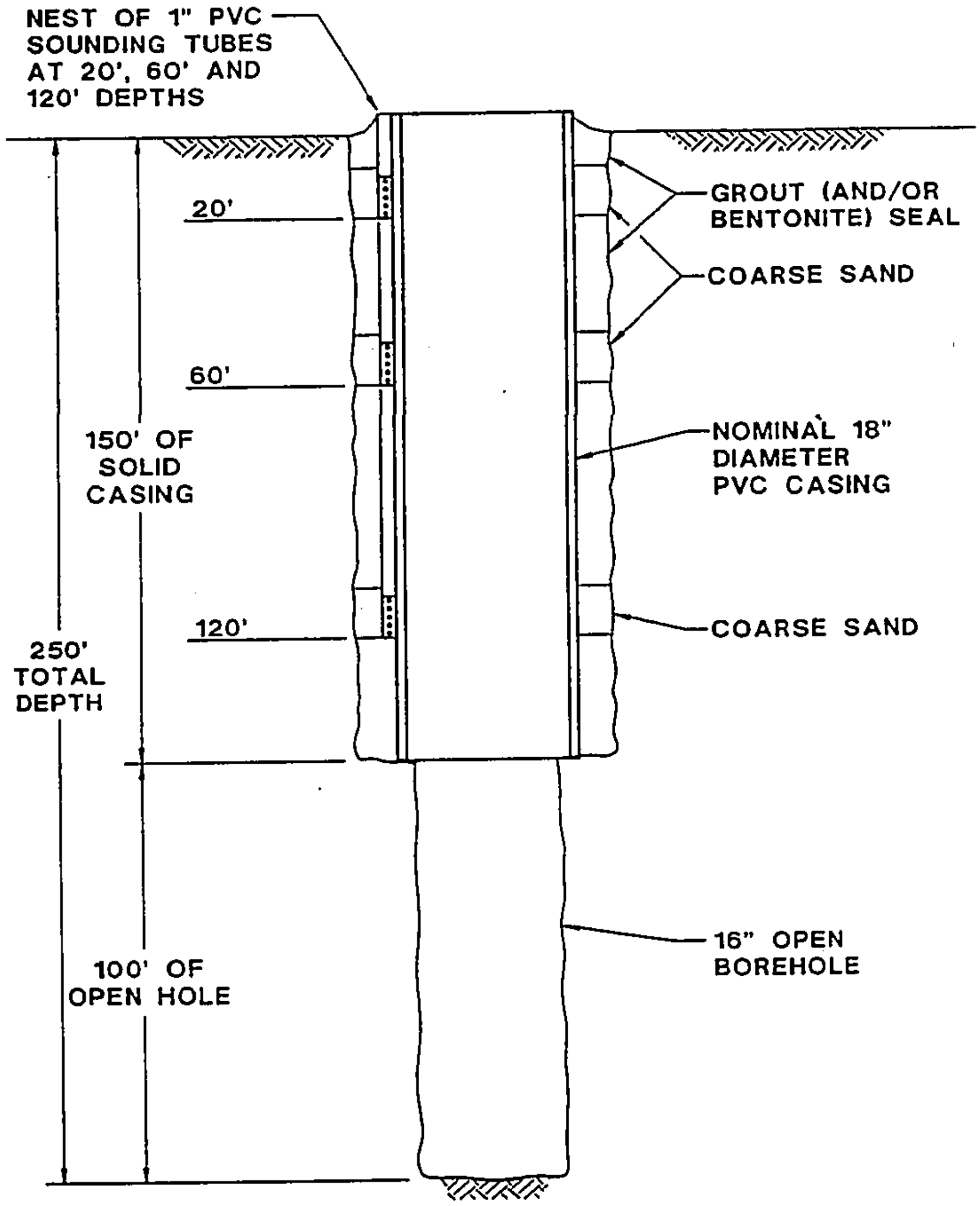


FIGURE 5-18

PROTOTYPE PRODUCTION WELL SCHEMATIC PROFILE

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layers to be measured, thereby demonstrating that pumping could occur without de-watering the overlying surficial lagoonal deposits.

In addition to the drilling and testing of a single prototype production well, 4 smaller diameter boreholes will also be drilled, to depths of about 250 ft, in order to confirm the subsurface geologic strata of the entire proposed groundwater source area at the Ala Wai Golf Course.

Finally, to confirm and insure that the proposed groundwater source waters have the necessary and required water quality characteristics to serve as flushing waters for the AWC, both water quality and toxicity tests will be performed. The water quality monitoring for the test well will consist of the periodic collection and analysis of water samples for constituents which are included in the State of Hawaii's water quality standards, other parameters of potential impact to biological responses, and potentially toxic heavy metals. The proposed parameters to be measured include:

Dissolved Oxygen
Ph
Salinity
Nitrate + Nitrite
Ammonium
Phosphate
Total Nitrogen
Total Phosphorus
Turbidity
Total Suspended Solids

Heavy metals to be measured include:

Aluminum	Lead
Arsenic	Magnesium
Barium	Manganese
Cadmium	Mercury
Chromium	Nickel
Copper	Selenium
Calcium	Silver
Iron	Zinc

Whole water bioassay tests will be performed utilizing larval fish, shrimp and sea urchin gametes as test organisms. Appropriate numbers and replicates of test organisms will be exposed to the groundwater source well water for periods of 96 hours for larval fish and shrimp, and for 1 hour for urchin gametes. The mortality of test organisms will be compared to that of test organisms exposed to sea water controls; parallel tests utilizing known concentrations of standard toxicants (sodium dodecyl sulfate and copper sulfate) will also be run.

Well water tests will be performed within one week after the start of the test well pumping, once at the mid-point of the test period, and once immediately before the end of the test period. The estimated cost of this prototype production well testing program is estimated to be about $300,000.

5.4. SUMMARY AND RECOMMENDATIONS

The following summarizes the conceptual design evaluation of the various candidate options and Table 5.1 provides a summary cost comparison of the three options.

TABLE 5.1
Summary of Cost Comparisons for the
Three Flushing Seawater Supply Alternatives

Alternative Description	Cost
Submerged Pipeline System Laid In The AWC	
Estimated Construction Cost	$ 8,471,500
Estimated Annual Operating & Maintenance Cost	$ 71,500
Directionally Drilled Pipeline System	
Estimated Construction Cost	$ 28,079,000
Estimated Annual Operating & Maintenance Cost	$ 55,000
Deep Groundwater Well Supply System	
Estimated Construction Cost	$ 3,324,000
Estimated Annual Operating & Maintenance Cost	$ 190,000

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1. One concept involves injecting seawater into the Kapahulu end of the Ala Wai Canal using an ocean seawater source intake, located near the entrance channel to the Ala Wai Boat Harbor, whereby the seawater is conveyed using a submerged pipeline in the Ala Wai Canal. The entire pipeline system would be about 16,500 foot long comprised of 40 and 42 inch diameter HDPE pipe and would include an intake manifold in a water depth of about 40 feet below the surface, a submerged pump station with 3 pumps located in the Ala Wai Boat Harbor adjacent to Magic Island, and a diffuser system at the Kapahulu end of the AWC. This conceptual design is technically feasible, involves minimal risks, and fabrication of the pipeline system and its deployment are considered to be relatively uncomplicated tasks.

   The estimated construction cost with a 15% contingency is about $8,471,500 and the annual operating and maintenance costs are estimated to be about $71,500.

2. A second concept of obtaining ocean seawater involves using a directionally drilled underground pipeline system between the Kapahulu end of the Ala Wai Canal to a location off Waikiki Beach in a water depth of 40 feet. The 7,000 ft long hole, which and would be drilled to a large diameter for installation of a 40 to 42 inch diameter steel pipeline, is basically beyond the current state-of-the-art. If constructed, this pipeline would be the longest and largest diameter hole drilled in the world, using directional drilling technology.

   Significant risks are associated with this directionally drilled pipeline concept as follows:

   - The quality of the subsurface soil along the drilling path is not known in detail. The presence of unconsolidated, non self-supporting soils along the drill route would considerably increase the risk and cost of the drilling operations.

   - There is the potential that bentonite mud drilling fluid would not be allowed in the drilling operations due to environmental concerns and fear that the fluid may leak into the nearshore waters of Waikiki Beach. The use of a more "environmentally acceptable" drilling fluid would increase the risks and costs of the operations.

The preliminary construction cost estimate for the directionally drilled pipeline system including a 20% contingency factor is about $28,079,000 with an annual estimated operations and maintenance cost of about $55,000.

3. A third concept of obtaining a seawater supply involves drilling deep groundwater wells located at the Ala Wai Golf Course. The limited information on the subsurface geologic strata indicates that the prospects for successful development of saltwater wells along the mauka side of the east end of the Ala Wai Canal are reasonably good. These groundwater wells would draw water from coral layers lying below later stage volcanics or deeper coralline mud layers, thereby minimizing the risk of dewatering the surficial lagoonal deposits with its attendant subsidence problems. In all likelihood, aeration of the deep saline water would be necessary but no other treatment would be required.

The conceptual design for construction cost estimating purposes consists of five 200 foot deep wells with the upper 130 feet comprised of an 18 inch diameter solid casing pipe grouted in-place and the remaining 70 feet of open hole. Each well has been designed to deliver 2,500 gpm and the wells have been spaced 200 feet apart. A central aeration system has been included to increase the dissolved oxygen concentration of the saline water from an expected 0 to 5.0 mg/liter. The aerated saltwater would then be discharged into a diffuser system across the Canal width.

The estimated construction cost estimate for the deep groundwater wells with a 20% contingency is about $3,324,000 and the annual operating and maintenance costs are expected to be about $190,000.

In order to proceed further with the technical feasibility evaluation of the deep groundwater well supply concept, a prototype production well drilling and evaluation program will be necessary. The proposed prototype production test well would be drilled to a depth of about 250 feet or greater, the upper section of the hole would be cased, sounding tubes would be installed in the annular space at various depths to test for de-watering of the upper layers, and full scale pumping tests would be conducted.

In addition to the prototype production well, 4 small diameter boreholes will be drilled to depths of about 250 ft or greater, in order to provide subsurface geologic strata data on the entire proposed groundwater source area at the Ala Wai Golf Course.

Finally, to insure that the necessary and required water quality characteristics are available from the deep groundwater source, extensive water quality testing, including toxicity tests will be carried out. The estimated cost for the prototype production well drilling and testing program is about $300,000.

Based on the above conceptual design evaluations, the following recommendations are provided.

1. Due to the significant cost difference between the deep groundwater well supply concept and the laying of a submerged pipeline in the Ala Wai Canal, it is recommended that a Prototype Production Well Drilling And Testing Program be implemented in order to verify the subsurface geologic strata and water quality, determine the flow rate capability of the proposed wells, and evaluate potential impacts of the deep well concept.

2. If the well testing and evaluation program confirm the technical and environmental feasibility of the deep groundwater well concept, then it is recommended that an up-date and revision of the conceptual design and construction cost estimate for the saltwater well supply be performed. This up-dated construction cost estimate can then be evaluated for future implementation.

3. If the well testing program indicates that the deep groundwater well supply concept is not feasible, then it is recommended that the Alternative No. 1 submerged pipeline system in the Ala Wai Canal be considered for implementation.

CHAPTER 6.0

ENVIRONMENTAL IMPACT EVALUATIONS

CHAPTER 6
ENVIRONMENTAL IMPACT EVALUATIONS

6.1. INTRODUCTION

This chapter provides an evaluation of the environmental impacts associated with both the proposed deep groundwater well concept, and the submerged pipeline system constructed in the Ala Wai Canal with an intake in the entrance channel to the Ala Wai Boat Harbor. While the deep groundwater well system is the preferred alternative primarily based on its low estimated construction cost versus the submerged pipeline system, should this concept prove to be infeasible during a proposed prototype production well drilling and testing program, the alternate submerged pipeline system would then become the recommended alternative. The probable impacts common to both alternative concepts are discussed first, followed by discussions of impacts specific to each concept plan.

6.2. ENVIRONMENTAL IMPACTS COMMON TO BOTH PROPOSED SYSTEMS

One of the necessary criteria for the deep groundwater well system is that the supply water should have the same general characteristics as coastal seawater. Based on this criterion, the water quality impacts due to both proposed flushing water systems for the Ala Wai Canal are identical.

Chlorophyll Concentrations: The existing chlorophyll concentrations in the AWC, as generally represented by the Base Case 2-D model results, have maximum values that typically range to about 50 μg/l, with the worst concentrations existing at the Kapahulu end of the Canal which range from 50 - 30 μg/l varying from the surface to the bottom respectively. Field measured dissolved oxygen concentrations are generally in the 5 mg/l range throughout most of Canal waters except in the lower layers of the Inner Basin, the region between the confluence of the Manoa-Palolo Stream and the end of the Canal, and at the Kapahulu end of the Canal. In the bottom layer of the Inner Basin the dissolved oxygen concentration are about 1 mg/l.

The proposed injection of 20 cfs seawater into the Kapahulu end of the AWC will decrease the chlorophyll concentrations from present conditions, to maximum concentrations ranging from 3.5 - 6.5 μg/l, with the Kapahulu end of the Canal yielding chlorophyll concentrations between 6.5 to 0.2 varying from the surface to the bottom, respectively. If the maximum seawater inflow rate of 30 cfs is utilized, the maximum chlorophyll concentrations would typically range from 1 - 2 μg/l, with the Kapahulu end of the Canal having chlorophyll concentrations between 2.0 to 0.2 µg/l varying from the surface to the bottom, respectively. This reduction in chlorophyll concentration will result in improved water quality and water clarity.

Dissolved Oxygen Concentrations: Dissolved oxygen concentrations will improve when 20 cfs of seawater is injected into the Kapahulu end of the AWC. In the present situation, the dissolved oxygen concentrations in the Canal are typically in the 5 mg/l range, except in the bottom layers of the Inner Basin with concentration of about 1 mg/l and at the Kapahulu end of the AWC shows concentrations of 1-3 mg/l. When a 20 cfs seawater flushing water inflow is provided, the variations throughout most of the Canal waters are relatively small when compared to the existing conditions (Base Case), but the improvement in the Inner Basin and at the Kapahulu end of the AWC are more significant. In general, the dissolved oxygen concentrations in the Inner Basin and at the Kapahulu end of the Canal typically range between 4 - 6 mg/l, with no significant decrease in the lower layers. The dissolved oxygen concentrations for a 30 cfs seawater inflow are very similar to the 20 cfs seawater inflow case. The more dense seawater effectively flushes the bottom layers, thereby improving its water quality characteristics.

Water Clarity: During typical conditions in the Ala Wai Canal, when no significant rainfall events occur, the water clarity in the Canal waters is primarily determined by the water column chlorophyll concentrations. Under present conditions with typical maximum chlorophyll concentrations of 30 - 50 µg/l, the depth that a solid colored white object (Secchi Disk) can be visually seen is about 6 - 4 feet respectively. In the case of the Ala Wai Canal, since the bottom is dark in color, the ability to see the Canal bottom is reduced from these standard Secchi Disk values.

With reduced chlorophyll concentrations of the order of 5 µg/l as are expected to be produced for a 20 cfs seawater injection rate, the depth at which the Secchi Disk can be visually seen are expected to be on the order of 11 - 12 feet, or about 2 to 3 times the water clarity that presently exists in the Canal. For a 30 cfs seawater inflow rate, the expected chlorophyll concentrations of 1 - 2 µg/l convert to Secchi Disk distances of the order of 13 feet. Thus, it is expected that water clarity conditions will improve significantly.

Improvement in water clarity will provide a greater opportunity to see the bottom of the Ala Wai Canal. Since the Canal bottom is a repository of debris and trash accumulated over decades, this new view of the Canal bottom will probably be unsightly. This unattractive view will likely prompt concerned citizens to complain about this situation. Therefore, an active maintenance program of bottom debris removal and dredging

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should be implemented as recommended in the "Maintenance Plan for the Ala Wai Canal".

Odor: The injection of flushing seawater will generally not have any immediate impact on odor from the Ala Wai Canal waters. The odor associated with the Canal are primarily caused by hydrogen sulfide generated in the bottom sediments due to anoxic conditions. When these bottom sediments are disturbed during stormwater discharges or during dredging operations, temporary odor problems may occur. On the other hand, should the source of the odor come from suspended material in the water column, the reduced residence time of the Canal waters associated with the proposed flushing seawater system will tend to mitigate this odor problem.

In the long term, the continuously operated seawater flushing system will provide an improvement to the general odor problems of the Canal. With the expected significant reduction in phytoplankton growth, as evidenced by reduced chlorophyll concentrations, there would be less organic detritus materials which would settle on the bottom, thereby reducing the potential for hydrogen sulfide generation. When maintenance dredging of the Canal is combined with the seawater flushing effects, the potential to significantly improve the odor problems of the Canal are excellent.

Water Quality Impacts To The Boat Harbor And Ocean: While the 20 - 30 cfs seawater injection rates into the Kapahulu end of the Ala Wai Canal will improve the water quality conditions within the Canal and in the main channel between the Ala Moana Bridge and the ocean entrance channel, there would be only small change in the water quality conditions in the Ala Wai Boat Harbor vessel mooring areas. For example, the existing chlorophyll concentrations at a representative harbor location vary from 5.5 - 0.9 μg/l from the top to bottom layers, respectively, and the 20 cfs seawater flushing water inflow rate will change these values to 3.5 - 0.9 μg/l from the top to bottom layers, respectively. In general, the water quality of the bottom layers of the Ala Wai Boat Harbor is controlled by the circulation of the more dense ocean water, while the surface layer is controlled by the less dense Ala Wai Canal waters. Consequently, improvements in the Canal water quality only affects the upper layers of the Ala Wai Boat Harbor waters. In general, improvements in the Ala Wai Canal water quality improves the water quality in the upper layers of the waters in the Ala Wai Boat Harbor.

The discharge of the waters from the Ala Wai Canal into the nearshore ocean receiving waters through the entrance channel to the Ala Wai Boat Harbor, will provide an improvement over existing conditions when flushing seawater is injected into the Kapahulu end of the Canal. In the present situation as represented by the Base Case, the maximum chlorophyll concentration at the ocean end of the Ala Wai Canal near the Ala Moana Bridge is about 12 μg/l in the surface layer. When a 20 cfs seawater inflow rate is provided, the surface layer chlorophyll concentration is reduced to about 3.5 μg/l at this same location. Thus, the clarity of the discharging flow into the ocean receiving waters would be better when flushing water is provided. At the Ala Moana Bridge location, the 12 and 3.5 μg/l concentrations convert to Secchi Disk depths of approximately 9.4 and 11.8 feet respectively.

Beside the improved clarity of the discharging Canal water into the ocean receiving waters due to the seawater flushing system, the dissolved nutrient levels within the discharging waters will be higher than present conditions, since less opportunity has been provided for phytoplankton growth to uptake the nutrients. The large volume of ocean receiving waters are easily able to assimilate this additional nutrient load and there would be no biological consequences due to this added nutrient discharge.

Bacteria: In general, bacteria which enters the Ala Wai Canal does not grow within the Canal waters, but instead undergoes dieoff. Bacteria dieoff is very sensitive to water salinity, where the dieoff rate is much higher in a seawater environment than in fresh water. Bacteria dieoff rates are usually described by the time that it takes for 90% of the bacteria to die from its initial value, designated T_{90}. For example, coliform bacteria dieoff rates, T_{90}, in seawater are of the order of 15 - 60 minutes. In fresh water, coliform dieoff rates are estimated to be of the order of 24 hours. Consequently, bacteria concentration measurements in the Ala Wai Canal consistently show a significant decrease with distance below the surface, particularly between the brackish surface layer and the lower near-seawater layers.

Bacteria concentrations in the Ala Wai Canal will improve from their present conditions when the 20 - 30 cfs seawater inflow is injected into the Kapahulu end of the Canal. The injected seawater and its consequent circulation will induce vertical mixing, thereby increasing the salinity in the upper layers with its attendant biocidal effects. Moreover, the flushing seawater inflow will reduce the residence time of the waters in the entire Canal, and more rapidly transport the upper layers into the ocean receiving waters where the high salinity concentrations will promote rapid dieoff.

Hydraulic Capacity: The existing bathymetry of the Ala Wai Canal has insufficient capacity to handle the 100-year peak discharge flow of about 28,900 cfs due to rainfall runoff. At present, without maintenance dredging of the sill area between the McCully Bridge and the confluence of the Manoa-Palolo Stream, the carrying capacity of the AWC is about 12,700 cfs based on the average height of the makai bank of the Canal.

Even with the dredging of the sill area to -10 feet MLLW, the carrying capacity of the Canal is not greatly improved since the flow capacity is restricted by the narrow width of the channel between the McCully Bridge and the Ala Moana Bridge. Preliminary analysis indicates that the Ala Wai Canal would need to be dredged to about -20 feet MLLW in order to handle the 100-year peak flow discharge.

The proposed flushing seawater systems will have minimal circulation flow influence during any significant rainfall runoff discharges into the Ala Wai Canal. The 20 - 30 cfs is an insignificant additional flow when compared to even small rainfall runoff events which vary annually from typically 100 cfs to 4,000 cfs. The present suspended solids material which inflows into the Canal due to stormwater runoff, and which does not deposit in the Canal, produces significant turbidity and poor water clarity both in the Canal and in the Ala Wai Boat Harbor, and in the nearshore receiving ocean waters. This situation would not be changed by the addition of the minuscule 20 - 30 cfs flushing seawater inflow.

Water Quality Impacts During Significant Rainfall-Discharge Events: While the circulation flow physical effects are minimal during a significant discharge flow event, the water quality consequences are more significant. Table 6.1 describes the chlorophyll concentrations for the Base Case (existing conditions) including a 2,150 cfs stormwater discharge flow into the Ala Wai Canal, without and with the proposed 20 cfs seawater inflow at the Kapahulu end of the Canal. The 2,150 cfs stormwater discharge flow was arbitrarily selected as representing about a yearly return period peak stormwater discharge flow into the Ala Wai Canal.

Notice that for the BC plus 2,150 cfs stormwater discharge, the chlorophyll concentrations are all very low throughout the Canal except in the lower layers of the Inner Basin where they are very high reaching levels of about 150 μg/l. In this situation the less dense fresh water flow layer isolates the lower layers of the Inner Basin, due both to the vertical cap and due to the inability of ocean waters to flow into the Canal in the bottom layers. The result is an increase in the residence time of the waters in the lower layers of the Inner Basin, and consequent increase in chlorophyll concentrations and reduction in dissolved oxygen. When the 20 cfs seawater inflow is added to the BC plus 2,150 cfs stormwater inflow, Table 6.1 indicates that the chlorophyll concentrations in the lower layers of the Inner Basin improve to 90 - 100 μg/l. These chlorophyll concentration results should be viewed as qualitative indications of the water quality effects since the 2-D model results are associated with steady-state, equilibrium conditions, and the 2,150 cfs stormwater inflow rate is not expected to last for many days. In general, the flushing seawater inflow would have a small, beneficial water quality effect during significant stormwater discharges into the Ala Wai Canal.

TABLE 6.1

Chlorophyll Concentrations for Base Case with 2,150 cfs Storm Discharge with and without 20 cfs Seawater Inflow Condition

Description	Station Number								
	4	5	6	7	9	10	11	12	Harbor
BC With Storm Discharge (Total 2,150 cfs)									
TOP	0.12	0.10	0.14	0.14	0.12	0.13	0.16	0.74	0.55
MIDDLE	0.27	0.19	0.26	0.23	0.21	0.17	0.15	0.80	1.07
BOTTOM	0.71	0.25	0.33	0.40	7.17	148.8	157.5	0.18	0.74
MAX	0.71	0.25	0.33	0.40	7.17	148.8	157.5	0.80	1.24
BC With Storm Discharge & 20 cfs Seawater Inflow									
TOP	0.11	0.10	0.13	0.13	0.12	0.13	0.14	0.32	0.60
MIDDLE	0.25	0.17	0.22	0.19	0.17	0.15	0.14	0.19	1.08
BOTTOM	0.71	0.22	0.28	0.33	4.40	91.53	101.9	0.16	0.74
MAX	0.71	0.22	0.28	0.33	4.40	91.53	101.9	0.33	1.30

During significant stormwater discharge events, the flushing seawater inflow will have essentially no effect on the existing turbidity and water clarity of the discharges into the ocean receiving waters.

Discharge Manifold Velocity: For either flushing systems, the discharge waters from the diffuser system across the Kapahulu end of the Canal, would be designed to have a discharge exit flow velocity of about 4 ft/sec. This flow velocity would quickly dissipate (within about 25 - 50 feet from the diffuser) and the mean speed averaged across the cross-section would be imperceptible as described previously. The 4 ft/sec velocity is about equivalent to the discharge velocity from a typical 3/4 inch diameter water hose with the spigot fully opened, and consequently will not provide any danger to people or to vessel navigation.

Mean Water Velocity: The physical injection of 20 - 30 cfs seawater at the Kapahulu end of the AWC will have an insignificant effect on the mean water velocities in the Canal. In the area between the McCully Bridge and the Kapahulu end of the Canal where most

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of the canoe racing is performed, typical mean water speeds due to the maximum 30 cfs seawater inflow, increases by only 0.016 - 0.046 ft/sec (0.011 - 0.032 miles/hour). The maximum speed increases are in the area of the Sill due to the reduced cross-sectional area. These water current speed changes would essentially be imperceptible to the recreational users of the Canal. To place this current flow change in perspective, the maximum mean current flow speed increase of 0.032 miles per hour in the Sill area would be equivalent to the effects of a 1 mile per hour wind velocity blowing on the water surface.

Changes to Canal Configuration: It is noted that the new Waikiki Master Plan recommends creating a boat turning basin at the Kapahulu end of the Ala Wai Canal by incorporating a semi-circular waterway extension on the mauka end of the Canal. This Master Plan concept is compatible with the conceptual design of the diffuser discharge system. The discharge system can easily incorporate such changes in configuration of the Canal end section, while still performing its technical function. In this situation, the diffuser system would extend into the semi-circular turning basin, but located along the Kapahulu edge to minimize interference with vessel navigation. It is also possible to incorporate water fountains into the discharge system, which would promote both mixing and aeration of the injected water.

Hawaii and National Register of Historic Places: The Ala Wai Canal is presently being considered by the Hawaii Historic Places Review Board for nomination to the Hawaii and National Registers of Historic Places. The proposed deep groundwater well supply system or the submerged pipeline laid in the AWC to provide flushing waters at the Kapahulu end of the AWC, will not significantly impact the structural characteristics and features of the Canal, particularly the mauka and makai banks of the canal. At most, a small portion of the mauka bank would need to be excavated in order to construct the underwater diffuser system pipeline for the deep groundwater well system, or for the assembly and deployment of the discharge pipeline for the submerged pipeline system laid in the AWC, and upon completion of this construction, the bank would be re-built to its original design. Thus, no impacts associated with the nomination and possible acceptance of the Ala Wai Canal on the State and National Registers of Historic Places are envisioned.

6.3. IMPACTS SPECIFIC TO THE DEEP GROUNDWATER WELL SUPPLY SYSTEM

As part of the feasibility evaluations of the deep groundwater well system to provide saline water for flushing of the Ala Wai Canal, the subsurface geologic strata on the mauka side at the east end of the Canal was evaluated. The basis for an optimistic view of this concept is associated with the interpretation of the available deep drilled well data which show the potential for an impermeable layer (aquitard) to exist, which would restrict groundwater through-flow. The boring logs indicate the this aquitard, comprised of a later-stage volcanic layer, underlies the entire east end of the Canal and is located at depths of 80 to 120 feet below the ground surface with thicknesses of typically 50 to 80 feet. If this is the case, then the aquitard would provide effective vertical hydraulic separation between the pumped saline waters and the brackish groundwater. The saline in-flowing waters which make-up for the withdrawn waters would flow horizontally within the lower coral layers. The aquitard would also minimize dewatering of the surficial lagoonal deposits and thereby prevent any localized subsidence which could cause damage to structures and property.

The potential for subsidence due to dewatering and its effect on structures will also be minimized since the deep groundwater wells are proposed to be located on the Ala Wai Golf Course, and would be situated away from major building structures.

In addition, a calcareous mud layer also appears below the later-stage volcanic layer which could also function as an aquitard. On the Ewa Plane, a widespread calcareous mud layer at depth is currently being utilized as an aquitard, providing hydraulic separation of the overlying coral aquifer which is being used as a source of supply water, from an underlying coral aquifer which is used for disposal.

The proposed deep groundwater wells would be withdrawing water from an aquifer which is hardly used, and none of its uses occurs at the depth of pumpage proposed herein. Consequently, the proposed groundwater well supply system will not adversely affect any existing groundwater wells, whether potable or irrigation water.

The option to utilize a deep groundwater well system to supply flushing water for the Ala Wai Canal will need to be further evaluated through a Prototype Production Well Drilling And Evaluation Program. The objectives of this test program are to confirm the existence of the aquitard layer, test and insure that adequate flow rates can be produced without adverse effects, and verify the adequate water quality of the expected saline groundwater. Should any of the test results and evaluations indicate that this concept is not feasible based on the above-described criteria, then it is recommended that the alternate submerged pipeline system in the Ala Wai Canal be considered.

There would be some noise generated during the drilling of the deep groundwater wells, installation of the well casings and pumps, construction of the interconnecting underground pipelines, construction of the aeration system, and deployment of the diffuser system across the Canal width. The construction generated noise would be temporary, and since the entire system is expected to be constructed in open area, away from building structures, the construction noise impacts are expected to be minimal.

During operations, some noise is expected from the well and aeration pumps, but these pump noise levels would be reduced by acoustic containment in order to meet Department of Health noise regulations.

As part of the deep groundwater well supply system construction, the Kapahulu end of the Ala Wai Canal should be dredged to -6 feet MSL to provide a smooth transition for the discharging flushing waters. This dredging was a proposed option during the design of the 1977-1978 maintenance dredging project, but due to lack of funds this option was not implemented. It is recommended that during the next maintenance dredging of the Ala Wai Canal, that the Kapahulu end of the Canal also be dredged. If this is not performed as part of the maintenance dredging for the Canal, then the dredging of the Kapahulu end of the Canal would be performed during the construction of the deep groundwater well supply system.

It is estimated that about 5,000 yd^3 of material would be dredged from the last 400 feet of the Canal. Due to the small volume of material, it is likely that land disposal of the dredged spoil would be more cost-effective than ocean disposal. The expected dredging activities would include the hydraulic dredging and pumping to a de-watering site either at the contractor's work area or in an isolated part of the Canal. After sufficient de-watering to facilitate handling, the spoil would be loaded into trucks for transport to the landfill site. Potential environmental impacts include odor problems in the de-watering area, visual and noise effects, traffic interference due to truck traffic, and the use of landfill capacity which is a scarce commodity on Oahu. Between the end of the Ala Wai Canal and Kapahulu Avenue are located the Library for the Blind & Physically Handicapped and the Waikiki-Kapahulu Public Library. Noise levels in these areas will meet Department of Health noise regulations. The Thomas Jefferson Elementary School is located across the Ala Wai Boulevard and the Diamond Head School is located across Kapahulu Avenue. These two schools should not be affected by the dredging activities. The estimated time period for this dredging activity is about 2 weeks.

The construction of the diffuser discharge system across the Kapahulu end of the Ala Wai Canal will impact the existing benthic community structure. Since the Ala Wai Canal waters and bottom are a highly impacted area due to stormwater discharges with their attendant sedimentary loads, debris, and trash which deposits on the entire Canal bottom, the impact of the diffuser system construction will be insignificant.

6.4. IMPACTS SPECIFIC TO THE SUBMERGED PIPELINE SYSTEM IN THE ALA WAI CANAL

The proposed submerged pipeline system to discharge flushing seawater at the Kapahulu end of the Ala Wai Canal consists of an intake structure located of about 40 feet below the surface; 4,000 feet of 40 inch diameter high density polyethylene (HDPE) suction pipeline laid on the ocean bottom; a submerged 3-pump station adjacent to Magic Island with the top of the station 2 feet below the water surface; a 12,500 foot long, 42 inch diameter HDPE discharge pipeline extending from the submerged pump station to the Kapahulu end of the Canal, which is typically partially buried and routed on the mauka side of the Canal near the mauka bank; and an 80 foot long, 28 inch diameter HDPE pipeline discharge manifold located laterally across the width at the Kapahulu end of the Canal, placed on the bottom and secured with concrete collar weights.

Intake Structure And Pipeline: The intake structure will be placed on the west side of the Ala Wai Boat Harbor entrance channel. Two intake suction manifolds consisting of 36 inch diameter pipe sections will be elevated between 9 - 15 feet off the bottom in order to minimize the entrainment of bottom sand. A total of 360 3-inch diameter holes will be drilled into each suction manifold, yielding maximum (at 30 cfs inflow) intake velocities of less than 1 ft/sec. This maximum intake velocity together with the horizontal intake flow direction will minimize the suction of marine life and ensure that there would be no danger to divers. It is known that fish are sensitive to horizontal velocities and can sense and escape from this flow. But they are insensitive to vertical velocities and can easily be sucked into an intake if the intake flow was directed downward.

The highest point of the intake manifold structure would be about 40 feet below the surface, which is much deeper than the maximum draft of vessels that navigate in the area and into the Ala Wai Boat Harbor, and thus poses no danger to vessel navigation.

Both field measurements and analysis indicate that short-circuiting of the intake water with the exiting Ala Wai Canal and Boat Harbor waters would not be a problem. The flow layers are stratified in the area of the intake structure, with seawater comprising a major part of the lower water column and the less dense Canal and Harbor waters confined to the upper surface layers.

The intake manifold structure and the suction pipeline will be supported by hold down brackets which will elevate the bottom of the pipeline about 1 - 2 feet off the ocean bottom with a minimum clearance of 10 - 14 inches. The hold down brackets will be the only structure attached to the bottom, with 1-1/4 inch diameter holes drilled about 12 inches into the bottom and secured with 1 inch diameter grouted bolts (all thread rod) to firmly attach the hold down brackets to the ocean floor. A total of 360 hold down brackets will be used over the 4,000 feet of suction pipeline and it is estimated that 45 days of work by a two-man dive team will be required to install all the brackets. Thus, the impact to the marine benthic community will be minimal since the cumulative foot print of the hold down brackets on the ocean bottom is very small. Moreover, the navigation channel bottom area is a highly impacted zone, being originally constructed by dredging and influenced by significant vessel traffic. Thus, the impacts to both the benthic and reef fish community will be minimal.

The intake structure and suction pipeline system have been designed to withstand the 100-year design hurricane wave event. Consequently, it is expected that anchors deployed from the typical types of vessels that navigate in the area, should they snag onto the intake structure or pipeline, will not cause any damage to these systems.

Submerged Pump Station: The proposed location of the submerged pump station has been selected after a diving and nearshore reconnaissance survey. In order to decrease the installation costs and facilities maintenance operations, the selected site is close to the primary electrical power lines (located at Ala Moana Park, near the corner of Ala Moana Boulevard and Ala Moana Park Drive), with a consequent least cost for running the 3-phase power lines to the pumps. In addition, the predominant soil conditions at the proposed location are mainly coral and rubble which can be easily removed for installation of the pump station, instead of solid rock formations found towards the exit of the navigation channel, near the end of Magic Island. Moreover, access for cranes and heavy equipment to maintain and service the pumps becomes more available as the pump station is located closer to the main road.

The design of the subsurface pump station will minimize both the visual impacts to the Magic Island area and considerably reduce and minimize the noise associated with pump operations.

The submerged pump station has been designed to incorporate 3 identical pumps. One pump would supply the nominal 20 cfs flow rate and, if necessary, a second pump could be initiated which would provide a nominal 30 cfs of seawater inflow. The third pump has been provided as a backup pump and would also be used when other pumps are being maintained and serviced. This pump redundancy provides assurance that the flushing system will provide continuous service. It is expected that a once-per-year maintenance program will be required for each operating pump, and major overhaul is envisioned every 4 years of operation.

Discharge Pipeline: The 12,500 foot long discharge pipeline will convey water from the submerged pump station to the discharge manifold at the Kapahulu end of the Canal. The proposed route of the pipeline is on the mauka side of the Canal, located between 15 - 35 feet from the mauka bank, and will typically be partially buried or simply laid on the bottom in order to minimize the risk of undermining the existing mauka wall, and to reduce dredging costs.

The proposed discharge pipeline route will not interfere with the existing utility crossings that are buried in the Canal (electric power conduits and sewer siphons). Moreover, the flushing water pipeline will not be affected by future maintenance dredging of the Canal, which in the past has been confined to the central area starting at about 40 feet from either side walls. This dredging design was implemented to minimize the possibility of undermining the mauka and makai bank walls.

Concrete weights, 1 ton wet weight, typically spaced about 16 feet apart, are attached to the discharge pipeline to insure that the pipeline partially sinks into the bottom soil and to provide stability along the natural bottom slopes. In the areas where the pipeline is completely buried, the concrete anchor weights are spaced at 8 foot intervals. The design also provides for the future moving of sections of the pipeline, where flanged ends have been periodically incorporated. This allows pipe sections to be capped, floated by filling with air, and moved to a new location and submerged again. The concrete weights attached to the pipeline only represent about 20 - 25% of the total buoyancy of the pipe when filled with air.

To minimize the visual impacts, the discharge pipeline will be constructed so that the minimum depth from the water surface to the top of the pipeline is 3 feet, with a minimum clearance of 2.5 feet between the top of the concrete weights and the water surface. While the pipeline can probably be seen from the mauka bank, it would generally be unseen from other locations, particularly from the makai wall.

When the discharge pipeline crosses the Manoa-Palolo and Makiki Stream outlets, the pipeline will be buried such that the top of the pipeline is a minimum of -13 feet MLLW. This allows for maintenance dredging of these areas to depths of -10 feet MLLW. In the area between the Ala Moana Bridge and the submerged pump station, crossing the navigation channel, the discharge pipeline will be buried about 3 ft below the bottom.

Dredging For The Discharge Pipeline: Significant dredging will be required to partially and fully bury the discharge pipeline. It is estimated that about 50,000 yd^3 of sedimentary material would need to be removed. Based on this dredged spoil volume, the most likely scenario for disposal would be ocean disposal at the Environmental Protection Agency (EPA) designated site located about 5 miles from the Ala Wai Boat Harbor. The EPA disposal area is described by a circle, with a radius of 1,000 yds and a center point located at 21°14'19" North Latitude and 157°54'20" West Longitude.

The envisioned dredging operations would involve hydraulic suction dredging, where a rotating cutting head would dislodge the bottom sediments and create a water-sediment slurry which would be drawn into the suction line thereby reducing water turbidity impacts. Due to the low vertical clearances and small horizontal widths associated with the various bridge structures that cross the Canal, it is not possible to use barges to transport the dredged spoil from the dredging site to the ocean disposal site. Thus, as performed during past maintenance dredging operations, a pump (8-10 inch) located on a floating barge would discharge the slurry through a long pressure pipe (10 - 12 inches diameter) into a hopper barge located at a temporary mooring in the Ala Wai Boat Harbor adjacent to Magic Island. Due to the length of this floating discharge pipeline, booster pumps may be required.

The slurry would be pumped directly into the hopper barge and silt curtains would be installed around the barge to mitigate and control any excessive spillage of slurry water into the Harbor. The dredged spoil loaded barges would be towed by tugboats to the designated EPA disposal site for disposal.

Based on past maintenance dredging projects, it is expected that large-size objects (car bodies, sofas, beds, refrigerators, trees, etc.) which are not able to pass through the slurry handling system would need to be removed by other means such as cranes. These large objects would need to be temporarily placed in the contractor's work area, de-watered if necessary, and transported to a landfill for disposal. There is the potential that odor problems would occur due to this temporary storage and de-watering of large objects, as well as visual impacts. The envisioned contractor's work area would be between Ala Wai Elementary School and the Ala Wai Canal and the Manoa-Palolo Stream. The contractor's work area will be fenced off during the construction period for security and safety reasons. Noise levels during the dredging operations will meet Department of Health noise regulations. The estimated dredging period is about 5 - 6 months.

Discharge Manifold: The discharge manifold located at the Kapahulu end of the Canal will evenly distribute seawater across the Canal width. The manifold has been designed as a simple L shape consisting of a 28 inch HDPE pipe sitting on or near the bottom. Concrete weights have been distributed along the discharge manifold to keep it in place. A total of 32 5.5-inch diameter holes, located 60° from the horizontal plane passing through the pipe centerline, are equally spaced along the manifold to evenly distribute flow and to reduce the flow velocity. The discharge manifold is made out of two, 40 foot long sections of pipe flanged together to facilitate maintenance operations. The pipe and concrete weights will be placed in a water depth of 6 feet to provide minimum clearance between the pipe and water surface of 3 feet, and 2.5 feet clearance between the top of the concrete weights and the surface. These clearances will minimize interference with existing boat traffic, canoe racing, and kayaking activities.

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