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BASELINE SURVEY OF AQUATIC BIOTA AND WATER QUALITY CHARACTERISTICS OF THE ANCHIALINE PONDS AT KALAHUIPUAA, HAWAII

Prepared for:
MAUNA LANI RESORT, INC.
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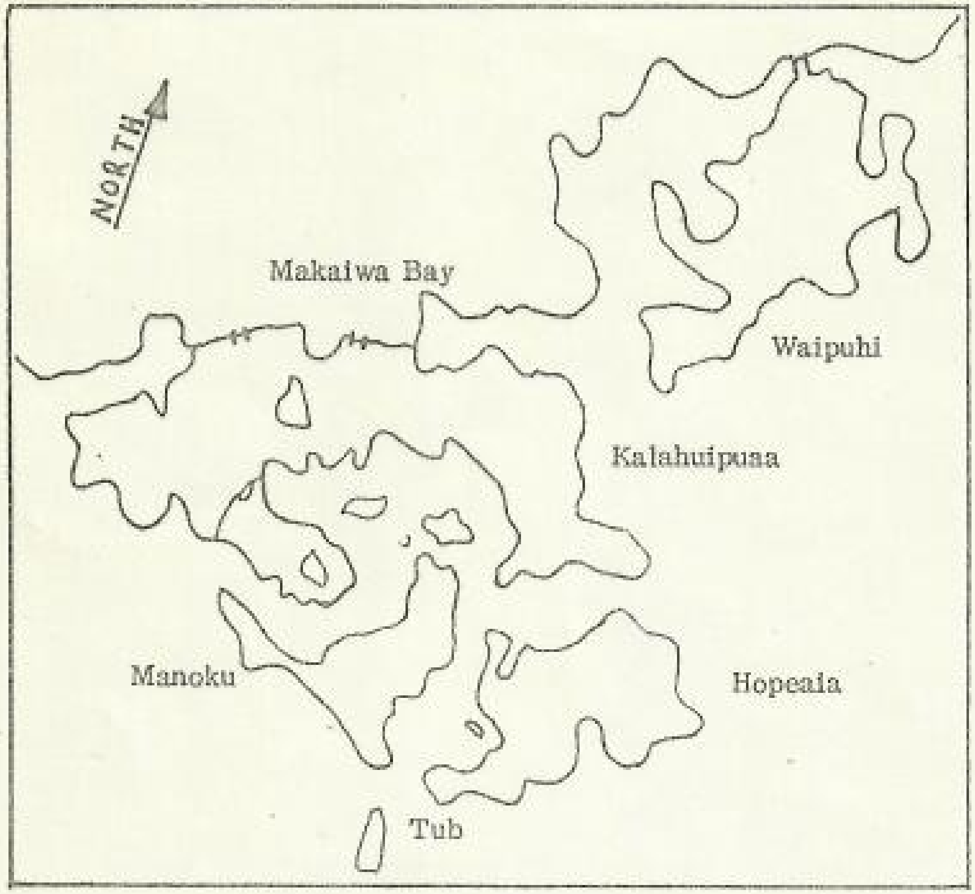

Figure 1. Reference Map of Ponds

I. INTRODUCTION

This report presents the results of a year-long survey of the anchialine fishponds at Kalahuipuaa, Hawaii. The purpose of this study was to collect data which would describe the biological, chemical, and physical conditions of the major ponds to serve as baseline, predevelopment reference material and to be used to determine the best strategy which would restore and maintain the ponds in a healthy and attractive state.

The five ponds examined in this study are shown in Figure 1. The small, concrete-bordered mauka pool, designated "the Tub", is representative of the more than 20 small pools on the property that provide habitat for the very distinctive endemic opae'ula and other crustaceans and molluscs. Hopeaia and Manoku are fishponds that were formed in natural depressions in the lava that extend down into the water table. They are termed "closed" ponds because they have no direct surface connection to the ocean. The larger fishponds, Kalahuipuaa and Waipuhi, were previously coastal embayments that were enclosed with permeable walls and makahas made of lava rock. In the 1930's and '40's these ponds were working aquaculture systems managed by traditional fish culture methods of the Hawaiians. Kalahuipuaa and Waipuhi are termed "open" ponds, having surface connections to the sea through the rock walls and makahas and contain marine reef species as well as the euryhaline fauna found in all the fishponds. The ponds collectively represent a unique class of ecosystems described as "anchialine" from the Greek term "anchialos," meaning near the sea.

The anchialine biotope is an oasis set in prehistoric (Ka'u Volcanic Series), low elevation pahoehoe lava that flowed from Mauna Loa volcano less than 10,000 years ago. The Kaniku lava flow, which surrounds the back sides of the ponds, is more recent, though still prehistoric, and is comprised of a'a lava. This topography makes the ponds irregular in shape and bottom configuration. They have rocky basins covered by various thicknesses of soft, fine sediment and are filled with mixohaline water. The hydraulic behavior within the ponds is controlled by subterraneous lateral transport of tidal seawater and basal groundwater through interstices in the lava.

Perennial streams are lacking in the vast expanses of barren, porous lava that comprises the Kona coast. The climate at Kalahuipuaa is hot and dry, with rainfall averaging less than 10 inches per year. Orographic winds are most common resulting in gentle onshore breezes during the day and switching to offshore breezes at night when the land loses heat and the warmer seas pull wind offshore.

During the past year, observations of biological and environmental characteristics provided baseline information for a better understanding of anchialine pond ecology and the response of these aquatic systems to adjacent development activities.

In general, the ponds were found to be highly productive and attractive ecosystems which support large communities of aquatic flora and fauna. Phytoplankton blooms fluctuate in density and diversity in a steady-state equilibrium, exploiting the natural resources of the environment. The vascular pondweed, *Ruppia maritima* colonizes areas in some of the ponds. Coconut and milo trees and halophytic groundwater plants surround the pond borders in the lava and coral substrate. The small pools contain benthic algal mats that are grazed upon by crustaceans and molluscs. Opae are ubiquitous. The large fishponds support rich populations of mullet, awa, papio/ulua, and aholehole. The coastal ponds contain reef species, including several large barracuda.

All the ponds appear to be in a steady-state condition with respect to physical parameters and hydrology. The water column is well oxygenated at all depths above the sediment layer. Nutrient concentrations have shown considerable increases over the last nine months, most likely due to nutrient enrichment from golf course fertilizers that have leached down through the porous lava into the ground water system.

Recommendations for fishpond restoration and management are presented. We strongly urge that an intensive clean-up (landscaping and dredging) and repair program be initiated to remove accumulated debris from in and around the ponds and to restore the walls and gates to working condition. We feel that the ponds today represent a beautifully rich environment and require minimal changes. If an intensive fish production system is adopted it must be accompanied with increased efforts in pond maintenance and water quality monitoring. We offer our suggestions as options to be evaluated in the overall planning process for Manua Lani Resort.

II. SCOPE OF SURVEY

This study included inspection of five major anchialine ponds - Tub, Manoku, Hopeaia, Kalahuipuaa, and Waipuhi - over the past year. A comprehensive sampling period was conducted in September, 1980 and was followed by monthly sampling visits conducted from January through June of 1981.

The body of this report contains two major sections. The first describes the baseline data assessing aquatic biota, water chemistry, sediments, and hydraulic behavior obtained during all the site visits. The data, presented in narrative and tabular form, first describes the results of the initial intensive sampling period and is followed by measurements made during supplementary monthly sampling. The second section presents restoration and management recommendations offered for consideration by Mauna Lani Resort, Inc., in regard to clean-up, repair and upkeep.

III. BASELINE DESCRIPTION

1. Materials and Methods

A. Aquatic Biota

The inspection included identification of the dominant members of the biological community in and surrounding the ponds. After a preliminary inventory in September, 1980, of the flora and fauna, observations continued to note any major changes or additions to species diversity and abundance. The assessment of aquatic biota was done solely by visual observations. Because of the problems of counting dispersed and motile organisms in a large, non-transparent water body, only the presence and absence of the dominant species in and around each pond was determined.

B. Water Chemistry

Water sampling entailed measurement of 10 water chemistry parameters, including physico-chemical data (temperature, salinity, and dissolved oxygen concentrations), nutrient concentrations (nitrate, nitrite, ammonium, and phosphate ions), and phytoplankton biomass indicators (chlorophyll a, phaeopigment, and phaeopigment to chlorophyll a (P/C - ratios). These parameters were measured at 10 stations in the ponds described in Figure 2.

In September, 1980, measurements were taken during Low Tide (+.2 feet MLLW), High Tide (+2.0 feet MLLW), Diurnal (4-6 pm), Nocturnal (4-6 am) conditions. These sampling efforts determined mean values with standard deviations of measured parameters and assessed both their tidal and diurnal variability. Measurements were taken from 1 meter depths at all 10 stations during these sampling periods. In addition, surface measurements were taken during the High Tide/Diurnal Phase at all 10 stations and 1.5 meter samples were collected at Stations 3 and 7 to assess vertical stratification.

From January through June of 1981, site visits were made one day each month during similar tide conditions (approximately +.2 - +.4 feet MLLW) and at similar times of day (between 10 am and Noon). Measurements and samples were taken at 1 meter depths at all 10 stations.

A two person rubber raft with wooden oars was paddled to reach each of the 10 stations in the ponds. Water samples were collected using a 70 milliliter Nisken type bottle. Nutrient samples were prefiltered through .45 micron glass fiber filters, stored in 40 ml teflon plastic bottles, placed on ice, and frozen for laboratory analysis. Nutrient concentrations were determined using standard methods on the Technicon Autoanalyzer II at the Oceanic Institute. Phytoplankton biomass were collected from 40 ml water samples on .45 glass fiber filters, the extracts suspended in acetone, and kept darkened and on ice until laboratory analysis at the Oceanic Institute. Pigment concentrations were determined fluorometrically according to standard methods (Strickland and Parsons, 1972). Salinity measurements were made in situ using a field, hand-held A-O Goldberg Salinity refractometer. Dissolved oxygen concentrations and temperatures were measured in situ with a YSI model 54 Oxygen meter with automatic stirrer.

C. Sediments

Seventeen transects were made in early 1980 through all the major ponds to determine vertical profiles of water depth and sediment thickness. Probes for each transect were made at the banks, quarter, and mid-points of the ponds. The presence of macroalgae, Ruppia was also noted.

Three random alliquots of soft, fine surface mud were dried to constant weight and subsequently combusted for 4 hours at 400°C to determine both the relative water content and inorganic/organic composition in the pond sediments.

In September, two plastic, hollow tubes 3 inches in diameter and 6 feet in length were sunk down vertically through pond sediment until they reached the lava basin in Manoku and Kalahuipuaa in places indicated in Figure 2, in an effort to determine the approximate age of the sediment bottom. These areas contained 4 and 6 feet of sediment, respectively. The cores were capped and pulled out by suction, compressing the sediment in the tubes to 2.25 and 3 feet, respectively. The cores were sealed and frozen and taken to the University of Hawaii Institute of Geophysics for analysis by standard methods of radiocarbon dating.

D. Hydraulic Behavior

Measurements were made in Kalahuipuaa, Manoku, and Hopeaia ponds to determine the time lag and degree of response to tides in adjacent coastal waters, during a complete 24 hour tide cycle. Changes in water elevations in these ponds were measured at 4 stations in these ponds from 10 am September 25 to 10 am on September 26, 1980. Readings were taken through a level transit to yardsticks attached to stakes driven into the pond bottoms. The ocean tide cycle was measured by means of a tide gauge temporarily set up on the ocean side of the east makaha in Kalahuipuaa pond. One reading was taken from each of the four stations shown in Figure 2 every fifteen minutes over the 24 hour period. Two lows and two highs were included in these readings.

2. Results and Discussion

A. Aquatic Biota

a. Flora

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A summary of the predominant flora present in and around the 5 major ponds is given in Table A. The vascular plants which surround the perimeters of all the ponds except the Tub include both trees - coconut (Cocos nucifera) and milo (Thespia populnea) and groundcover halophytes - hinahina (Heliotropium anomalum), ohelukai (Lycium sandwicense), and akulikulikai (Batis maritima). They are all salt tolerant crops whose roots extend down into the brackish groundwater and are sometimes completely emersed in pond water. Widgeon grass (Ruppia maritima) is the representative macroalgae found in sparse concentrations in Hopeaia and Manoku ponds, and in dense stands in the two unnamed small pools found between Manoku and Kalahuipuaa ponds. Microscopic inspection showed large numbers of epiphytic diatoms attached to the blades of the Ruppia. Phytoplankton are ubiquitous and form dense blooms in all the fishponds. The dominant members are flagellated unicells of the genus Gyrodinium, Pyranomonas, and Chlorocentrum. There is also a substantial community of benthic algal mats (Lyngbia sp.) found in the small anchialine ponds.

NO
vascular plant completely submerged

b. Fauna

A summary of the zoological community members found in the ponds is given in Table B. The predominant inhabitants of the Tub and unnamed ponds are two species of opae'ula, Halocaridina rubra and Metabetaeus lohena. These tiny, bright red shrimp are similar in appearance but differ in size, feeding habits and morphology. Metabetaeus is a carnivore and preys on Halocaridina, an herbivore which grazes on phytoplankton, benthic algae, and organic detritus. These opae'ula co-exist with glass shrimp (Palaemon debilis) and a small number of freshwater prawns (Macrobrachium grandimonus).

The predominant fauna in the large fishponds are molluscs and fish species. Small snails (*Assiminea* sp., *Melania,* sp., and an edible gastropod, *Theodoxus cariousus*) and rock crabs (*Metapograpus*) inhabit the rocky margin areas of the large ponds. Glass shrimp (*Palaemon debilis*)are ubiquitous in the large ponds, their transparency provides protection from predator fish. Herbivorous/omnivorous fish include awa (*Chanos chanos*), and mullet (*Mugil* sp.). Carnivorous predator-fish are primarily aholehole (*Kuhlia sandvicenis*) papio/ulua (*Caranx* sp.), and kaku (*Sphyraena barracuda*). Several species of reef fish including manini (*Acanthurus* sp.) and mamo (*Abudefduf* sp.) are found inside the sea wall of Kalahuipuaa.

TABLE A

Dominant Vegetation Found in and Around Major Ponds at Kalahuipuaa

	Tub	Manoku	Hopeaia	Kalahujpuaa	Waipuhi
Heliotropium		x	x	x	x
Lycium		x	x	x	x
Batis		x	x	x	x
Cocos		x	x	x	x
Thespia		x	x	x	x
Scaevola					x
Prosopis					x
Ruppia			x		
Diatoms/phytoplankton	x	x	x	x	x
Lyngbia	x				

TABLE B

Dominant Aquatic Fauna found in Major Ponds at Kalahuipuaa

	Tub	Manoku	Hopeaia	Kalahuipuaa	Waipuhi
Amphipoda	x	x	x	x	x
Halocaridina	x				
Metabetaeus	x				
Palaemon	x	x	x	x	x
Macrobrachium	x				
Assiminea	x	x	x	x	x
Melania		x	x	x	x
Theodoxus			x	x	x
Metopograpus				x	x
Chanos		x	x	x	x
Mugil		x	x	x	x
Kuhlia		x	x	x	x
Caranx		x	x	x	x
Sphyraena		?	?	x	x
Abudefduf				x	x
Acanthurus				x	x

B. Water Chemistry

1. Physico-Chemical Parameters

a. Comprehensive Sampling Period.

Tables 1 through 3 describe temperature, salinity, and dissolved oxygen data obtained during the three sampling periods, Low Tide (L.T.), High Tide/Diurnal Phase (H.T./D.P.), and Nocturnal Phase (N.P.), September 24 through 26, 1980. For each lagoon, the means and standard deviations of measurements taken from all depths and sampling periods are described in Figures 2 through 4. Diurnal differences and tidal differences between measurements taken at one meter depths at all stations are reported with means and standard deviations in Tables 4 and 5.

Temperature ranged from 20.2 to 30.0°C. The lowest value occurred at the Tub during the nocturnal sampling period. The highest value occurred at Stations 1, 6, 9 and 10 (H.T./D.P.) and at Station 9 (N.P.). These values are primarily influenced by warming in shallow basins from incoming solar radiation during daylight hours and by the relative percentages of colder groundwater and warmer seawater quantities present at the sampling site. The change in temperature from day to night (mean 2.84) may indicate that sunshine heating has a stronger affect in the change of temperature in the lagoons than tidal variation (mean .20).

Salinity ranged from 3 to 25 parts per thousand (ppt or o/oo). Full fresh water is 0 ppt and full sea water is 34 ppt. The lowest value occurred at the Tub (N.P.), representing a characteristic salinity of brackish groundwater. As expected salinity increased as the stations moved seaward, being highest in value in Kalahuipuaa and Waipuhi lagoons.

Dissolved oxygen levels ranged from 6.0 to greater than 20.0 mg/l (the maximum reading on the D.O. meter being 20 mg/l). All of these values represent oxygen saturation in water or very close to saturation depending on temperature and salinity. Hoopeaia consistently showed lower oxygen levels than the other lagoons, possibly reflecting shallower water and heavy organic debris causing higher oxygen demand through decomposition. Previous measurements taken in June, 1980, at the ponds have shown that pond mud is anaerobic. The lowest values at all the depths measured are still close to saturation and present no lethal or dangerous conditions for the biological community. The change in oxygen concentrations from day to night show a mean of 5.83, reflecting supersaturated conditions from photosynthetic oxygen generation during daylight and net oxygen consumption without photosynthesis during darkness. High tide also showed a large mean difference of 3.76, reflecting higher levels of oxygen input through circulation and exchange with coastal seawater.

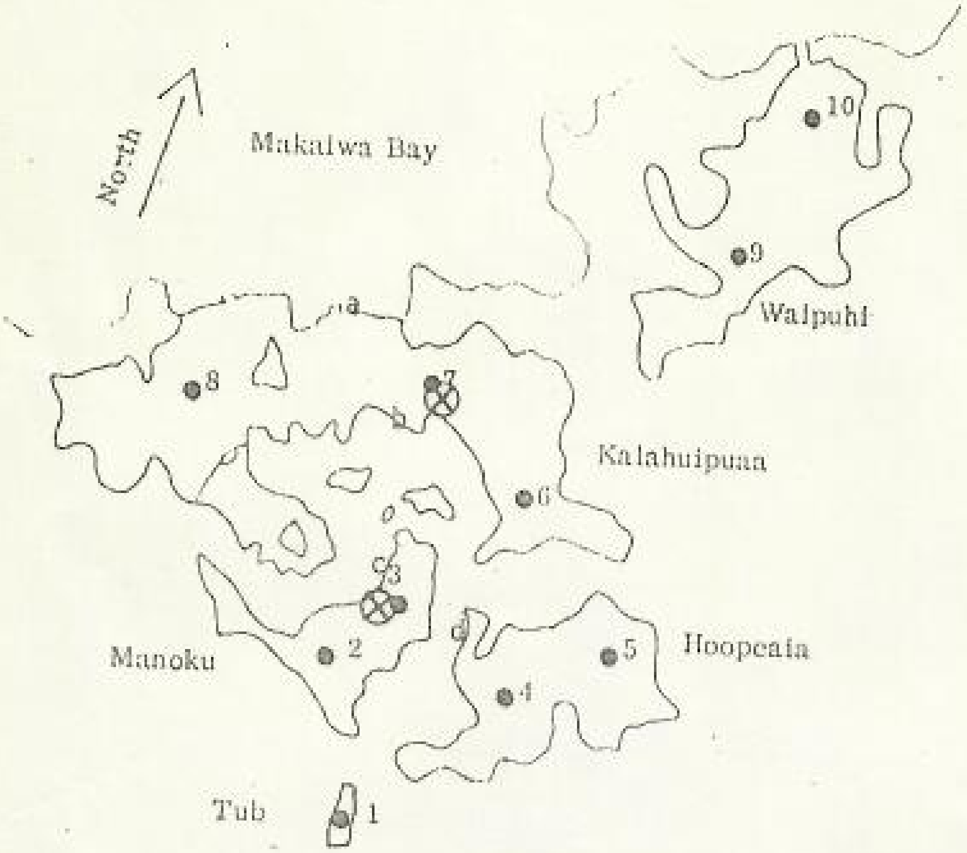


Figure 2. Reference map showing 10 water chemistry sampling stations, 2 sediment core locations and 4 tide measurement stations (a-d).

Table 1. Physico-chemical data in major lagoons at Kalahuipuaa. Sampling conducted on September 24, 1980, at low tide (+0.2 feet MLLW) from 9-11 am.

Station	Depth (m)	Temperature (°C)	Salinity (‰)	Oxygen (mg O_2/l)
1	1	21	5	8.4
2	1	28	7	6.8
3	1	25	7	7.1
4	1	24	7	8.4
5	1	23	8	12.0
6	1	29	25	10.0
7	1	26	22	10.2
8	1	28	20	12.0
9	1	29	22	8.5
10	1	29	20	12.0

Table 2. Physico-chemical data in major lagoons at Kalahuipuaa. Sampling conducted on September 24, 1980, at high tide (+2.0 feet MLLW) and diurnal conditions from 4-6 pm.

Station	Depth (m)	Temperature (^{o}C)	Salinity (‰)	Oxygen (mg O_2/l)
1	S(urface)	30	5	10.0
1	1	22	5	8.2
2	S	26	5	6.4
2	1	24	5	6.0
3	S	26	7	6.5
3	1	25	5	6.1
3	1.5	25	7	6.0
4	S	27	8	16.0
4	1	25	8	12.1
5	S	27	7	16.0
5	1	25	7	12.6
6	S	24	12	8.4
6	1	30	22	+20.0
7	S	25	15	8.5
7	1	27	22	16.0
7	1.5	28	25	16.0
8	S	26	20	17.8
8	1	26	24	+20.0
9	S	25	14	10.0
9	1	30	24	16.0
10	S	24	15	10.0
10	1	30	20	16.0

Table 3. Physico-chemical data from major lagoons at Kalahuipuaa. Sampling conducted on September 26, 1980, during nocturnal conditions (tide +2.0 feet MLLW) from 4-6 am.

Station	Depth (m)	Temperature (°C)	Salinity (‰)	Oxygen (mg O_2/l)
1	1	20.2	3	8.4
2	1	22	6	7.0
3	1	22.2	6	7.0
4	1	21.5	6	7.7
5	1	21.5	7	7.6
6	1	20.5	20	7.2
7	1	22	26	7.5
8	1	23	24	7.3
9	1	30	24	7.7
10	1	26	22	7.3

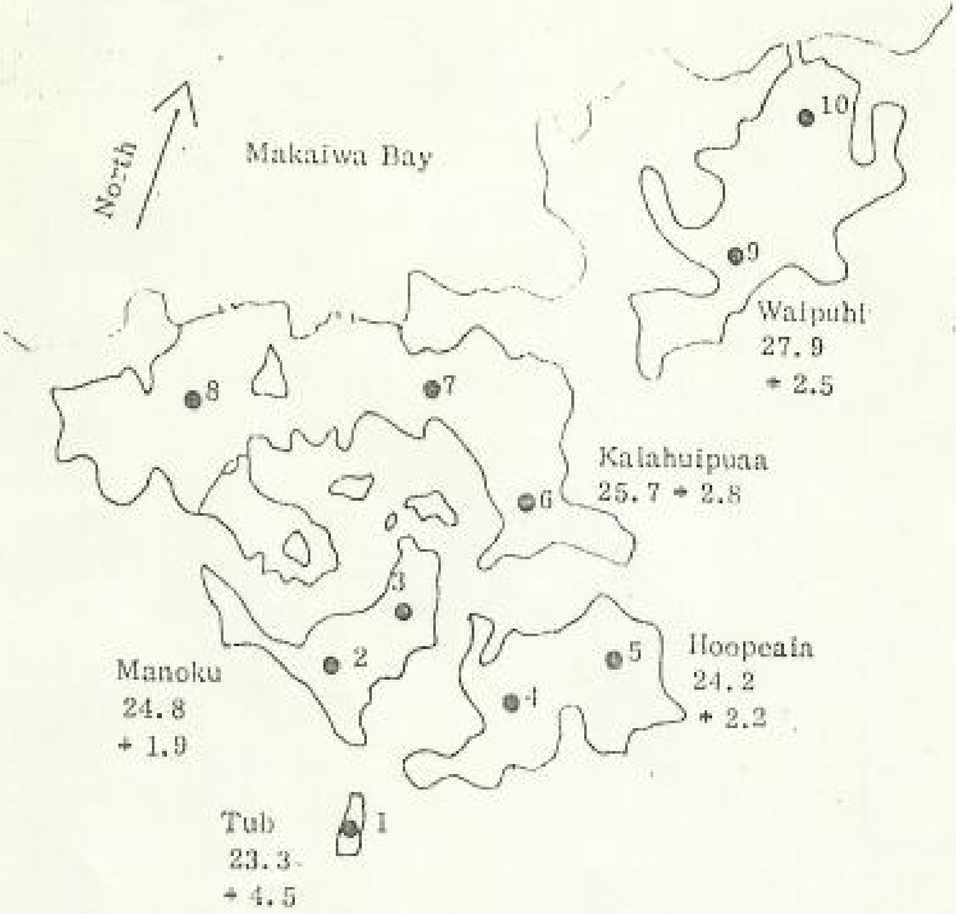


Figure 3 Distribution of temperature (°C) in major lagoons at Kalahuipuaa. Values represent means (+/- standard deviations) of all measurements taken on September 24-26, 1980.

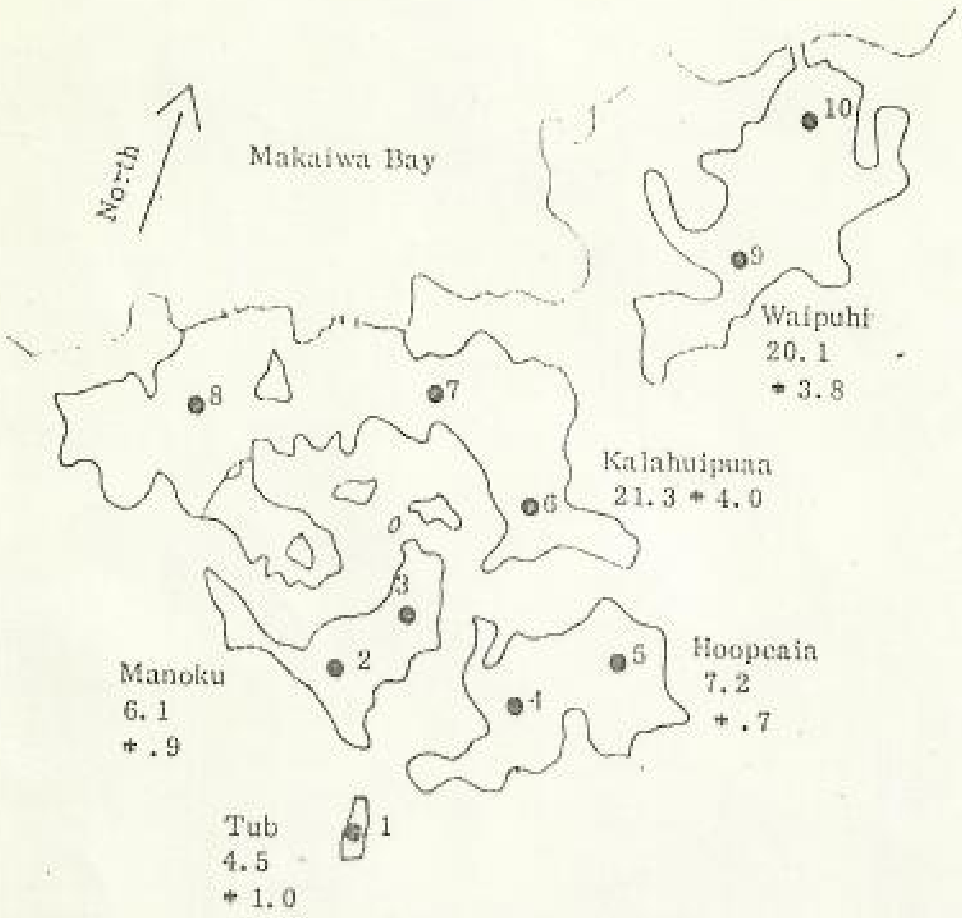


Figure 4. Distribution of salinity (o/oo) measurements in major lagoons at Kalahuipuaa. Values represent means (+/- standard deviations) of all measurements taken on September 24-26, 1980.

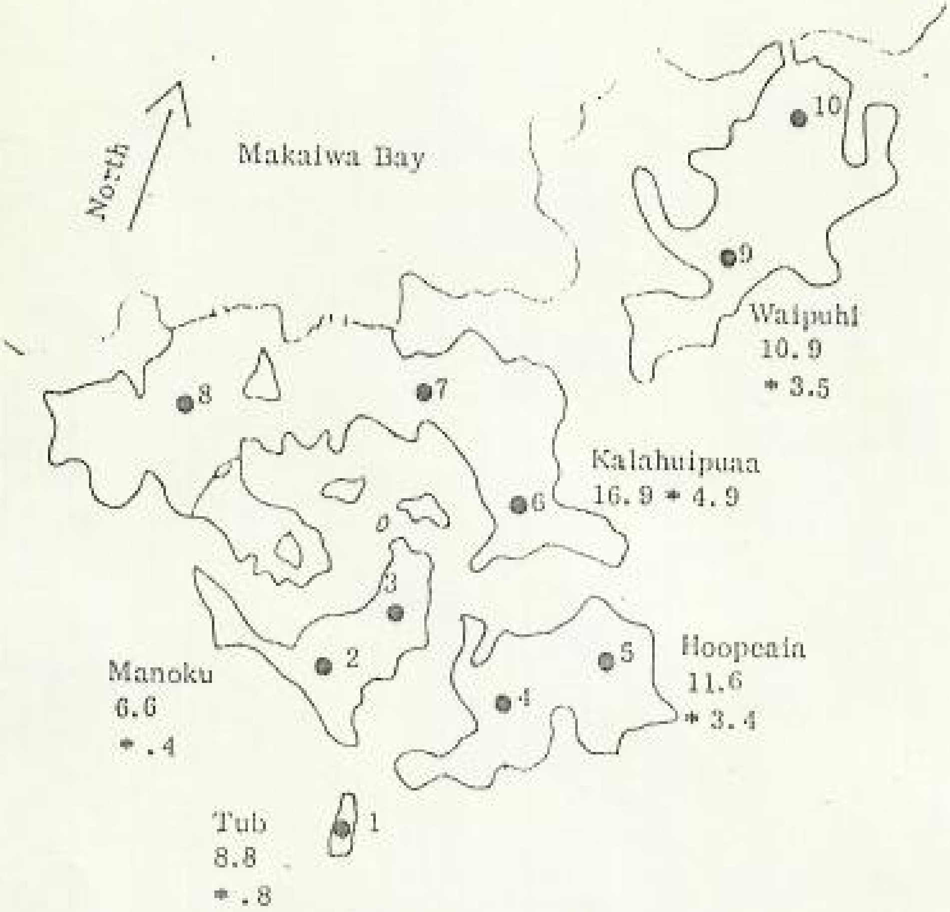


Figure 5. Distribution of dissolved oxygen (mg/l) concentrations in major lagoons at Kalahuipuaa. Values represent means (+/- standard deviations) of all measurements taken on September 24-26, 1980.

Table 4. Measured differences (with means +/- standard deviations) of physicochemical parameters between Diurnal and Nocturnal conditions at 10 sampling stations and 1 meter depths. Diurnal: 9/24/80, 4-6 pm. Nocturnal: 9/26/80, 4-6 am. Tide conditions +2.0 feet MLLW during both sampling periods.

Station	Temperature	Salinity	Oxygen
1	1.0	2.0	-0.2
2	2.0	-1.0	-1.0
3	2.0	-1.0	-0.9
4	3.5	2.0	4.4
5	3.5	0.0	5.0
6	*	2.0	12.0
7	5.0	-4.0	8.5
8	3.0	0.0	12.7
9	0.0	0.0	8.3
10	4.0	-2.0	8.7
Mean	2.84	-0.20	5.83
S.D.	1.45	1.93	5.25

* Data considered not representative for this test.

Table 5. Measured differences (with means +/- standard deviations) of physico-chemical parameters between High and Low tides at 10 sampling stations and 1 meter depths. High tide: 9/24/80, 4-6 pm, +2.0 feet MLLW. Low tide: 9/24/80, 9-11 am, +0.2 feet MLLW.

Station	Temperature	Salinity	Oxygen
1	1.0	0.0	-0.2
2	-4.0	-2.0	-0.8
3	0.0	-2.0	-1.0
4	1.0	1.0	3.7
5	2.0	-1.0	0.6
6	1.0	-3.0	10.0
7	1.0	0.0	5.8
8	-2.0	4.0	8.0
9	1.0	2.0	7.5
10	1.0	0.0	4.0
Mean	0.20	-0.10	3.76
S.D.	1.81	2.00	4.00

b. Supplementary Monthly Sampling

Tables 6 through 8 describe temperature, salinity, and dissolved oxygen data obtained during monthly site visits from January through June, 1981. Also reported are the average values from the Comprehensive Sampling Period and the overall range of values in each pond obtained during all the sampling efforts.

In these measurements, temperature ranged from 20 - 31°C. The minor fluctuations in degrees at each station reflect changes in the physical environment caused by solar heating, weather conditions, mixing and diffusion processes. The gradual increase in temperature moving seaward is caused by ambient seawater being warmer than groundwater and the relative composition of each in the mixohaline ponds.

Salinity showed the least variation at each station and the overall range in all ponds was from 4 to 24 parts per thousand. Again, these values reflect the relative mixing of seawater and groundwater, with less dense freshwater floating on top of heavier seawater, and with salinity increasing towards the makai stations having greater input from coastal seawater. The highest value (24 ppt) is equal to approximately 71% seawater, suggesting that groundwater influx is a substantial contribution to all these pond ecosystems, even those which border the coastal marine environment.

Dissolved oxygen levels at all stations and times ranged from 6.2 to 16.9 milligrams/liter. For the existing temperatures and salinities at each station, these values represent oxygen super saturation or near saturation concentrations. The highest values suggest intense photosynthesis which generates higher rates of oxygen input than output from equilibration with the environment. Lower values indicate that supersaturated oxygen has come out of solution or may reflect recent groundwater inputs that were previously out of contact with the atmosphere and photosynthetic activity but may have been subject to community respiration. The heavy biological oxygen demand caused by community respiration of the large biomass levels in the fishponds is compensated by water turnover, mixing and photosynthetic oxygen inputs in a flow-through system.

TABLE 6

Temperature data (°C) taken during monthly site visits
(January through June, 1981). Overall range = 20 - 31°C.

Station #	Sept.	J	F	M	A	M	J	Overall Range/Pond
1	23.3	26	21.5	22	23	21	23	21 - 26
2	24.8	24.5	21.6	22	24	23	24	21.6 - 24.8
3		24.2	21.6	22	24	22	24	
4	24.2	24	21	22.2	24	22	25	20 - 25
5		25	21.6	22.5	24	20	24.5	
6	25.7	27.5	26	22.5	30	31	29	22.5 - 31
7		27	26	23	29	30	27	
8		26	25	31	27.5	29	29	
9	27.9	31	26.5	24	27	24	29	24 - 31
10		29	26	24	27	24	28	

TABLE 7

Salinity data (parts per thousand) taken during monthly site visits (January through June, 1981). Overall range = 4 - 24 parts per thousand

Station #	Sept.	J	F	M	A	M	J	Overall Range/Pond
1	4.5	4	4	4	4	5	5	4 - 5
2	6.1	6	7	8	7	6	8	6 - 8
3		7	7.5	8	7	6	8	
4	7.2	6	8	6	6	6	8	6 - 8
5		6	8	6	6	6	8	
6	21.3	20	24	17	23	21	22	17 - 28
7		18	22	18	22	21	22	
8		18	22	18	22	18	20	
9	20.1	18	22	14	12	10	22	10 - 24
10		19	22	17	10	10	22	

TABLE 8

Dissolved oxygen concentrations (milligrams/liter) measured during monthly site visits (January through June, 1981). Overall range = 6.2 - 16.9 milligrams/liter.

Station #	Sept.	J	F	M	A	M	J	Overall Range/Pond
1	8.8	6.2	8.7	8.5	8.3	9.5	9.2	6.2 - 9.5
2	6.6	10.9	8.3	10.4	11.0	10.5	13.8	6.6 - 15.0
3		10.2	8.7	10.4	11.5	10.5	15.0	
4	11.6	9.2	8.1	14	10.0	12	13.5	8.1 - 14.8
5		10.4	9.6	14.2	10.8	11.5	14.8	
6	16.9	11.4	14.2	9.4	8.0	15	11.0	9.4 - 16.9
7		12.0	16.0	9.5	8.0	15	10.8	
8		8.0	16.6	12.0	10.4	14	10.5	
9	10.9	13.0	15.4	13	10.5	12.5	12.5	10.9 - 15.4
10		13.5	12.0	12	13.6	13.2	12.0	

2. Nutrient Concentrations and Phytoplankton Biomass Indicators

a. Comprehensive Sampling Period.

A summary of the nutrient and phytoplankton data for the intensive sampling period is given in Tables 9 through 11. The spatial distribution of the means and standard deviations of each parameter taken from all depths and sampling periods for each pond is described in Figures 6 through 12. The diurnal differences and tidal differences between measurements taken at one meter depths at all stations with means and standard deviations are reported in Tables 12 and 13.

Nitrate concentrations ranged from 1.012 to 15.620 ug-at/l (micro-gram atoms per liter). The lowest value occurred at Station 7, in Kalahuipuaa (H.T./D.P.). This reflects a negative correlation with salinity; ambient seawater typically has much lower levels of nutrients than groundwater. The highest value occurred at the Tub (H.T./D.P.) exemplifying the enriched conditions of groundwater, the low phytoplankton biomass which would remove this nutrient, and the short resident time of water in the small, porous basin. Nitrite ranged from 0.121 to 1.958 ug-at/l. These low values represented no significant influence on the ponds and measuring this ion was discontinued in later sampling.

Ammonium, a reduced radical nitrogen compound, ranged from 1.107 (Manoku, N.P.) to 9.653 (Kalahuipuaa, N.P.) ug-at/l. Ammonium is not present in high levels naturally in either seawater or groundwater. It is however, a common excretory product of aquatic fauna and may concentrate in eutrophic environments, such as the ponds under study, containing significant animal biomass. Nitrogen is an important nutrient for aquatic plants (phytoplankton and macro-algae). The significant mean difference of ammonium from day to night (-2.29) may be reflecting the phenomenon that active uptake of this nutrient by phytoplankton occurs during the day and so ammonium concentrations accumulate during the night. Levels are not limiting primary productivity in the lagoons.

Phosphate levels ranged from 0.120 (Hopeaia, H.T./D.P.) to 2.004 (Tub, H.T./D.P.) ug-at/l. Phosphorus is another important plant nutrient as a component of energy compounds used in cell metabolism. Phosphate (PO_4^{-3}) is the most common form of soluble phosphorus in aquatic ecosystems. Phosphate levels are naturally high in groundwater and low in seawater; the distribution of phosphate in the ponds confirms this trend as the Tub has consistently higher levels than the open ponds.

Phytoplankton pigments give a measure of the standing crop of microscopic plant biomass in the ponds. This affects both the water quality (by removing nutrients as fertilizers for growth) and animal biomass (whose food supply is ultimately determined by the amount of plant material available). Chlorophyll _a_, the primary photosynthetic material unique to plants, had values which ranged from 0.42 (Tub, H.T./D.P.) to 57.948 (Waipuhi, N.P.) ug-at/l. Phaeo-pigment levels ranged from unmeasurable (Manoku, N.P., Waipuhi, H.T./D.P.) to 24.168 (Waipuhi, L.T.) ug-at/l. The distribution of phaeo-pigment concentration generally follows that evidenced by chlorophyll _a_ as phaeo-pigment is a degenerative form of chlorophyll _a_ resulting from plant senescence or digestion by a herbivore.

Table 9. Nutrient data and phytoplankton pigments in the major lagoons at Kalahuipuaa. Sampling conducted on September 24, 1980, 9-11 am, at low tide (+0.2 feet MLLW).

Station	Depth	NO_3	NO_2	NH_4	PO_4	Phytoplankton Pigments		
	(m)	(ug-at/l)	(ug-at/l)	(ug-at/l)	(ug-at/l)	Chlorophyll a (ug/l)	Phaeo-pigments (ug/l)	P/C ratio
1	1	8.800	0.198	1.188	0.936	.080	.076	.9550
2	1	12.210	0.913	4.212	0.276	8.997	4.049	.4500
3	1	11.110	1.012	3.267	0.156	19.787	7.844	.3964
4	1	11.440	1.958	4.158	0.360	24.027	9.611	.4000
5	1	10.505	1.826	2.781	0.204	36.747	13.710	.3731
6	1	1.166	0.187	3.645	0.360	32.507	8.339	
7	1	1.034	0.154	2.673	0.396	22.614	3.816	.1687
8	1	0.627	0.165	2.349	0.420	16.960	5.865	.3458
9	1	2.090	0.748	4.590	0.660	11.114	5.081	.4571
10	1	1.617	0.759	5.076	0.744	7.067	24.168	3.4200

Table 10. Nutrient data and phytoplankton pigments in the major lagoons at Kalahuipuaa. Sampling conducted on September 24, 1980, 4-6 pm, during diurnal conditions, at +2.0 MLLW.

Station	Depth (m)	NO_3 (ug-at/l)	NO_2 (ug-at/l)	NH_4 (ug-at/l)	PO_4 (ug-at/l)	Phytoplankton Pigments Chlorophyll a (ug/l)	Phaeo-pigments (ug/l)	P/C ratio
1	S(urface)	15.400	0.616	1.620	2.004	.042	.059	1.4192
1	1	15.620	0.121	1.674	1.992	.152	.127	.8342
2	S	10.560	0.165	4.806	0.180	13.760	4.684	.3404
2	1	10.945	0.253	1.782	0.720	6.880	3.017	.4385
3	S	10.230	0.198	4.347	0.120	25.440	5.795	.2278
3	1	11.165	0.242	2.079	0.192	13.760	5.134	.3731
3	1.5	10.670	0.154	2.268	0.060	28.267	5.371	.1900
4	S	9.405	0.957	1.269	0.120	49.468	11.802	.2386
4	1	10.505	0.803	1.431	0.168	52.294	4.169	.0797
5	S	9.350	0.847	2.430	0.156	39.574	4.876	.1232
5	1	10.670	0.709	1.323	0.480	40.987	1.060	.0259
6	S	11.055	0.264	1.836	1.776	1.817	.471	.2593
6	1	2.228	0.242	1.917	0.744	33.921	6.925	.2042
7	S	8.360	0.407	1.782	0.912	7.938	.609	.0767
7	1	10.588	1.430	1.107	0.216	13.231	1.164	.0880
7	1.5	1.012	0.231	2.403	0.552	46.641	7.420	.1591
8	S	8.360	0.330	2.403	0.960	6.719	.000	.0000
8	1	1.584	0.220	1.836	0.396	14.818	2.726	.1839
9	S	8.525	0.297	1.512	1.116	18.374	10.459	.5692
9	1	2.558	0.561	1.728	0.480	24.027	.000	.0000
10	S	8.085	0.341	1.107	0.744	12.172	.873	.0717
10	1	4.015	0.402	2.106	0.432	22.614	5.017	.2219

Table 11. Nutrient data and phytoplankton pigments in the major lagoons at Kalahuipuaa. Sampling conducted on September 26, 1980, 4-6 am, during nocturnal conditions, at +0.2 feet MLLW.

						Phytoplankton Pigments		
Station	Depth (m)	NO_3 (ug-at/l)	NO_2 (ug-at/l)	NH_4 (ug-at/l)	PO_4 (ug-at/l)	Chlorophyll a (ug/l)	Phaeo-pigments (ug/l)	P/C ratio
1	1	15.400	0.297	1.350	0.912	.088	.068	.7773
2	1	11.770	0.550	2.943	0.672	4.367	.000	.0000
3	1	10.285	1.221	2.646	0.468	16.406	6.086	.3710
4	1	10.588	1.430	1.107	0.216	26.854	5.583	.2079
5	1	11.440	1.205	4.779	0.528	19.582	2.911	.1486
6	1	2.101	0.440	9.653	0.636	49.468	2.191	.0443
7	1	1.518	0.187	4.563	0.516	11.114	2.382	.2143
8	1	1.936	0.330	2.538	0.588	28.267	.565	.0200
9	1	2.998	0.781	6.885	0.924	4.535	3.603	.7944
10	1	3.850	0.704	4.563	0.900	57.948	12.932	.2232

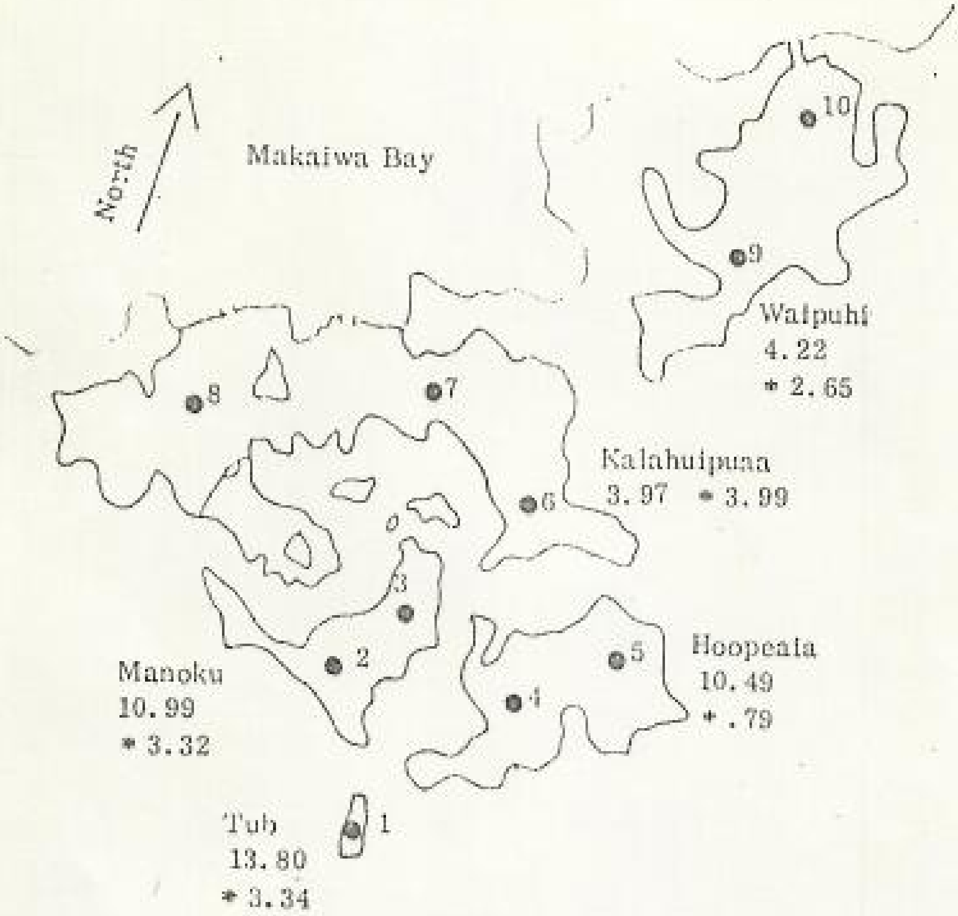


Figure 5. Distribution of nitrate concentrations (in ug-at/l) in major lagoons at Kalahuipuaa. Values represent means (+/- standard deviations) of all measurements taken on September 24 through 26, 1980.

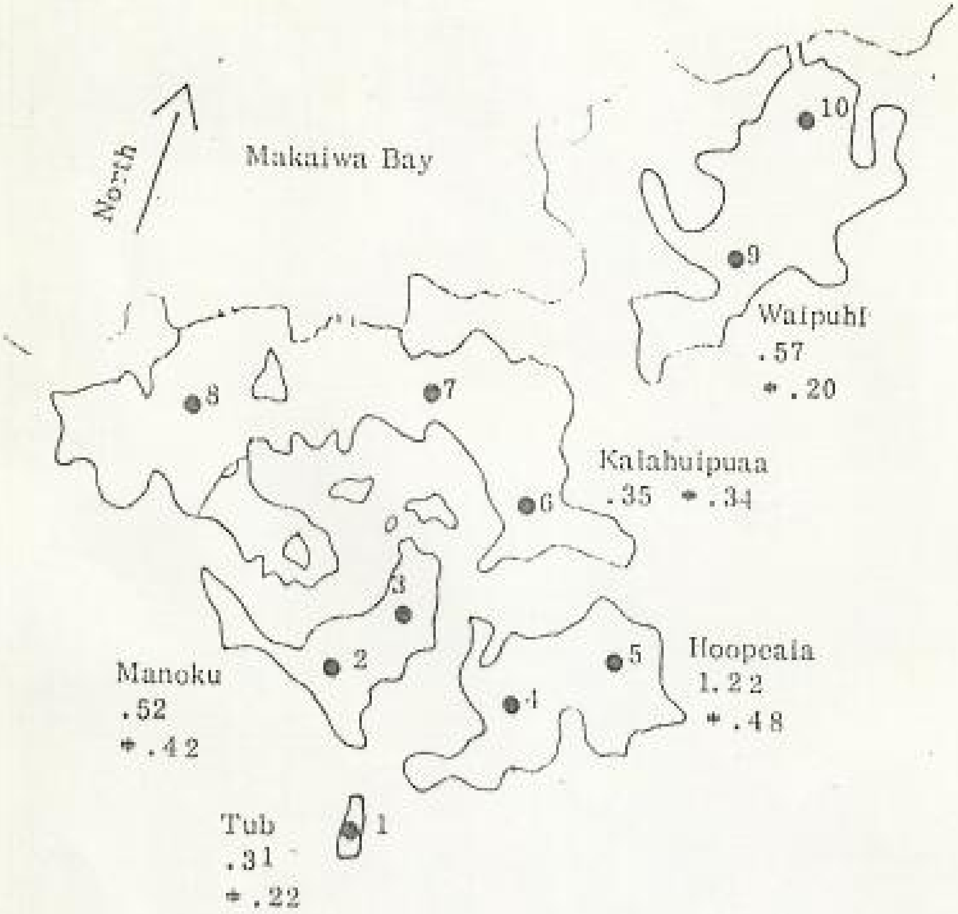


Figure 7. Distribution of nitrite concentrations (in ug-at/l) in major lagoons at Kalahuipuaa. Values represent means (+/- standard deviations) of all measurements taken on September 24-26, 1980.

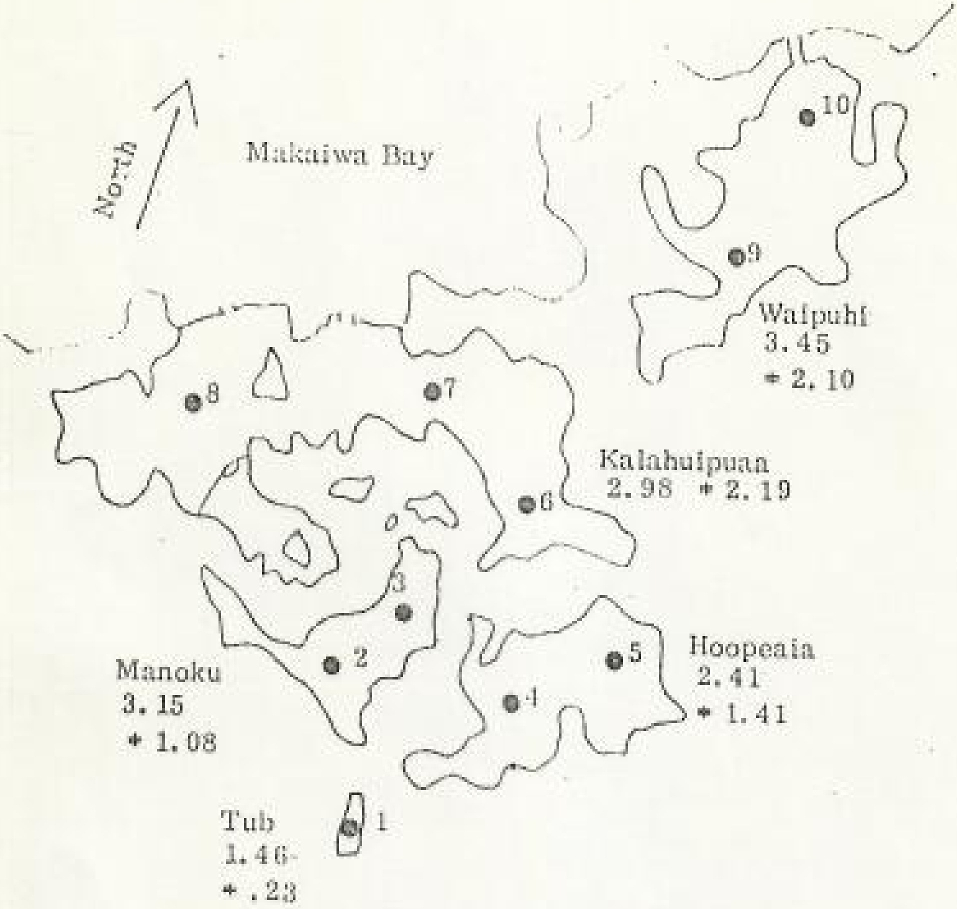


Figure 8. Distribution of ammonium concentrations (in ug-at/l) in major lagoons at Kalahuipuaa. Values represent means (+/- standard deviations) of all measurements taken on September 24-26, 1980.

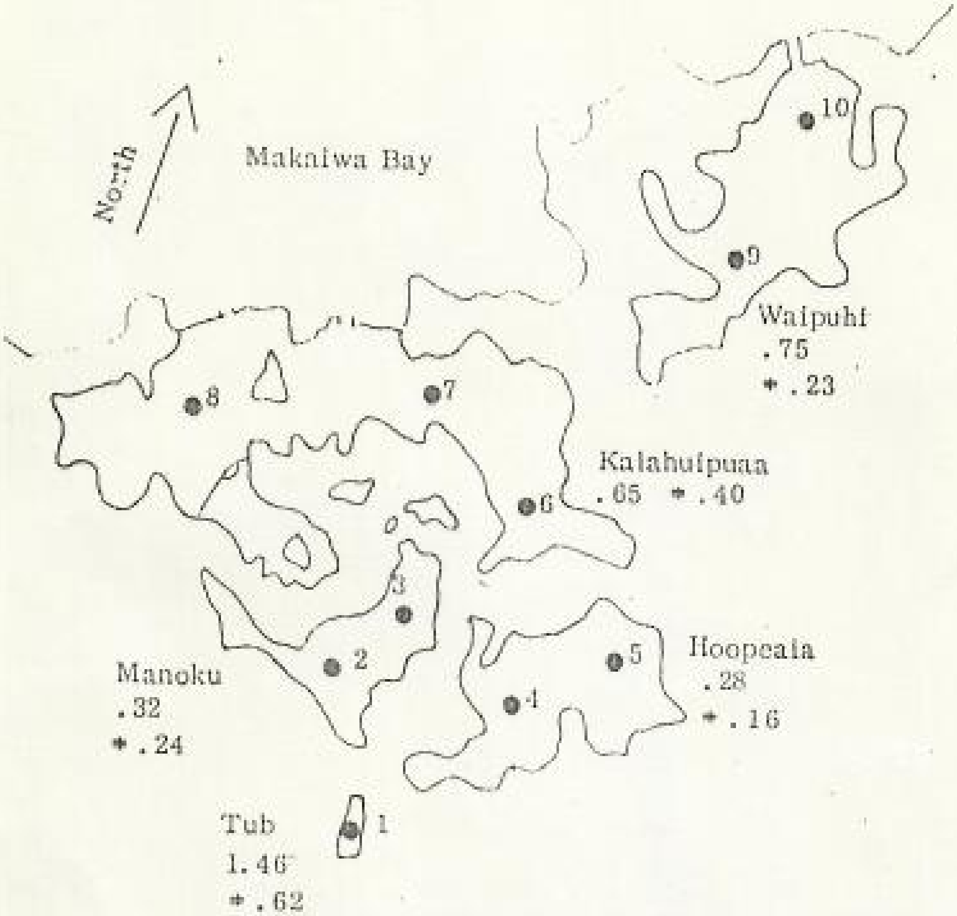


Figure 9. Distribution of phosphate concentrations (in ug-at/l) in major lagoons at Kalahuipuaa. Values represent means (+/- standard deviations) of all measurements taken on September 24-26, 1980.

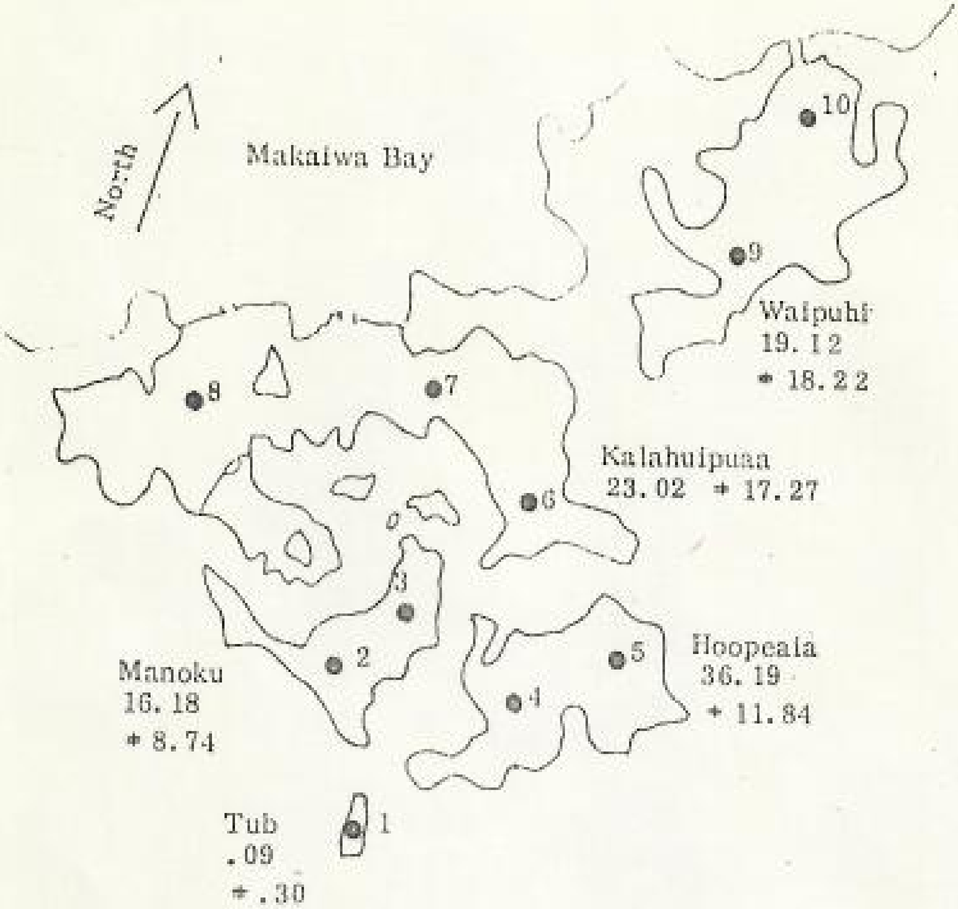


Figure 10. Distribution of chlorophyll a concentrations (in ug/l) in major lagoons at Kalahuipuaa. Values represent means (+/- standard deviations) of all measurements taken on September 24-26, 1980.

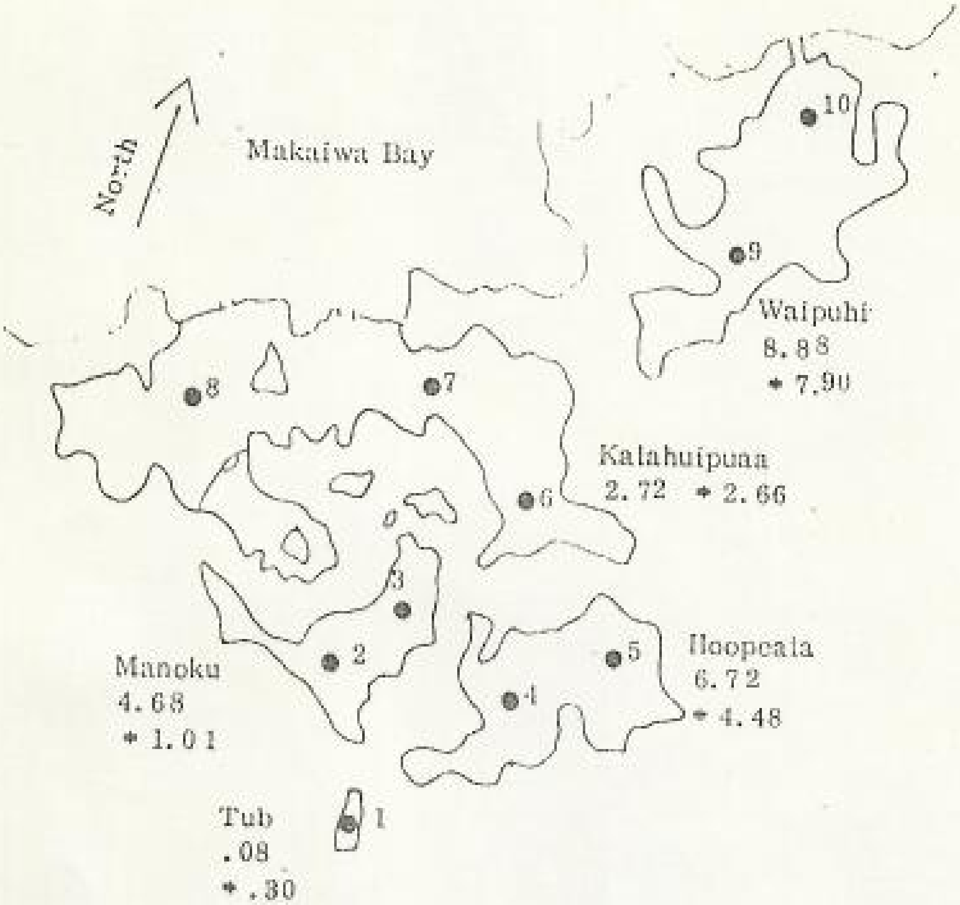


Figure 11. Distribution of phaeo-pigment concentrations (in ug/l) in major lagoons at Kalahuipuaa. Values represent means (+/- standard deviations) of all measurements taken on September 24-26, 1980.

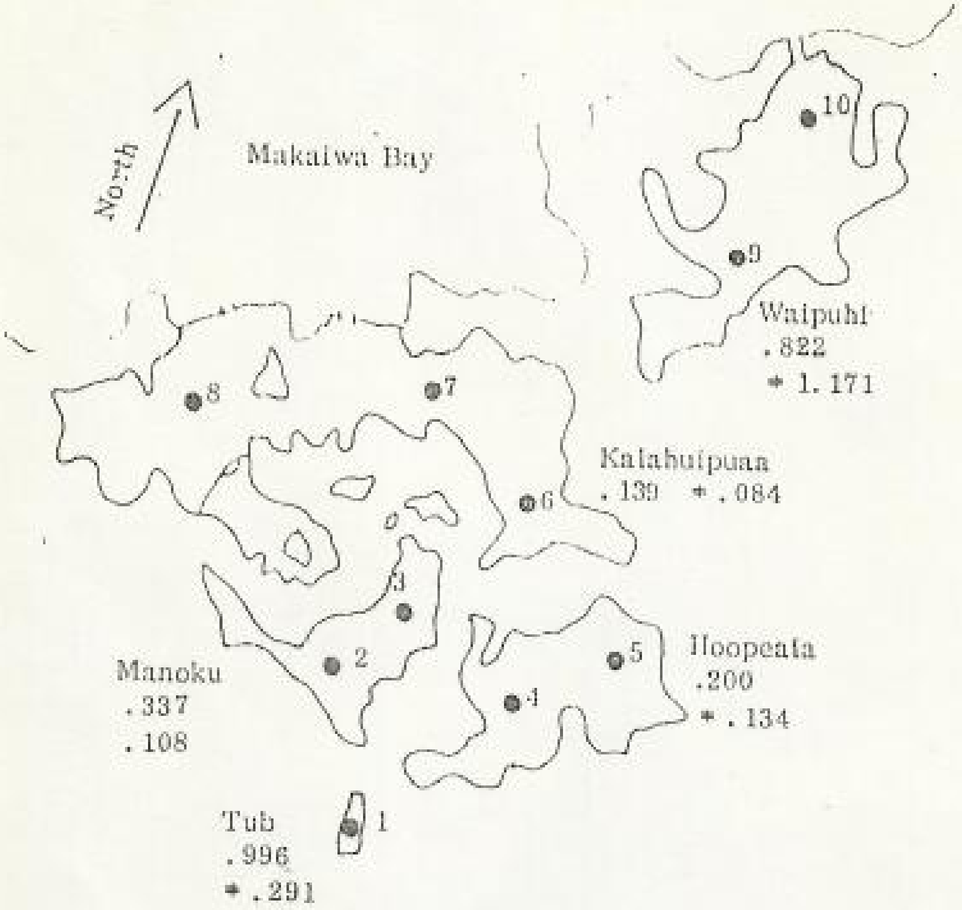


Figure 12. Distribution of phaeo-pigment/chlorophyll a (P/C) ratios in major lagoons at Kalahuipuaa. Values represent means (+/- standard deviations) of all measurements taken on September 24-26, 1980.

Table 12. Measured differences (with means +/- standard deviations) of nutrients and phytoplankton pigments between Diurnal and Nocturnal conditions at 10 sampling stations and 1 meter depths. Diurnal: 9/24/80, 4-6 pm. Nocturnal: 9/26/80, 4-6 am. Tide conditions +2.0 feet MLLW during both sampling periods.

Station	NO_3	NO_2	NH_4	PO_4	Phytoplankton Pigments		
					Chlorophyll a	Phaeo-pigments	P/C ratio
1	0.42	-0.18	0.32	1.08	0.06	0.05	0.06
2	-0.83	-0.30	-1.16	0.05	*	*	*
3	0.88	-0.98	-0.57	-0.28	-2.65	-0.95	0.002
4	-0.08	-0.63	0.32	-0.05	25.44	-1.41	-0.13
5	-0.77	-0.50	-3.46	-0.05	21.41	-1.85	-0.12
6	0.13	-0.20	-7.74	0.01	-15.55	4.73	0.16
7	*	*	*	-0.30	2.12	-1.22	-0.13
8	-0.35	-0.11	-0.70	-0.19	-13.45	2.16	0.16
9	-0.44	-0.22	-5.16	-0.44	*	*	*
10	0.16	-0.30	-2.46	-0.47	-35.33	-7.92	-0.001
Mean	-0.10	-0.38	-2.29	-0.06	-2.24	-0.80	0.0001
S.D.	0.56	0.28	2.73	0.44	19.81	3.63	0.12

* Data considered not representative for this test.

Table 13. Measured differences (with means +/- standard deviations) of nutrients and phytoplankton pigments between High and Low tides at 10 sampling stations and 1 meter depths. High tide: 9/24/80, 4-6 pm, +2.0 feet MLLW. Low tide: 9/24/80, 9-11 am, +0.2 feet MLLW.

Station	NO_3	NO_2	NH_4	PO_4	Phytoplankton Pigments		
					Chlorophyll a	Phaeo-pigments	P/C ratio
1	6.82	-0.08	0.49	1.06	0.07	0.05	-0.12
2	-1.27	-0.66	-2.43	0.44	-2.12	-1.03	-0.01
3	0.06	-0.77	-1.19	0.04	-6.03	-2.71	-0.02
4	-0.94	-1.16	-2.73	-0.19	28.27	-5.44	-0.32
5	0.17	-1.12	-1.46	0.28	4.24	-12.65	-0.35
6	1.06	0.06	-1.73	0.38	1.41	-1.41	-0.06
7	*	*	*	-0.18	-9.38	-2.65	-0.08
8	0.96	0.06	-0.51	-0.02	-2.14	-3.14	-0.16
9	0.47	-0.19	-2.86	-0.18	*	*	*
10	2.40	-0.36	-2.97	-0.31	15.55	-19.15	-3.20
Mean	1.08	-0.47	-1.71	0.13	3.32	-5.35	-0.48
S.D.	2.41	0.48	1.18	0.42	11.70	6.39	1.03

* Data considered not representative for this test.

b. Supplementary Monthly Sampling - Nutrients and Phytoplankton

Tables 14 to 19 present nutrient and phytoplankton data obtained during the monthly site visits (January through June, 1981), as well as the September mean values, ranges in each pond, and overall range for each parameter measured.

Nitrate-nitrogen values are the most outstanding feature of the nutrient data. From the average value in September of 13.8 microgram atoms per liter (ug-at/l), nitrate concentrations showed a consistent general increase with time at all of the stations. Previous preliminary sampling conducted in March and June of 1980 gave nitrate levels which ranged from 25.6 to 77.6 and 11.5 to 53.0 ug-at/l, respectively. The overall range from January to June, 1981 was 3 to 142 ug-at/l, significantly different than previous measurements. The highest values were found in the Tub. Groundwater was most likely receiving nutrient enrichment from the golf course fertilizers. Application every six weeks of approximately 40,000 pounds of "Turf Supreme" fertilizer (composed primarily of nitrate-nitrogen) leaching down through the porous lava in the water table is believed to be the major source of the substantial increase in nitrate levels. These levels are not decreased by nutrient uptake of the low biomass of phytoplankton and the short resident time of groundwater in the closed ponds. High nutrient removal by the high turnover of coastal seawater and small levels of groundwater input in Kalahuipuaa and Waipuhi ponds resulted in consistently lower levels of nitrate at these stations.

Ammonium-nitrogen levels ranged overall from 0 (undetectable by the analytical methods used) to 6.17 ug-at/l. These are acceptable values found in eutrophic ecosystems and in buffered seawater present no danger of toxicity in gaseous NH3 form. The fluctuations over time in given stations reflect the patchiness of biological activity which changes with environmental conditions. Generation of ammonium by decomposition of excretion by aquatic fauna is offset in differing degrees with active nutrient uptake by phytoplankton and oxidation by select bacteria.

Phosphorus, in the form of ortho-phosphate, was measured to range in value from 0 (undetectable) to 2.39 ug-at/l. Another nutrient having a short resident time in solution, phosphorus is liberated from decomposing biomass (both plant and animal), and once dissolved, is rapidly removed from solution through uptake by algae or bacteria to be used primarily in energy compounds. The higher values found with lower salinities again reflect groundwater enrichment.

Phytoplankton biomass indicators were also sampled each month to assess seasonal variations of these plant communities. The overall chlorophyll a concentrations measured from January to June, 1981, ranged from .02 to 70.25 ug-at/l. The lowest values were in the Tub, due to the very short residence time of water volume and consequently the continual outflushing of phytoplankton standing crops. The majority of aquatic flora in the small anchialine pools are benthic algal mats, whose biomass was not assessed in this study. All the other values of phytoplankton pigments reflect the extremely dense populations of these microscopic plant cells that exploit the optimum conditions of sunlight, nutrients, and temperature for their growth. Phaeopigments were measured and ranged from 0 (undetectable) to 763.83 ug-/l. High values, found primarily in Kalahuipuaa and Waipuhi, may reflect lysing of marine phytoplankton cells introduced to water of lower salinity. Since phaeopigments are constantly degraded by sunlight, persistant high levels indicate that whatever processes generate phaeopigments are also continuous. Phaeopigment to chlorophyll a ratios (P/C) give an indication about the nature of biological processes occuring in these ecosystems. A high P/C ratio could represent active grazing by zooplankton or other filter feeding consumers which digest chlorophyll a rapidly into phaeopigments. A low value might imply a more stagnant environment with a less active consumer trophic level. There is no systematic variation of P/C levels apparent except the general trends described for each parameter separately.

TABLE 14

Nitrate concentrations (microgram-atoms/liter) measured during monthly site visits
(January through June, 1981.) Overall range = 3 - 142 µg-at/1.

Station #	Sept.	J	F	M	A	M	J	Overall Range/Pond
1	13.8	72.7	107.92	95	103.9	140	136	13.8 - 140
2	11.0	69.4	90.57	53.1	71.6	121	110	11.0 - 121
3		68.2	87.32	55.3	62.6	116	102	
4	10.5	65.4	134.25	104.8	93.6	139	107	10.5 - 142
5		71.4	127.93	104.4	97.1	142	109	
6	4.0	27.6	10.13	20.3	8.7	14.7	5.67	4.0 - 27.6
7		24.1	10.04	7.3	7.3	11.4	9.98	
8		41.9	22.40	6.3	14.5	36.7	14.9	
9	4.21	31.9	9.12	21.6	12.7	73.8	14.8	4.2 - 73.8
10		25.0	3.68	16.3	20.2	72.0	13.0	

TABLE 15

Ammonium concentrations (microgram-atoms/liter) measured during monthly site visits

(January through June, 1981.) Overall range = 0 - 9.17 µg-at/1.

Station #	Sept.	J	F	M	A	M	J	Overall Range/Pond
1	1.46	6.17	8.35	.80	1.67	.86	5.23	.8 - 9.17
2	3.15	2.50	4.11	.24	4.23	.17	2.89	.17 - 4.23
3		1.33	2.94	.17	2.90	.66	2.38	
4	2.41	1.46	2.41	.20	3.66	.12	1.36	.12 - 3.66
5		1.11	1.34	.62	.14	.28	1.26	
6	2.98	1.27	1.55	.80	.42	2.30	2.18	0 - 2.98
7		1.48	1.73	.00	0	.16	1.94	
8		1.55	1.26	.64	0	.26	2.18	
9	3.45	1.20	1.21	.0	0	.16	.74	0 - 3.45
10		1.60	1.47	.0	1.13	.77	.78	

TABLE 16

Phosphate concentrations (micrograms-atoms/liter) measured during monthly site visits (January through June, 1981.) Overall range = 0 - 2.39 µg-at/l.

Station #	Sept.	J	F	M	A	M	J	Overall/ Range/Pond
1	1.46	1.32	2.23	0.76	1.59	2.39	2.23	.76 - 2.39
2	.32	.71	.72	.02	1.71	.38	.75	.02 - 1.71
3		.73	.38	.03	.89	.27	.23	
4	.28	.42	.84	.02	1.32	.26	.53	.02 - 1.32
5		.31	.44	.04	.36	.25	.50	
6	.65	1.52	.20	.08	.25	.84	1.03	.08 - 1.52
7		.66	.32	.08	.32	.84	1.14	
8		.51	.21	.10	.33	.70	1.12	
9	.75	.68	.46	.00	.08	.50	1.00	.0 - 1.00
10		.68	.38	.02	.41	.32	.80	

TABLE 17

Chlorophyll a concentrations (micrograms/liter) measured during monthly site visits (January/June, 1981.) Overall range = .02 - 70.25 ug/1.

Station #	Sept.	J	F	M	A	M	J	Overall Range/Pond
1	.09	.02	.06	.10	.05	.04	.10	.02 - .10
2	16.18	53.61	26.81	8.03	29.49	17.42	28.15	8.03 - 53.61
3		53.61	33.51	16.08	28.15	24.12	21.44	
4	36.19	44.23	14.74	37.53	26.81	25.47	28.15	14.74 - 44.23
5		34.85	20.10	42.89	25.47	22.78	34.85	
6	32.02	3.01	37.53	10.04	13.55	38.87	25.47	1.92 - 70.25
7		70.25	57.63	26.81	8.53	24.12	12.55	
8		1.92	28.15	56.87	9.03	11.04	5.10	
9	19.12	62.99	61.65	30.83	46.83	14.74	9.03	8.61 - 62.99
10		49.59	34.85	42.89	36.80	13.55	8.61	

TABLE 18

Phaeopigment concentrations (micrograms/liter) measured during monthly site visits

(January/June, 1981.) Overall range = 0 - 34.14 µg/1.

Station #	Sept.	J	F	M	A	M	J	Overall Range/Pond
1	.08	.14	.0	.09	.19	.36	.22	0 - .36
2	4.68	16.94	4.69	6.12	20.91	16.59	15.95	4.68 - 24.77
3		16.46	9.33	5.33	24.77	11.15	17.61	
4	6.72	3.65	4.16	7.83	16.03	7.29	17.21	3.65 - 19.33
5		15.55	6.35	7.51	18.63	17.53	19.33	
6	2.72	17.28	9.09	3.64	7.68	12.79	8.55	0 - 34.14
7		34.14	.0	23.59	3.73	14.93	3.96	
8		1.86	5.87	.0	9.84	6.41	1.64	
9	8.88	6.30	10.16	5.71	38.07	6.68	6.53	3.43 - 63.83
10		18.44	6.73	12.54	63.83	3.43	5.89	

TABLE 19

Phaeopigment/Chlorophyll *a* ratios measured during monthly site visits
(January through June, 1981.) Overall range = 0 - 9.53

Station #	Sept.	J	F	M	A	M	J	Overall Range/Pond
1	1.00	9.34	.0	.88	4.17	9.53	2.25	0 - 9.53
2	.34	.32	.18	.76	.71	.95	.57	.18 - .95
3		.36	.28	.33	.88	.46	.82	
4	.20	.08	.28	.21	.60	.29	.61	.08 - .77
5		.45	.32	.18	.73	.77	.56	
6	.14	5.74	.24	.36	.57	.33	.34	0 - 5.74
7		1.91	.0	.88	.44	.62	.32	
8		.97	.21	.0	1.10	.58	.32	
9	.82	.10	.16	.19	.81	.45	.72	.10 - 1.74
10		.37	.19	.29	1.74	.25	.68	

C. Sediments

Results from the transects of vertical profiles are shown in Figure 13. The Tub, being relatively absent of sediment, was not included in this transect work. Water depth (from surface to lava basin) was greatest in Kalahuipuaa pond (18 feet), as was the sediment thickness (7 feet). Much of the sediment in Kalahuipuaa was sand brought in from adjacent coastal beaches under high surf conditions.

The profile data indicates that the majority of the sediment material collects in the undisturbed, deeper portions of the pond basins from gravity and hydraulic forces. Sediment build-up is entirely absent along the rocky or sandy makai fringes of Kalahuipuaa and Waipuhi ponds and also absent in the transect adjacent to the west makaha in Kalahuipuaa. The sources of fine sediment are both biogenic (debris and detritus from natural productivity within and around the ponds) and physical (windblown lava/soil erosion and transport). Three random surface samples of mud that were dried and combusted gave the following results:

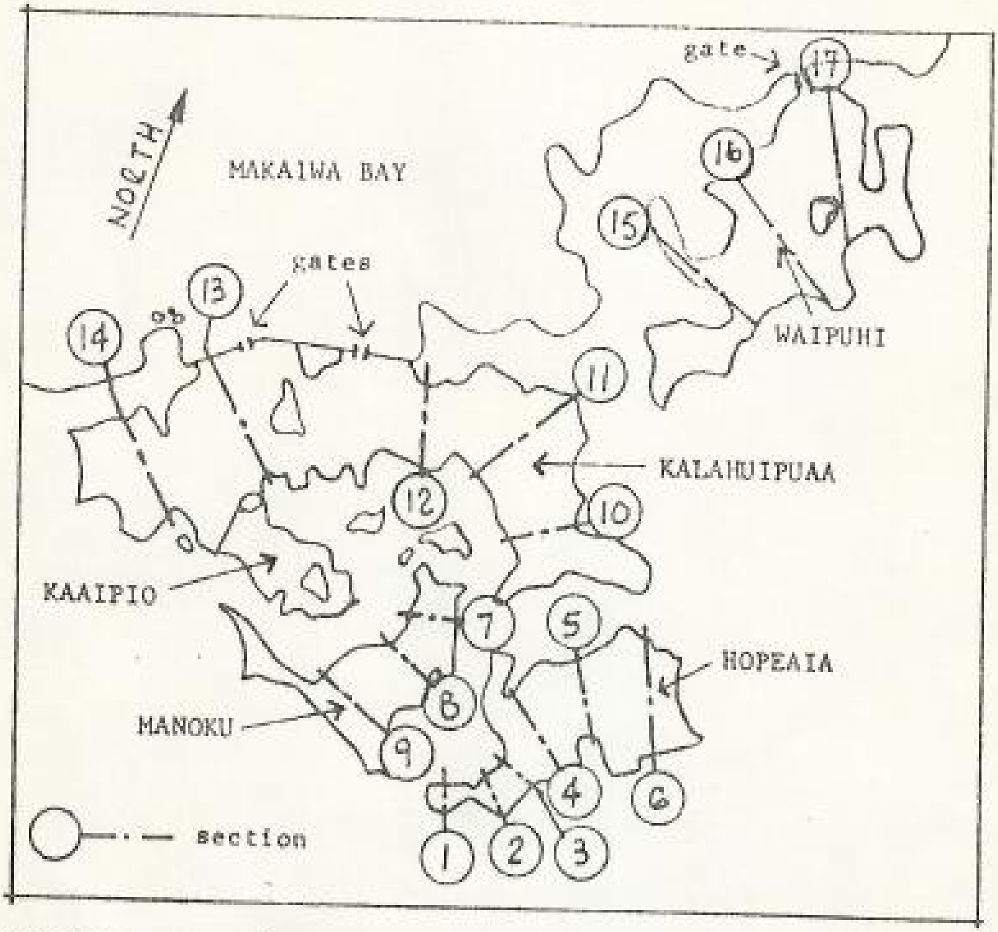
Average water content	78%
Average solids content	22%
Average dry weight of inorganic mineral salts	86%
Average dry weight of ash free organic matter	14%

Carbon 14 analysis of the core bottom sediment layer (4 feet in Manoku, 6 feet in Kalahuipuaa) gave these results:

	Manoku	Kalahuipuaa
Average water content	60%	31 - 65%
Average solids content	40%	35 - 69%
Carbon content	3 - 4%	0 - 4%
Core bottom date	250 B.C.	1000 A.D.
Average sedimentation rate	.06 cm/yr.	.19 cm/yr.

An optimum sample would contain 50% carbon, these bottom sediments contained only 4% carbon. That meant that very large samples of core sediment had to be combusted. The yields, therefore, were extremely crude, giving very rough estimates that the bottom of the sediment layer was formed approximately 2,200 years ago in Manoku and 1000 years ago in Kalahuipuaa. For more accurate dating of the pond sediments, it was recommended that carbonate mollusc shells (found in layers in the core samples) be dated instead of the fine, inorganic sediment.

Figure 13



Reference map and accompanying figures report data from transects taken to determine water depth (to lava basin) and sediment thickness.

For the vertical profiles, NOTE:

Horizontal is not to scale.
Probes were made at banks,
quarter-, and mid-points.

⌇⌇ Macroalgae

☐ Soft, fine sediment

	Range (in feet) of	
	Water Depth	Sediment Thickness
Hopeaia	1 - 8.5	0 - 3
Manoku	3 - 16.5	0 - 6.5
Kalahuipuaa	1 - 18	0 - 7
Waipuhi	1.5 - 5.3	0 - 2.5

Figure 13 (contd.)

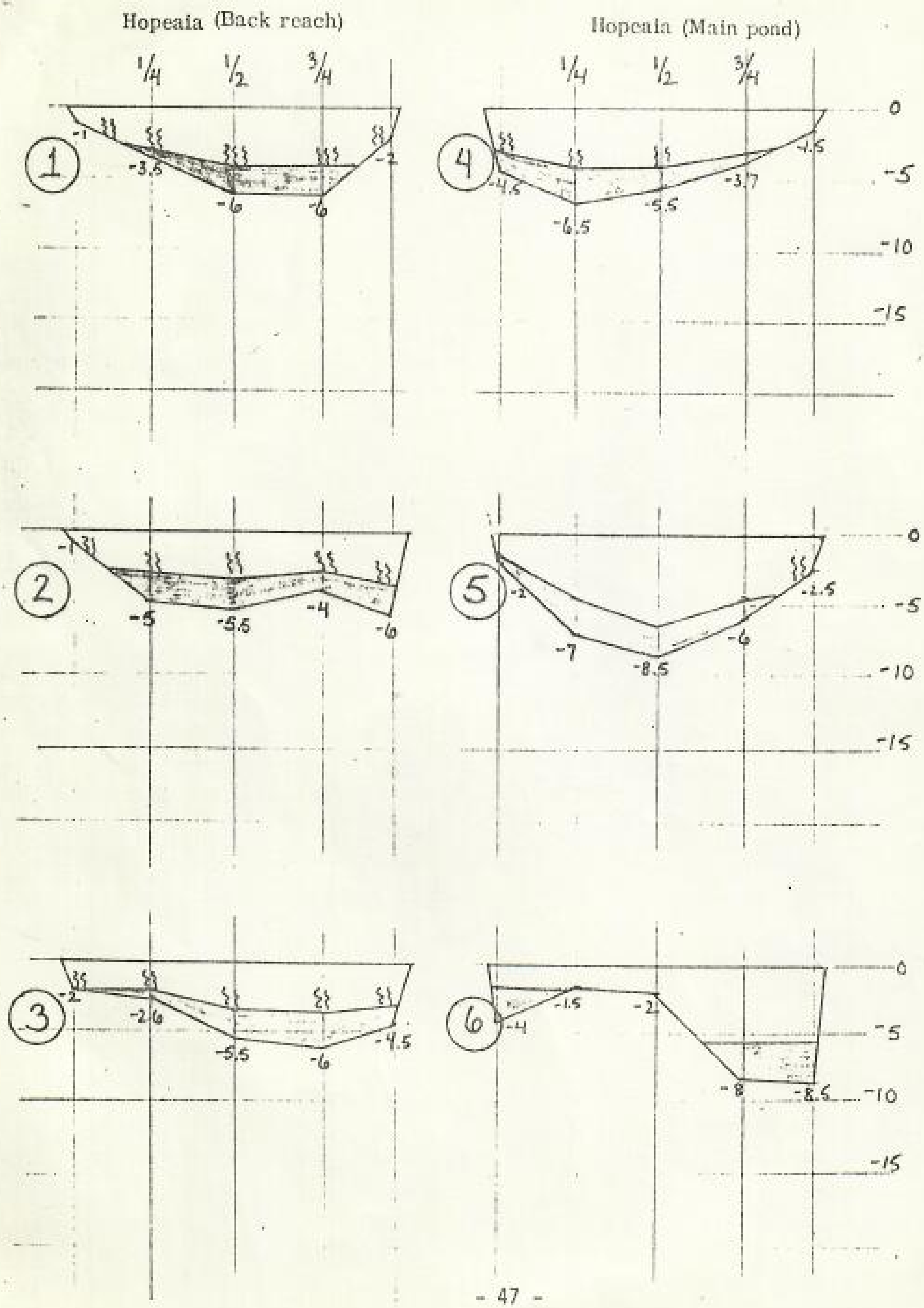
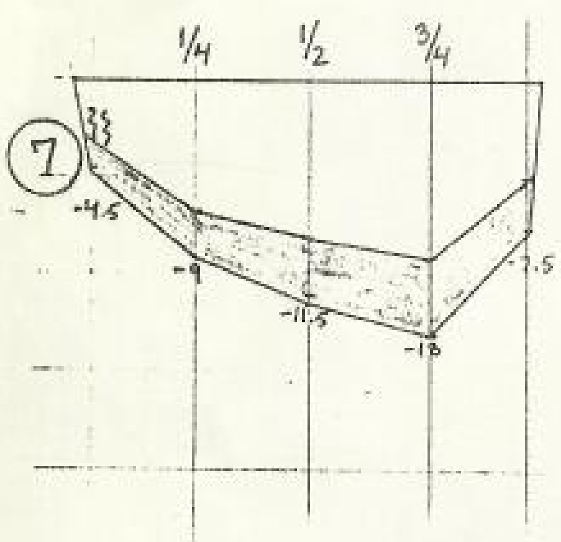
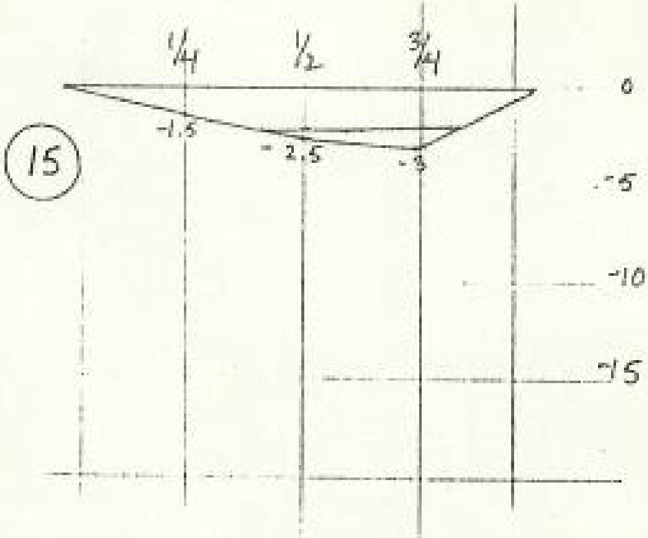


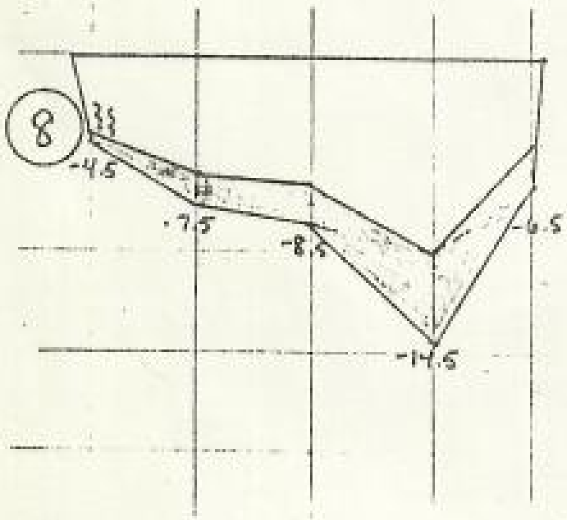
Figure 13 (contd.)

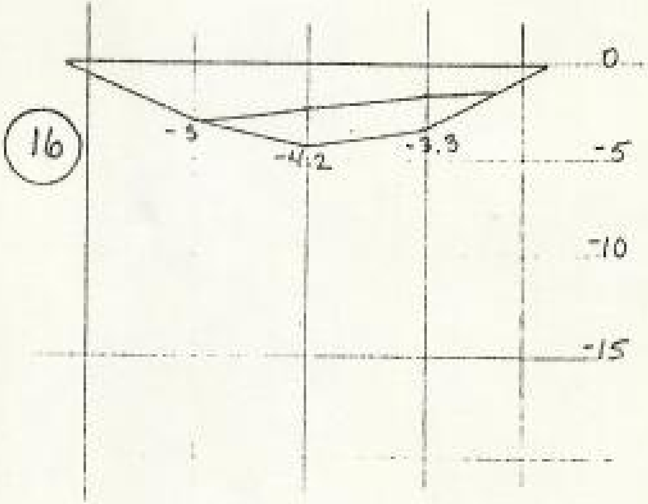
Manoku

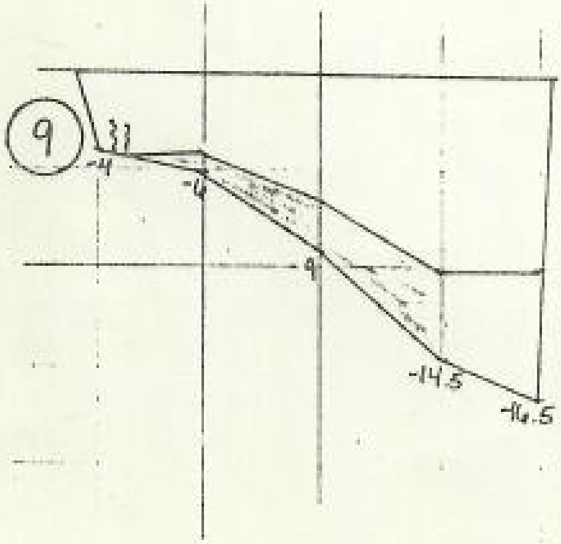
Waipuhi











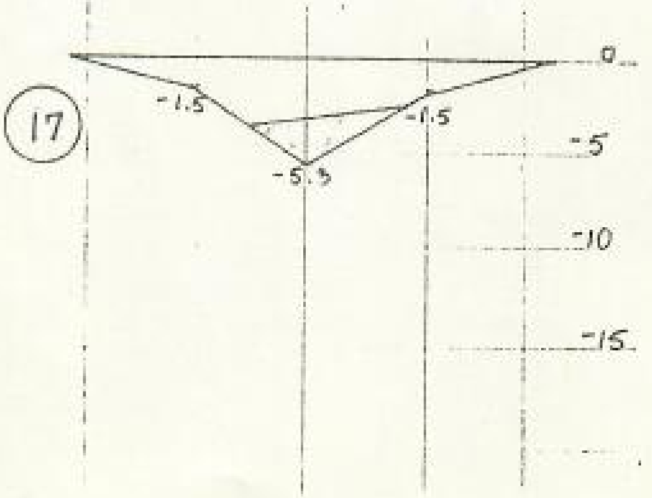
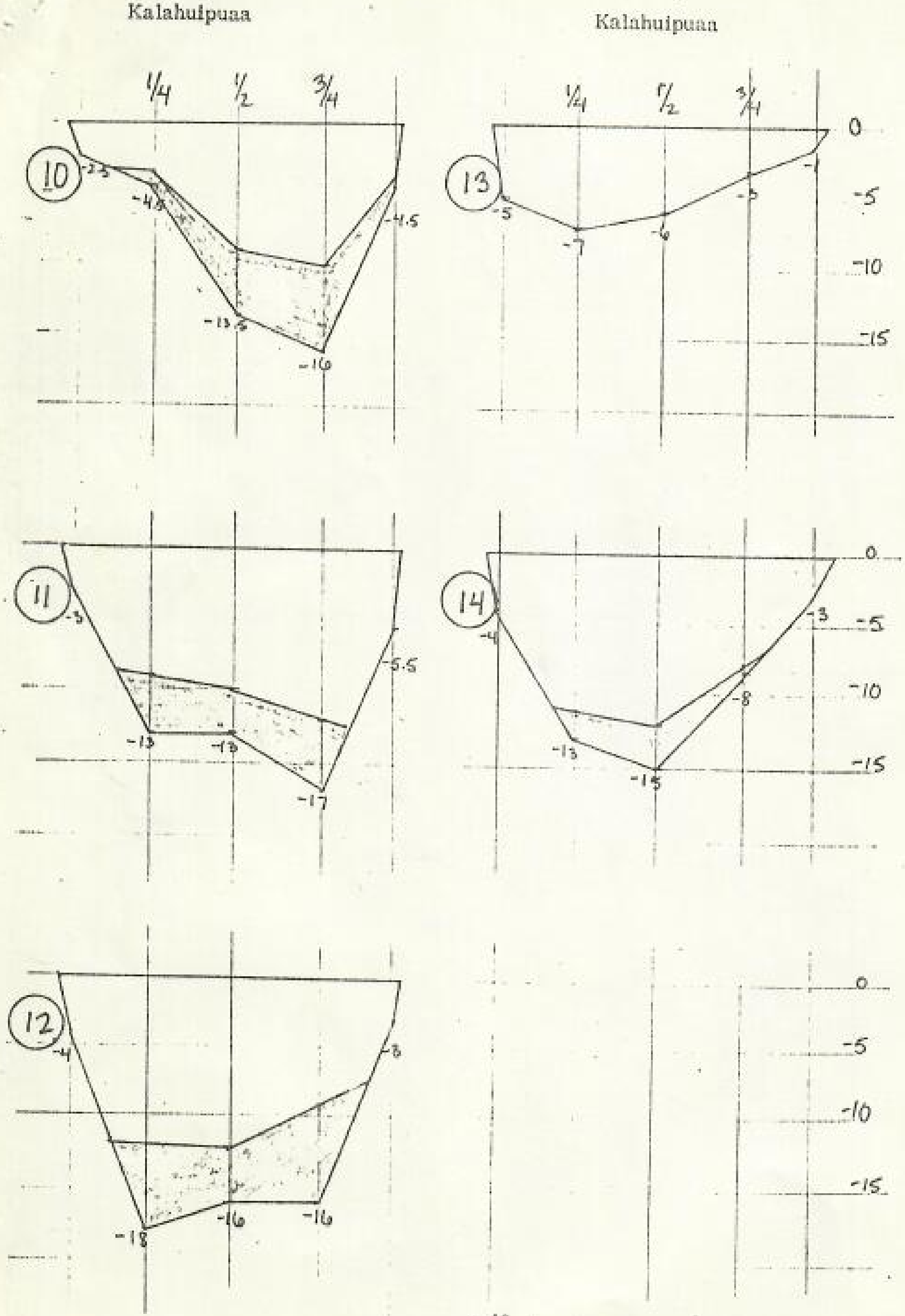


Figure 13 (contd.)



D. Hydraulic Behavior

The ponds show substantial changes in water level and volume in response to tides in adjacent coastal waters. Measurements taken from 4 stations: the Sea, Kalahuipuaa, Manoku, and Hopeaia during a 24 hour tidal cycle are reported in Table 20. From these observations, the water levels in general decreased in expression of the tides in the mauka direction, the dampened tidal response in Hopeaia and Manoku is presumably because their basins are less porous from sediment build-up or are blocked physically with underground dikes or other obstructions. The elevation range is 75 - 85% of the tide range measured outside the seawall. The phase lag between the oceans and these ponds varies from 15 minutes in Kalahuipuaa to one hour 10 minutes in Hopeaia. This suggests that the ponds behave hydraulically as a unit in response to the tides, although the phase lag and partial expression of tide changes from the sea mauka suggest decreased permeability through the walls and floors of the mauka ponds.

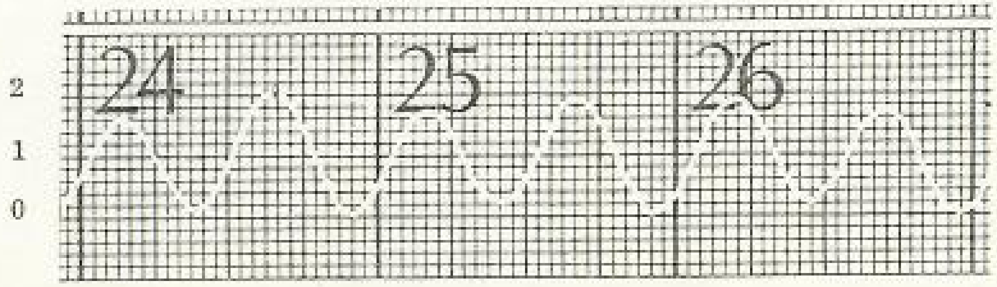
The hydraulic behavior of the ponds is controlled subterraneously by the lateral flow and ebb of seawater with the tides and from the persistent intrusion of groundwater of the basal lens which extends over the entire island near sea level.

Freshwater from rainfall accumulates in widespread bodies to form this basal lens which floats on the slightly heavier seawater permeating the entire island base, slightly below sea level. The interface of tidal water and groundwater, known as the Ghyben-Herzberg lens, is the brackish mixing of seawater and freshwater found within the ponds. The extent of groundwater/seawater mixing and flow patterns is dependent upon the topography and structure of underground lava in the surrounding area. Dikes may block groundwater outflow and channel it into lava tubes as underground streams.

In addition to subterranean movement of sea and fresh water, the makahas on the seawalls of Kalahuipuaa and Manoku allow direct flow from the sea in and out of the ponds. This direct flow is impeded at present by rocks, debris, and sediment choking the sluices.

Table 20. Tidal response in the Kalahuipuaa fishponds. Measurements were taken from each of four stations every fifteen minutes from 10 am on 25 September to 10 am on 26 September, 1980. Times of highs and lows are estimated from curves drawn through plotted observations.

Station	Low		High		Difference (ft)	Low		High		Difference (ft)
	Time	Height	Time	Height		Time	Height	Time	Height	
Sea	1100	-.46	1700	+1.60	2.06	2305	-.56	0515	+1.78	2.34
Kalahuipuaa	1115	-.28	1720	+1.40	1.68	0000	-.51	0600	+1.55	2.06
Manoku	1130	-.26	1730	+1.45	1.62	0005	-.48	0605	+1.58	2.06
Hoopeaia	1140	-.19	1745	+1.43	1.71	0015	-.41	0615	+1.57	1.98



IV. RECOMMENDATIONS FOR POND RESTORATION AND MANAGEMENT

The inventory of biological and environmental characteristics, obtained over the past year, show that in an anthropomorphic sense the ponds are in good health and are showing signs of growing old. Senescence is common to enclosed water bodies and results in the gradual disappearance of ponds due to the accumulation of biogenic and mineral deposits from sources in and surrounding the ponds. As sediments fill in the basins, salt tolerant plants encroach from the edges into the mud and a damp, marshlike ecosystem evolves as the ponds become increasingly shallow and eutrophic. Conditions promoting senescence include high exposure to sunlight and nutrients,shallow basins, and weak connections to the water table or coastal seawater. All these conditions are apparent at Kalahuipuaa.

In addition to the natural senescence phenomenon, the ponds are also influenced by development activities occuring on the site. Windblown dust from nearby construction and topsoil from the golf course have recently accelerated a sedimentation rate, witnessed by visual observations over the past year. In addition, fertilizer nutrients are leaching down through the porous lava substrate under the golf course turf layer and are appearing in the groundwater which feeds the ponds. All ponds show signs of nutrient enrichment.

1. Continued Monitoring

The ponds will continue to respond to new modifications that will be made to the surrounding area. These include cesspool operation of the Club House, planned condominium construction, and landscaping within the fishpond complex, as well as changes made to the fishponds themselves such as rehabilitation of makahas, dredging for removal of silt, and management of fish stocks.

To be alerted of potentially dangerous inputs to the ponds, which could threaten all or a portion of the flora and fauna, periodic sampling of selected indicators is suggested.

1. Nitrate concentrations should be measured on a monthly or bi-monthly basis to determine whether the current trend of increase persists. The Tub would be most sensitive to detecting further enrichment.
2. Herbicides, or other synthetic chemicals can be monitored in the ponds as they may also be leaching down into the groundwater and may present toxic conditions to crustaceans and fish if allowed to accumulate.
3. Dissolved oxygen concentrations should be periodically spot-checked, especially at the pond bottoms of Hopeaia and Manoku and during early morning hours before daylight when oxygen levels would be lowest from nocturnal community respiration.

2. General Maintenance

Full time maintenance is necessary to avoid the poor state of housekeeping that has been observed in and around the ponds. Fallen debris (fronds, nuts, leaves, branches, etc.) from coconut and milo trees should be removed weekly. Trimming of milo and coconut and culling excessive volunteer plants should be frequently done to maintain the well established community in a controlled natural process. Continuous cleaning will improve the appearance of the ponds and also directly minimize the input of excessive organic matter which increases the biomass load in the fishponds. Encouraging the growth and colonization of the halophytic ground cover plants is recommended to enhance and perpetuate the natural beauty of this unique ecosystem.

3. Makahas

The size and configuration of the fishponds make them extremely difficult to control or harvest fish populations. They are far from resembling the engineering design of present day aquaculture systems that maximize control and capture ability in regular rectangular shaped containments. The back ponds, Hopeaia and Manoku, have no means of harvest control and fish must be seined or trapped. Waipuhi and Kalahuipuaa are worked through their makaha systems. The makahas have been little used in recent times and require substantial attention for their repair and restoration. The gates, sluices, and walls of Kalahuipuaa and Waipuhi ponds should be cleared and repaired to permit free exchange of seawater in and out of the ponds. Sand, rock, and other debris should be cleared from the sluice down to hard sill. The outer gates should be replaced with new wood and stones.

4. Control of Predators

Complete removal of predator populations (papio,ulua, kaku) from the fishponds is impossible. Larvae of all these species are microscopic in size and they will enter through the mesh of any practical gate screen that separates the fishponds from the sea. Once in the fishponds, these carnivorous larvae will rapidly grow on the abundant food supply of microorganisms. As they grow, they also remove any small juvenile mullet or milkfish recruits that are introduced into the ponds.

A workable objective therefore, is to control, and not eliminate, predators by selectively culling larger individuals on a routine basis. This can be done by working the gates and trapping them by hook and line fishing, seining the entire ponds with a very heavy, small mesh net, or by blasting them out of the water from the shooting towers already on site. In addition, any new recruits that are intentionally introduced should be large enough to escape from the mouths of the predators.

5. Individual Pond Management

Tub: The Tub and other small anchialine pools should be maintained in their present condition, designated as natural preserves for the endemic opae species and kept free of fish stocks. The flora and fauna of these ecosystems are perpetuated by biological checks and balances. They require no modification other than maintenance for removal of trash and dead organic matter.

As previously mentioned, these shallow enclosed pools are most directly affected by changes in the groundwater, evidenced by nutrient enrichment measured over the past nine months. Because of this, they will be most sensitive to large doses of pesticides or herbicides introduced to the groundwater.

Hopeaia: Having no direct connection to the sea, and having up to 3 feet of bottom silt, Hopeaia suffers from minimal tidal flushing. The pond is shallow, eutrophic, and reflects groundwater enrichment. It is difficult to harvest due to sediment buildup and a very irregular shape. We first recommend that Hopeaia be seined to remove large predators and to thin out stocks of mullet and milkfish. The objective is to maintain a small population of mullet and milkfish to lessen the biomass load on the ecosystem. In addition, we have suggested that this pond be considered for dredging. Details are discussed in correspondence to Manua Lani Resort Inc., July 2, 1981. We recommend that the fringe areas be dredged using a suction hose/trash pump to alleviate odors from microbial decomposition and to improve the hydraulic exchange in the ponds.

Manoku: Although Manoku has a greater water depth (3 - 16.5 feet) than Hopeaia, it has greater sediment buildup (0 - 6.5 feet) and is also characterized by minimal tidal flushing, eutrophication, and groundwater enrichment. We recommend that this fishpond be seined to remove predators and to thin out stocks with the same objective described for Hopeaia. Manoku is also recommended for dredging considerations to improve the quality and to extend the lifespan of the pond ecosystem.

Waipuhi: Because of its proximity to the sea, this fishpond has adequate water exchange and the least sediment buildup of all the ponds. It is also the most shallow due to its natural configuration. Most of the predators in Waipuhi were removed during the summer of 1980, though several large kaku still need to be eradicated. It was noted at that time that few fish larger than 2 feet occupy the pond. It appears that under extreme tide or surf conditions, the larger fish are able to escape over the makai embankment to the sea. This embankment should be strengthened to avoid these losses. After repair of the embankment and makaha, the excess stock from seining Hopeaia and Manoku ponds should be introduced into Waipuhi. In addition, the back reach of Waipuhi is suitable for a nursery pond. No dredging is recommended.

Kalahuipuaa: This pond seems to be the most highly productive and well balanced of all the major fishponds. Healthy populations of large mullet and milkfish coexist with other fauna. Turbidity is generally low and water turnover rate is high. Water quality levels are most stable. As the largest pond, it is also the deepest and most difficult to seine. Maintenance of the makahas is required for harvesting and control of predators. The Kaaipio portion of Kalahuipuaa is suitable for a nursery grow-out pond which provides protection for small fish, until they are large enough for the main pond. No dredging is necessary.