Technical Report No. 60

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THE QUALITY OF COASTAL WATERS: FIRST ANNUAL PROGRESS REPORT

SEPTEMBER 1972

Water Resources Research Center

University of Hawaii, Honolulu, Hawaii

QUALITY OF COASTAL WATERS

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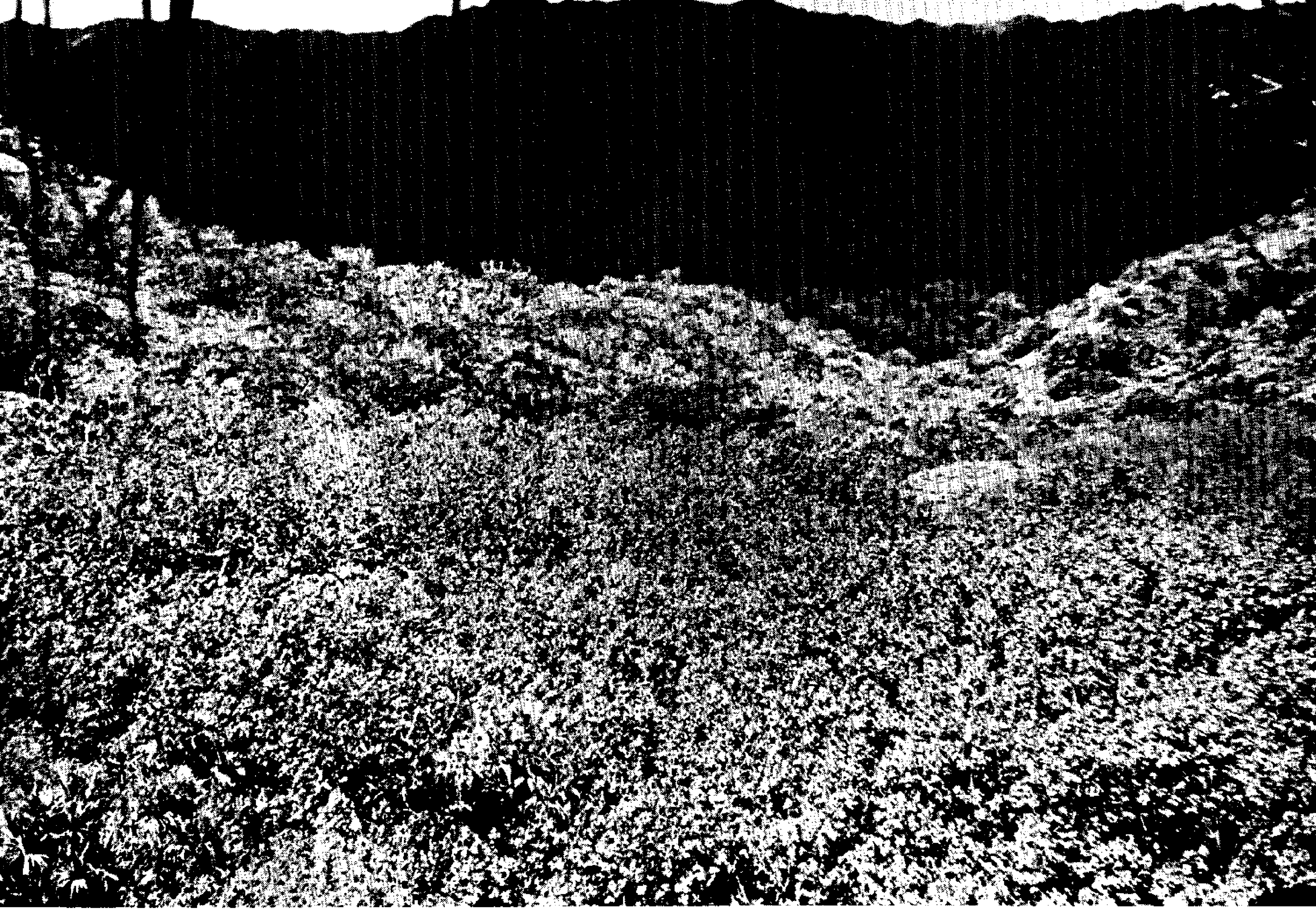
UNIVERSITY OF HAWAII HONOLULU, HAWAII



FRONTISPIECE. VIEW OVERLOOKING PRISTINE AREA OF KAHANA VALLEY, OAHU.

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FIRST ANNUAL PROGRESS REPORT

sea grant program, year 04

Project Principal Investigator

L. STEPHEN LAU

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Year 04

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Planned Duration of Research:

Sea Grant 04, 05, 06 years, September 1971 - August 1974

ABSTRACT

The nature and results of the first year of experimental and evaluative work of the Coastal Water Quality project of the University of Hawaii's Sea Grant Program are summarized in this report. The project is a multi-directional, multi-disciplinary study directed to the general objectives of identifying and evaluating the social, political, economic, educational, institutional, and scientific and technological factors which impede or expedite the protection and restoration of coastal water environments in Hawaii, as well as of developing the crucial scientific and rational parameters needed in formulating effective policies institutions and systems. To this end, the attainment of eight specific objectives is assigned to appropriate faculty specialists participating in 14 activities which comprise the Project. These specialists have the additional duty of assisting the Principal Investigator in planning the work and in interpreting its results in terms of the general objective.

The project is unique in that it seeks to evaluate water quality in terms of stress or well being of aquatic communities, using the traditional chemical, biological, and bacterial parameters of water quality only to identify the factors and their concentrations which are of ecological significance. In turn the ecological findings are utilized to refine the standards and criteria applicable to traditional parameters.

Kahana Bay was selected as a coastal water under the influence of relatively undeveloped land. Data already available on the physiography and hydrology of its drainage area, its estuarine and oceanographic aspects, and the nature and movement of its sediments were supplemented by a program of analysis of water and sediments and its biota. As in all situations especial attention was given to the pesticides, heavy metals, and nutrients in water and sediment and to evidence of stress on aquatic communities.

Significant findings, which will, if further substantiated, be of value to regulatory agencies of the State, are that only when diluted heavily with fresh water did the dissolved oxygen content in the estuary meet the class AA standard designated for Kahana waters and the phosphorus content was mostly at class AA level (0.02 mg/l) but this value was exceeded seasonally. Nitrogen, and coliform organisms showed a similar, although more variable pattern. Thus Kahana Bay tended to satisfy the class A standards rather than the class AA standards for which the Bay is classified by the State.

DDT and PCB (pesticides) in Kahana Bay waters and sediments appeared at levels which seem to be ubiquitous in nature. Heavy metals, particularly Pb, Cd, Zn, and Cu appeared in the sediments in no identifiable pattern and apparently depend on the parent geologic formations from which the sediments are derived.

Sugarcane production and milling wastes were studied on Kauai. Observations of mill waste discharge and coastal water, sediments, and biota were made both before and after the 90-year old Kilauea Sugar Company closed down its operations in north Kauai. Untreated mill wastes were found to be the major contributor of wastes from the industry, carrying coliforms, sediments, trash and bagasse. The effect was largely an extensive visible plume and debris in the waters. Sediments, rather than water, harbored most of the nutrients, heavy metals, and pesticides in the ocean. DDT, although not used by the sugarcane industry, was present in small amounts in all waters and

sediments. Herbicides used in sugarcane culture did not appear in coastal water. A striking improvement in the aesthetic aspects of the coastal water quickly followed the cessation of mill waste discharges. Fish and other aquatic biota reappeared rapidly after the cessation of mill operations. Longer term changes in the biota are yet to be assessed.

Studies were begun in south Kauai late in the report period to assess the effect of changed operational practices by the McBryde Sugar Company subsequent to an EPA survey of coastal waters of the area in 1968. Company practices demonstrate that it is possible to operate milling operations without discharge to the ocean, and to prevent irrigation tailwater overflows except flooding due to intense rainfall. At the time of reporting no pesticide residues were found offshore except for the 1 part per trillion DDT which seems to be present everywhere.

Studies by others on the Hamakua Coast and elsewhere generally show reduction in abundance of biota within the area (perhaps one mile) where waste sediments from mill discharge blanket the normal bottom.

The effects of urban wastewater, especially sewage, were studied during the report period largely by cooperating with the City and County of Honolulu and the federal agencies in Hawaii engaged in major investigations and projects such as sewage treatment at Sand Island, Pearl Harbor, Kaneohe Bay, and Mokapu Point. The role of the Coastal Water Quality Project in these major enterprises are described in the report. In less extensive situations at Sandy Beach, Waikiki, Maunalua Bay, and Manoa Stream, the Project is amassing data for the effects on the coastal environment of surface runoff and general human activities in urbanized areas. Preliminary findings are included in the report.

The overall objective for the identification and evaluation of the separate effects of various land uses on the quality of coastal waters is to interpret them in terms of changes in the institutional, economic, and social systems needed to achieve the environmental objectives of the state.

To enable researchers to begin this aspect of the study, statutory changes and the zones of mixing that have been granted since 1967, when the federal-state water quality standards were adopted, have been compiled. By continuing to tabulate such institutional changes, the opportunities to integrate relevant scientific knowledge into social policy will be enhanced.

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chapter 1

Introduction

NEED FOR STUDY

A need for studies of the type herein reported stems both from broad general factors of major national significance and from more specific environmental considerations of water quality which are of immediate concern to the nation and to the state of Hawaii.

In the broader of these categories, two factors are particularly noteworthy (1) mounting pressure of human population on declining non-renewable natural resources, and (2) inadequacy of a fragmented approach to environmental management to serve the long-term welfare of man and his fellow creatures or, perhaps, to assure their very survival. Both of these factors are so new to American experience that a brief discussion of their implications may contribute to an understanding of the rationale underlying the work herein reported.

As the decade of the 1970's began, Americans generally agreed that in numbers mankind had gotten out of scale with the carrying capacity of the earth, but disagreed sharply on what to do about it. The basis for agreement was identified by Kenneth Boulding when he noted that man has gradually "been accustoming himself to the notion of a spherical earth, and the closed sphere of human activity"; and that the development of the air age has finally caused the global nature of the planet to enter the popular imagination. The basis of disagreement was likewise pointed out by Boulding, "Even now," he said, "We are very far from having made the moral, political and psychological adjustments which are implied in the transition from the illimitable plain to the closed sphere."

Disagreement on what to do about population and population-generated environmental problems reflects both the humanitarianism, which leads man to reject nature's harsh measures for population control, and his imperfect understanding of his own role in a closed system. In common with the rest of mankind, Americans crowd into cities and complain with supreme illogic that there is no "open space" there. And indeed there is not enough space in cities to dilute man's numbers; the air and water are insufficient to dilute his wastes; and little land is available to accept his residues and rejects. The fact that by physical coalescence man may be creating more open space is ignored in the presence of a catastrophic overloading of the physical resources of an area. Thus the urban dweller is easily persuaded that man is a super-predator and can be prevented from destroying the ecosphere only by measures which, if carried out, would likely cost us our entire scientific agriculture, much of our population, and most of our level of civilization. Because this is a price society shows little willingness to pay, it is all the more urgent that the transition from "illimitable plain to the closed sphere" be promptly made so that effective measures may be taken to conserve resources. Clearly from the standpoint of population pressure on natural resource there is a need for the study herein reported.

From the viewpoint of the inadequacy of a fragmented approach to water quality management, the need is no less urgent. Fragmentation of concern for air, water, and land resources and fragmentation of the jurisdictions and institutions established to deal with each has been so customary as to become traditional. Thus depreciated water quality is thought of in terms of "the pollution problem" as though it existed as some discrete entity which could be reshaped more nearly to man's desires through the application of physical force or institutional pressure. Perhaps this is one reason why the quality of water resources has continued to deteriorate despite many efforts to isolate water pollution and bring it under control. However, as the concept of a closed sphere emerges, it becomes evident that in reality there is no such thing as "pollution problems" - only *situations* which represent the consequences of actions of both man and nature in a vastly complex system. In the language of systems, what appears to us as "problems" are the feedbacks resulting from many interactions within the system. In no context is this fact more observable than that of the quality of coastal waters. Consequently, past failure of the fragmented approach, as well as the pressures of population, identifies a need for studies which assess the potential of urban man in his metropolitan, industrial, and agricultural land development and land use practices to degrade the quality of coastal waters, together with an evaluation of its possible consequences and of methods for its control.

When the specific environmental implications of the quality of coastal waters is the matter of concern the need for study appears in sharper detail. The 1970 census revealed, for example, that more than 80 percent of the nation's population lives in cities. Moreover, during the decade of the 1960's, a general shift in population to both the east and west coasts took place, bringing to 75 percent the fraction of the U.S. population living in states bordering on the oceans or the Great Lakes. Twelve of the nation's 13 largest cities are located in the coastal zone, with 53 percent of all U.S. citizens living within 50 miles of the sea coast. Other reports reveal that more than 60 percent of all recreation is water-oriented. Thus it is self-evident that the impact of urban man on the coastal water environment is of paramount national concern.

Several factors combine to make coastal water quality a far more critical matter in the state of Hawaii than in the nation as a whole. Unlike the mainland where the shoreline-to-land ratio is quite small, direct association with coastal waters and with the shoreline environment is a cultural heritage of essentially 100 percent of native Hawaiians. At least four other phenomena contribute to a situation unique to Hawaii:

a) The state is experiencing both the western migration of man which has been going on for centuries, and which has so dramatically overpopulated some areas of the mainland, plus an eastern migration of people for a variety of complex social reasons, of which only the superficial economic motives are well understood.
b) The favorable climate of Hawaii, its semi-tropical water and air temperatures, its ocean beaches, and a still viable aura of romance increasingly attracts tourists from both west and east in numbers which are of great importance to the state's economy.
c) Because Hawaii has no continental shelf, much of the state's finest recreational and ecologically important waters depend upon the integrity of coral reefs, where life may be threatened by changes in coastal water quality.
d) The state is comprised of islands with different economic bases. For example, the sources of water pollution on the island of Oahu may include urban, industrial, and agricultural activities of man, whereas, on another island, Kauai, activity of the sugar industry may account for most of the man-generated wastes reaching coastal waters.

From considerations such as the foregoing, it is concluded that the need for study involves specific situations in Hawaii which have in them the elements necessary to produce information that can be interpreted in terms of that specific situation, the nation in general, and the broad social and cultural problems of resource management.

RATIONALE OF STUDY

Although the full implications of the concepts which define a need for study are beyond the scope of this writing, the study reported here proceeds from the rationale that what man does on the land pursuant to any of his various goals determines his contribution to the nature of coastal waters and to the quality of life within such waters. This does not imply that the contribution itself can be easily isolated and evaluated in detail, but it does recognize that proclaiming specifications or standards for discharged water will not per se resolve something popularly called, "the pollution problem". The heritage of Americans to own land and to manage it with a minimum of constraints is too deeply established to be drastically altered by piecemeal attempts to control air pollution and water pollution by enforcement of standards. In such a situation, reason suggests that control of man's freedom to develop, use, and manage land is the key to coastal water quality and, indeed, to all other of his environmental goals. At the same time, reason cautions us that the economic life of the nation, every aspect of the welfare of its citizens, and the national standard of living depends upon exploitation of the resources of the land. Therefore, the study proceeds from the rationale that the relationship between various land use practices and coastal water quality should be determined as a basis for wise and effective policy decisions and institutional arrangements for carrying out public policy. To this end, it is postulated that scientists must reveal the linkages or bridges in the overall waste-generating system where effective actions are possible, and indicate what action is appropriate; legislators and society at large must weigh the consequences of such actions in terms of loss of freedom of choice in other contexts, as well as of effects on economic life; and institutions must reflect the considered judgment of society rather than any current emotional reaction to some single environmental dislocation in the system.

OBJECTIVES OF STUDY

Pursuant to the needs and the rationale outlined in preceding sections, the study herein reported was directed to both general and specific objectives.

General Objective

The general objectives of the project were to identify and evaluate the social, political, economic, institutional, educational, and scientific and technological factors which either impede or expedite the protection and restoration of the quality of coastal waters in Hawaii and to develop and interpret the crucial physical, chemical, biological, and rational parameters needed in formulating effective policies, institutions, and systems.

Specific Objectives

To achieve the general objectives of the study eight specific objectives were established. These were to:

a) Identify the origin and measure the amounts of such quality factors as nutrients, pesticides, toxic metals and chemicals, degradable organic matter, and sediments which enter coastal waters in the selected typical situations.
b) Determine the fate of the foregoing influent quality factors by measuring their concentration in coastal water, sediments, and biota of selected coastal environments.
c) Monitor the changes in water quality and in associated ecosystems, which follow changes in discharge of sewage and of sugar mill wastes at opportune locations.
d) Evaluate the adequacy of coastal water quality standards and criteria, as presently conceived, to insure the desired quality of ecological environments in such waters.
e) Develop scientific data and parameters on which to base coastal water quality protection measures and systems in future urban or agricultural land development in the state of Hawaii.
f) Recommend the changes in policy, institutional arrangements, water quality parameters, and practical measures necessary to protect coastal waters.
g) Assess the economic and social effects of changes associated with the measures recommended under objective.
h) Maintain an informational and advisory program designed to keep citizens, lawmakers, public officials, students, and members of the lay and professional communities informed of the project findings and the implications of the recommendations they support.

The specific objectives of the study were further broken down to identify the tasks to be achieved by each of several project activities which, as described in subsequent sections of this chapter, comprised the project.

NATURE AND SCOPE OF PROJECT

The Quality of Coastal Waters Project which comprises the study was planned as a multi-disciplinary, multi-directional approach to two types of problems:

a) Those which involve solutions to specific critical instances of coastal water pollution already existing in Hawaii, and
b) Those which provide the scientific parameters and define the institutional arrangements necessary to preclude a repetition of past coastal water pollution situations as land development proceeds in other areas of the state.

Pursuant to the objectives of the study a single project was designed in such a fashion that the exigencies of budgetary support or other unpredictable constraints might be met by changes in the scale of the project without affecting its scope in other than a time dimension. In scope, the project was designed to embrace typical situations in which quality factors are influenced by identifiable land use or land management practices. The initial list of types of land use and resulting waste discharges, together with typical situations in which relationships might be studied was:

a) Undeveloped land areas, *e.g.*, Waialua Bay, Oahu
b) Sugar mill wastes, *e.g.*, Kilauea and McBryde Sugar Companies, Kauai
c) General agricultural land, *e.g.*, Waialua Bay, Oahu
d) Urban land development, *e.g.*, Sand Island, Mamala and Kaneohe Bays, Oahu
e) Industrial development, *e.g.*, Kapalama Stream, Oahu

Subsequently, situtations of lesser geographic scope were added as opportunities for cooperation with other ongoing studies presented themselves. These are reported in individual chapters dealing with the 6 foregoing types of land use or waste discharge.

The project was structured into 14 areas of activity. As shown in Tables 1.1, 1.2, and 1.3, some of these were investigative in nature while others combined investigative and evaluative work. Three activities included evaluation, interpretation, and reporting. A portion of the investigative work was experimental, the remainder involved personal interviews, consultation with others, and literature searches. Both aspects included constant cooperation with agencies and projects concerned with coastal water quality studies and management systems.

Organization of Project

Responsibility to the Sea Grant program of the University of Hawaii was delegated to L. Stephen Lau, Director, Water Resources Research Center in the role of Principal Investigator of the Project. Each project activity was delegated to an appropriate Affiliate Investigator in order to bring to each activity the highest possible level of competence. Names of these investigators, together with their specialty areas and the phenomena to be investigated, are presented in Tables 1.1, 1.2, and 1.3.

In addition to the investigators in charge of each project activity, a number of Participating Faculty brought breadth of interest, scientific stature, and special competence to the various activities. Included in this group were:

H. Yamauchi, Associate Professor of Agricultural Economics
A. Russo, Instructor, Leeward Community College
G.L. Dugan, Associate Professor of Civil Engineering
Doak C. Cox, Director, Environmental Center
P.C. Ekern, Professor of Agronomy and Soils
Arthur Bevenue, Professor of Agricultural Biochemistry
S.J. Townsley, Professor of Zoology
Philip Helfrich, Associate Marine Biologist and Associate Director, Hawaii Institute of Marine Biology
P.F. Fan, Associate Professor of Geosciences
B.S. Gallagher, Assistant Professor of Oceanography
M.J. Chun, Assistant Professor of Environmental Health
J.M. Johnson, Assistant Professor of Environmental Health
Yoshihiko Kawano, Assistant Biochemist

The responsibility of each investigator shown in Tables 1.1 to 1.3 included management of his project activity, attainment of its goals within the allotted budget, preparation of activity reports, and service on a Project Control Group. This group, which also included Participating Faculty, met regularly at the call of the Principal Investigator to keep the project oriented to its stated objectives, to evaluate and interpret

TABLE 1.1. STRUCTURE OF COASTAL WATER QUALITY PROJECT.

AREA OF PROJECT ACTIVITY (INVESTIGATIVE) (RESEARCH)

OBJECTIVE FACTOR	INFLUENT TO COASTAL WATERS: ORIGIN	INFLUENT TO COASTAL WATERS: MATERIALS OR PHENOMENON TO BE INVESTIGATED	INVESTIGATOR	COASTAL RECEIVING WATER EFFECTS TO BE INVESTIGATED: CHEMICAL - PHYSICAL	COASTAL RECEIVING WATER EFFECTS TO BE INVESTIGATED: ECOLOGICAL AND BIOLOGICAL
VOLUME AND FLOW VARIATION	LAND SURFACE	WATER AND SEDIMENTS	R.H.F. YOUNG		
	MUNICIPAL WATER USE	SEWAGE		CONCENTRATION IN WASTE DISCHARGES	
POLLUTANTS (TYPES AND AMOUNTS)	LAND	NUTRIENTS	Y. KANEHIRO	CONCENTRATION IN COASTAL WATER AND IN SEDIMENTS	TOXICITY TO MARINE LIFE
	WATER	HERBICIDES	R.E. GREEN	DISPERSION IN OPEN SEA	EFFECTS ON CORAL AND ON REEF COMMUNITIES
	AGRICULTURE	INSECTICIDES	J.W. HYLIN	LOSS AT SEA	CONCENTRATION IN FOOD CHAIN
	MUNICIPALIT.	TOXIC METALS	H.Y. YOUNG	COMPARATIVE EFFECTS OF LAND DEVELOP- PRACTICES	REDUCTION IN SPECIES DIVERSITY
	INDUSTRY	COMMERCIAL & INDUSTRIAL CHEMICALS	H.W. KLEMMER		BIOSTIMULATION OF BIOTA
	HOUSEHOLDS	SEWAGE COMPONENTS	R.H.F. YOUNG		
		ECOSYSTEMS	E. ALLISON KAY		
		GROWTH OF CORAL	S.A. REED		
DISPERSION IN OCEAN	NATURAL LAND HUMAN ACTIVITY	SEWAGE AND POLLUTANTS	E.D. STROUP		

AREA OF PROJECT ACTIVITY (INVESTIGATIVE AND EVALUATIVE)

				RESULTS TO BE ACHIEVED
POTENTIAL FOR POLLUTION & POL. CONTROL	LAND USE, PRACTICES & POLICIES	POLLUTANTS ECONOMIC, SOC. & POLITICAL	D. POVEY	POTENTIAL OF LAND AND HUMAN ACTIVITY TO POLLUTE COASTAL WATERS; ECONOMIC & SOCIAL EFFECTS OF CONTROL

AREA OF PROJECT ACTIVITY (EVALUATIVE, INTERPRETATIVE, REPORTING)

OBJECTIVE FACTOR	COORDINATOR	RESULTS TO BE ACHIEVED
DEVELOPING ADVISORY & INFORMATION SERVICE	L.S. LAU	MAINTAIN DATA BANK AND EDUCATIONAL MATERIAL CONVERT PROJECT DATA AND EVALUATIONS INTO PRACTICAL RESULTS. SHOW NEED FOR, AND NATURE OF, REVISED LAWS AND INSTITUTIONS. INFORM PUBLIC OFFICIALS AND PUBLIC. EVALUATE ECONOMIC, BIOLOGICAL, AND PHYSICAL PROBLEMS OF COASTAL WATER QUALITY CONTROL.
RECOMMENDING WATER QUALITY CONTROL MEASURES		
REPORTING OF RESULTS		

TABLE 1.2. ORIGIN, QUANTITY, AND FATE OF COASTAL WATER QUALITY FACTORS.

ITEM NO.	INVESTIGATOR	SPECIALTY AREA	CONTRIBUTING RESEARCH ACTIVITY
1	R.H.F. YOUNG	SANITARY ENGINEERING	INFLUENT SURFACE AND WASTE WATERS AND ASSICUATED SEDIMENT LOADS
2	Y. KANEHIRO	SOIL SCIENCE	NUTRIENTS IN INFLUENT AND COASTAL WATERS AND SEDIMENTS
3	R.E. GREEN	SOIL SCIENCE	HERBICIDES IN INFLUENT AND COASTAL WATERS AND SEDIMENTS
4	J.W. HYLIN	BIOCHEMISTRY	ORGANOCHLORINE POLLUTANTS IN THE AQUATIC ENVIRONMENT
5	H.Y. YOUNG	SOIL SCIENCE	TOXIC METALS IN INFLUENT AND COASTAL WATERS AND SEDIMENTS
6	H.W. KLEMMER	MICROBIOLOGY	PESTICIDES AND COMMERCIAL CHEMICALS IN ECOSYSTEMS
7	R.H.F. YOUNG	SANITARY ENGINEERING	DOMESTIC SEWAGE FACTORS IN INFLUENT AND COASTAL WATERS
8	ALLISON KAY	GENERAL SCIENCE	ECOLOGICAL EFFECTS OF QUALITY FACTORS IN COASTAL WATERS
9	S.A. REED	ZOOLOGY	EFFECT ON QUALITY FACTORS ON GROWTH OF CORAL AND ON REEF COMMUNITIES
10	E.D. STROUP	OCEANOGRAPHY	DISPERSION INTO OPEN SEA
11	D.C. POVEY	PLANNING	POTENTIAL OF LAND MANAGEMENT TO DEGRADE COASTAL WATERS

TABLE 1.3. COORDINATING, EVALUATING, AND REPORTING INFORMATION.

ITEM NO.	COORDINATOR	SPECIALTY AREA	PROJECT ACTIVITY
12			ADVISORY AND INFORMATION SERVICE
13	L.S. LAU	WATER RESOURCES MANAGEMENT	CONTROL OF COASTAL WATER QUALITY
14			REPORTING OF RESULTS

results, and to determine appropriate changes in project emphasis or priorities. Duties of the Principal Investigator included both responsibility for project activities delegated to him by the Group, and overall budgetary and report accountability to the Director of the Sea Grant Program of the University.

Several agencies, beyond those cited in the Acknowledgements, participated in the project's data collection activities. Included were the City and County of Honolulu, Hawaii Department of Health, Civil Air Patrol, Kilauea Sugar Company, McBryde Sugar Company, Metcalf Farms Corporation, Kaneohe Marine Corps, the Corps of Engineers, the U.S. Navy at Pearl Harbor, EPA, Office of Pesticides, Division of Pesticide Community Study, and Kauai Community College.

NATURE AND SCOPE OF REPORT

The report is an Annual Progress Report covering the project activities for the period September 1971 to August 1972. An individual chapter is dedicated to each land use type studied and the various land use-water quality relationships which were investigated or evaluated for that type.

Because budgetary limitations, and in some cases the wealth of available information to be reviewed, precluded a simultaneous experimental study of all situations, some chapters are more inclusive than others. Nevertheless, some information is presented and evaluation in terms of the project objectives for all project activites scheduled for the year reported.

ACKNOWLEDGEMENT

Special acknowledgement is gratefully extended to Dr. P.H. McGauhey, Professor Emeritus, University of California, Berkeley, who has undertaken an important role in coordinating and preparing various sections of the report. John Mink undertook special tasks related to hydrology, geology, and geochemistry and reviewed the entire manuscript.

Among the project personnel, several have made special contributions to the preparation of the first report manuscript: Kay, Reed, and Russo in marine biota and benthic description, Stroup in Oceanography, Dugan in the Kilauea hydrology, Yamauchi in institutional arrangements, Gee in literature review and data summary, Klemmer and Fan in special data description.

Companion projects which contribute to the overall study of the quality of coastal waters include:

"A Marine Environment Study, Waikiki Beach," Department of Oceanography, University of Hawaii

"Diadromous Macrofauna and Kahana Stream--Estuary Ecosystem," U.S. Coop. Fish. Unit

"Mokapu Outfall Baseline Study," NSF and WRRC, University of Hawaii

"Reclamation and Reuse of Wastewater Effluents and Stormwater Runoff," WRRC, University of Hawaii

"Pollution in Hawaiian Watersheds," WRRC, University of Hawaii

"Recycling of Water from Sewage by Irrigation: A Pilot Field Study on Oahu," WRRC, University of Hawaii

"Water Quality Information Storage and Retrieval System for Hawaii," WRRC, University of Hawaii

chapter 2

Coastal Water Quality and Undeveloped Land

KAHANA BAY

Introduction

Inasmuch as the ocean is the sink in the hydrologic cycle where water flowing from the land abandons its burden of suspended and dissolved mineral and organic matter, some basic equilibria exist between land and coastal water quality and biota under even the most pristine of conditions. Obviously these equilibria are not replicated from situation to situation in Hawaii, or elsewhere, hence, no single area of undeveloped land can represent the full spectrum of conditions that might be expected to exist under undisturbed natural conditions. Nevertheless, the erosion of soil, the weathering of rocks, the decay of vegetation, and the extremes of nature govern the environment of estuaries, sustaining life on the one hand and helping at all times to make life dangerous. The integral of all these factors and their vagaries determines the nature and continuity of aquatic communities, and it it principally in the changes in stress on such communities that the most subtle effects of land development are reflected. The analytical chemist can help to identify the cause of any measurable stress and visual observation can reveal changes which may be merely esthetic or harmful or beneficial to certain species of aquatic organisms. Thus, if the effects of any wastewater discharge are to be estimated there must be some information on what conditions would have prevailed physically, chemically, and biologically had no waste discharge ever occurred.

To represent a typical situation of coastal water quality under the influence of relatively undeveloped land, Kahana Bay was chosen both for the comparatively pristine condition of its drainage area and its convenient geographical proximity to the Manoa campus of the University of Hawaii. Maciolek (1972) notes also that its "stream-estuary ecosystem is unique to that island [Oahu]."

In order to generalize the findings from Kahana to the greatest degree possible in terms of the quality of water generated on undeveloped land, other less extensive drainage areas were sampled and evaluated as opportunity permitted during the course of the study period herein reported. In this latter category were the upper reach of Manoa Stream, and data reported by the federal Environmental Protection Agency (EPA)(1971) for an undeveloped mountainous area in northern Oahu (see Figure 3.26, Chapter 3, p.125) for comparison with runoff from sugar canefields of the Waialua Agricultural Company.

General Physiography of the Kahana Bay Study Area

Kahana Bay is located on the windward northeast coast of the island of Oahu, Hawaii between Makalili Point and Puuomahi Point (see Figure 2.1). Topographically, it represents the seaward extension of Kahana Valley. The drainage area of the valley is 8.38 square miles, extending from sea level to the summit of the Koolau Range. Precipitous ridges from 1000 to 1800 feet in elevation form the sides of a U-shaped valley and break off sharply to the beach level as they near the coastline. The average elevation of the Koolau crest margin is about 2500 feet. Kahana Stream and its tributary, Kawa Stream, are the principal watercourses in Kahana Valley. Studies for the Coastal Water Quality Project shows that the stream is in dynamic equilibrium with its natural environment through a semilog plot of elevation of the stream valley versus the distance from the Koolau crest. Average gradients of Kahana Stream reported by Maciolek (1972) are shown in Table 2.1.

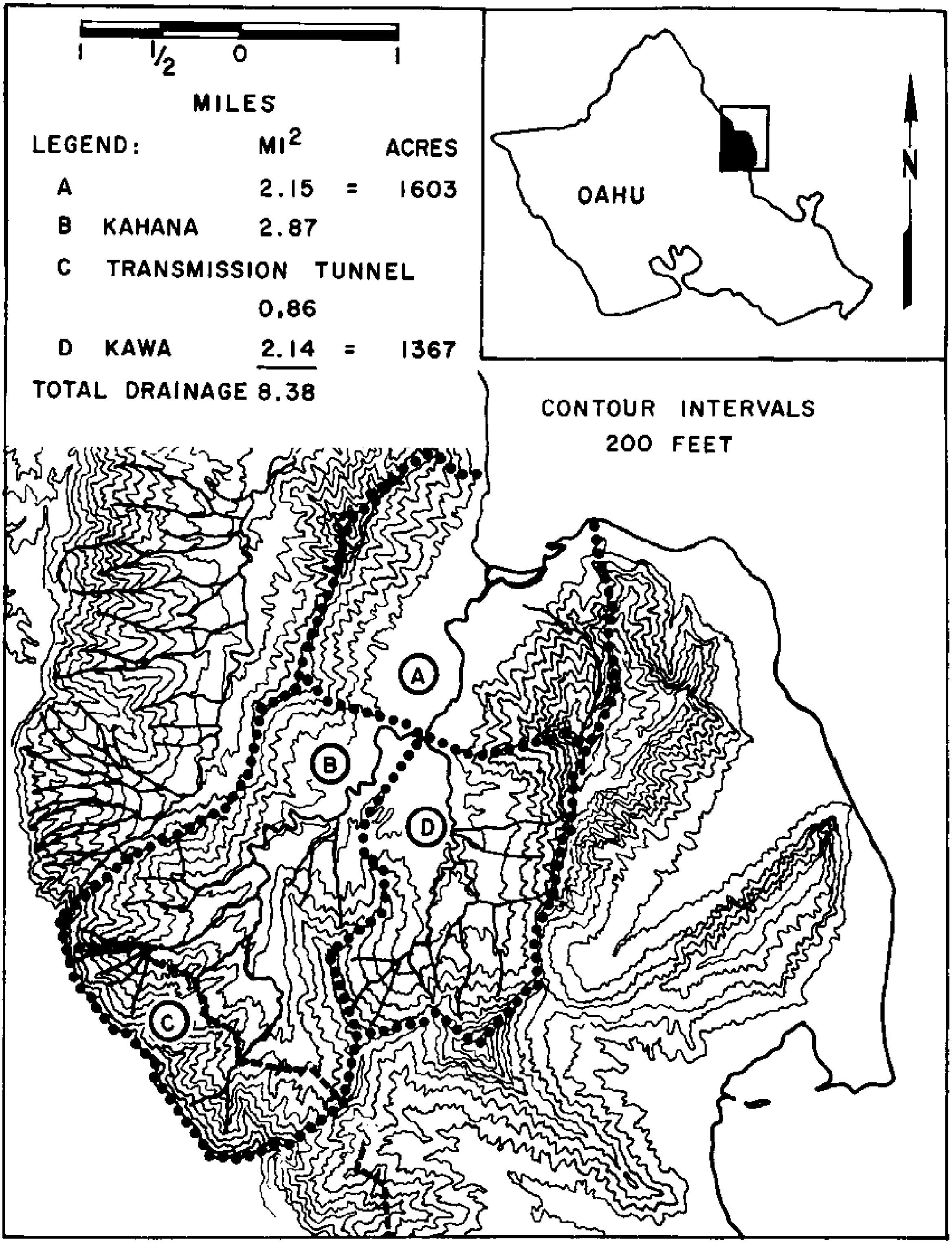


FIGURE 2.1. LOCATION AND DRAINAGE AREA, KAHANA BAY.

TABLE 2.1. GRADIENTS OF SUCCESSIVE SECTIONS OF KAHANA STREAM (MACIOLEK, 1972).

SECTION OF VALLEY	AVERAGE STREAM GRADIENT	
	FEET PER MILE	PERCENT
TERMINUS OF VALLEY	30	0.6
LOWER MID-VALLEY	60	1.1
UPPER MID-VALLEY	140	2.7
LOWER HEADWATERS	830	15.7
UPPER HEADWATERS	2600	50.0

In their upper reaches, Kahana and Kawa Streams traverse dense tropical vegetation along a boulder strewn bed. Below elevation 300 feet the stream gradient drops to 1.6 percent. About 1.5 miles from its mouth, Kahana Stream reaches a low swampy area through which it meanders mostly as an estuary amid tall California grass and lush growths of hao, plum, and guava trees. Two former beachlines appear as consolidated ridges near the present shore, forming the constraint which gives the estuarine section of the stream its characteristics. These ridges are permanently breached by Kahana Stream at a single point, although occasionally in the past overflows have accompanied floods.

It is because of its general condition of undisturbed cover and unregulated runoff below elevation 800 feet that Kahana Valley may be said to represent a relatively good example of undeveloped land in Hawaii.

However, a water diversion in the headwaters of the basin above an elevation of 800 feet diverts an average of 7 mgd from the valley by way of a transmission tunnel. The construction of the tunnel in the 1930's produced considerable debris which was dumped into the valley. The effect of the debris on present water quality is probably negligible.

Although a few people are permitted to live in Kahana Valley, and those that do live there permit horses and cattle to roam freely, the effects of their presence would seem to differ little from those of wild animals and aboriginal man of earlier centuries. However, the effect of man on the quality of water discharged by Kahana Stream is not known at this time but it is not expected to significantly affect the marine biota.

Hydrology and Oceanography

RAINFALL AND WATER BUDGET. Annual rainfall on the 8.38 sq mi of drainage area ranges from 240 to 250 inches at the Koolau crest of Kahana Valley to 70 or 75 inches per year at the bay shore. The average rainfall for the drainage area totals 60 mgd. Of this, Takasaki, *et. al.*, (1969) estimates that 55 percent percolates as ground water, 20 percent is lost by evaporation and transpiration, and 25 percent appears as direct runoff. A significant base flow occurs in Kahana Stream throughout the year as a result of ground-water seepage into the stream channel. Floods (maximum recorded, 5430 cfs) occur at times of heavy rainfall, often opening intermittently a flood channel at the central section of the beach, as shown by the broken arrow symbol in Figure 2.3.

A stream gaging station is located at elevation 30 feet, above which the drainage area is 3.74 sq mi. Average flows past the gaging station are 5 mgd as direct runoff and 15.2 mgd as ground water. For the entire valley the average flow is 29.5 mgd, of which 11.2 mgd is surface runoff and 18.3 mgd is ground-water flow. 4.0 mgd of ground water and 3.2 mgd of surface runoff have been diverted at elevation 800 feet by the Waiahole Ditch tunnel system for agricultural use.

A water budget for Kahana Valley reported by Takasaki, *et. al.*, (1969) in 1969 is presented in Table 2.2.

TABLE 2.2. WATER BUDGET FOR KAHANA VALLEY (TAKASAKI, 1969)

FACTOR	ABOVE GAGING STATION mgd	FOR ENTIRE VALLEY mgd
PRECIPITATION	33	60
EVAPOTRANSPIRATION	4	12
WATER YIELD	34	48
DIRECT AND INDIRECT RUNOFF AFTER RAIN	8	15
INFILTRATION TO GROUND WATER RESERVOIR	26	33
GROUND WATER IN TUNNEL OR STREAM FLOW	19	23
GROUND WATER UNACCOUNTED FOR AS UNDERFLOW	7	10

However, the water budget of the Kahana Valley is somewhat more complex than Table 2.2 and gaging station records might suggest. Studies for the Coastal Water Quality Project notes that the valley consists of two nearly independent systems -- one above a transmission tunnel at 800 feet elevation, and the other from 800 feet to sea level at the Bay. All of the surface water above the tunnel are diverted to the Waiahole system except when overflow accompanies flooding. There is also reason to suspect that most of the ground water above the tunnel complex drains into it, although there may be some leakage to the leeward.

Below the tunnel, the partitioning of water is rather straightforward, except that an undetermined underflow from Punaluu, and perhaps Kaaawa, moves toward Kahana Stream which drains it to Kahana Bay.

Figure 2.2 shows diagramatically the general disposition of water in the Kahana Basin.

ESTUARINE AND OCEANOGRAPHIC ASPECTS. About one mile from its point of discharge into Kahana Bay, Kahana Stream becomes estuarine in character. Above this point there is no tidal action or detectable salinity. Maciolek

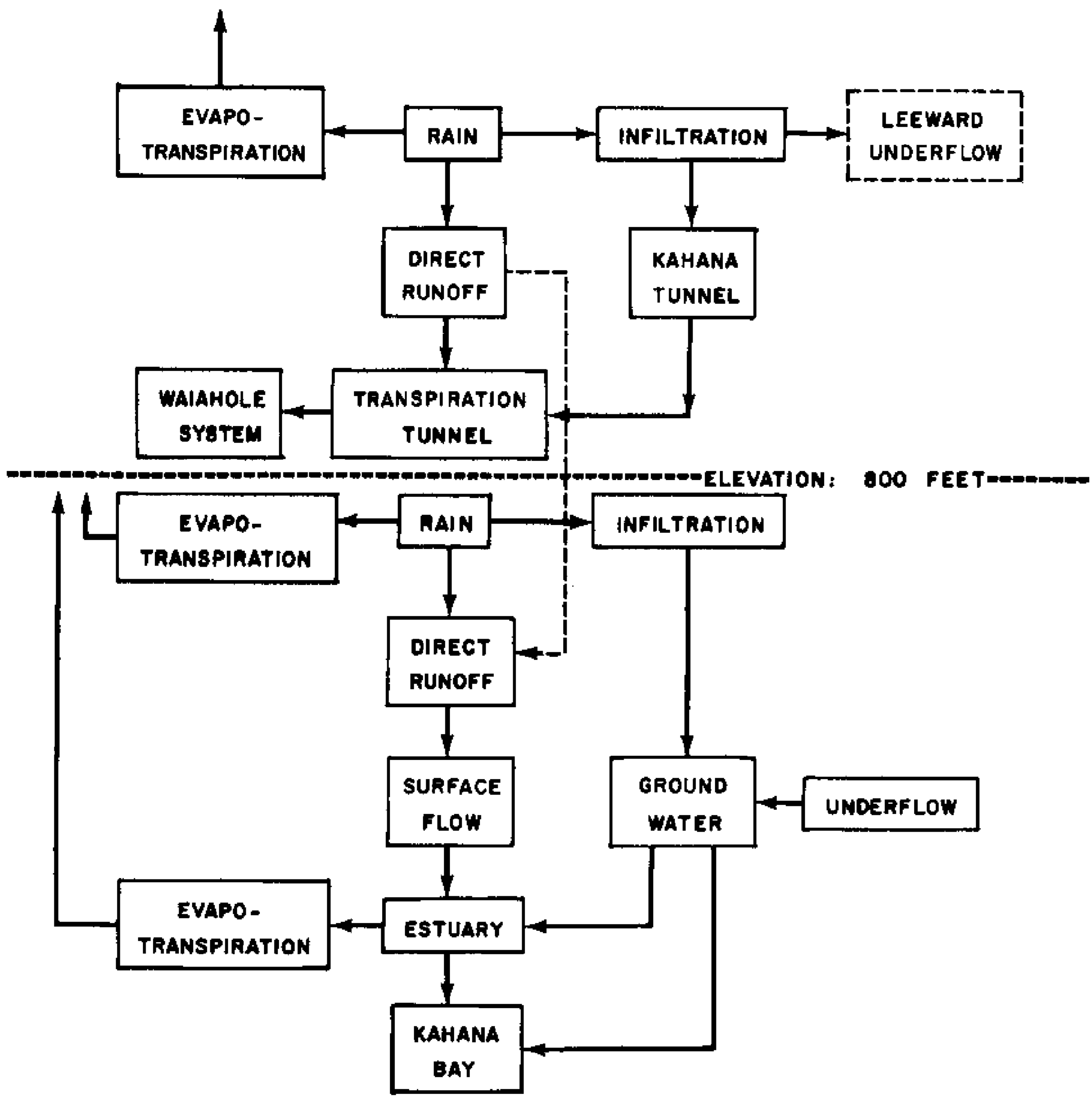


FIGURE 2.2. HYDROLOGICAL PARTITIONING OF KAHANA VALLEY.

(1972) describes this estuarine section as being a sinuous channel varying from 35 to 245 feet wide, 4 to 16 feet deep at mid-channel, and having a meantide surface area of 14 acres and a volume of 84 acre feet. The high stream flows which generally occur in the winter and spring carry the debris and sediments from the estuary, thereby, minimizing its potential as an "incubator" of water quality factors not normal to a freshwater discharge. During a period of study extending from June 1970 to February 1972, Maciolek found the surface temperature at various sampling stations in the estuary to be 1 to 2 degrees above that (22° C) of the stream water entering the estuary. The bottom temperatures were 2 to 3.5 degrees above the 23° C bottom level of the influent stream water. Density stratification and surface flow of stream water was evidenced by salinity measurements. In the influent stream, salinity ranged from 0 ‰ at the surface to 7.9‰ at the bottom of the stream. In the estuary, the range of surface values was 0.1 to 2.0 percent and bottom salinities ranged from 25.2 to 26.5 percent. Little change in pH (7.2) was noted and dissolved oxygen changes were relatively minor.

Because Maciolek's study concerned the diadromus microfauna of the Kahana Stream-estuary ecosystem, he did not carry his observations into Kahana Bay. Colbourn (1971), however, who was concerned with the sediments of Kahana Bay reported extensive observations of its oceanographic characteristics. The circulation and sediment transport systems of the Bay as reported by Colbourn are shown graphically in Figure 2.3 which he prepared.

At the southeast corner of the Bay is the remains of an old Hawaiian fishpond. Colbourn's report notes that in 1971 the pond had deteriorated into a salt-water marsh. He also noted that "a sand bar, shallow enough to be exposed at very low tides extends from the seaward corner of the pond to a point about one-third of the distance across the bay." There it gradually merges into the deeper bay floor to the west. Colbourn further described the general situation:

> Extending out from the shoreline along the east and west periphery of the bay are fringing reefs whose depths range from a little over 10 feet at the outer reef edges to sea level, where blocks of coral along the eastern reef margin are exposed at low tides...Except in nearshore areas, the reef edges are vertical cliffs, extending down 30 feet or more to the bottom of the bay. A patch reef is in the northwest portion of the bay.

USC & GS data show that the sand channel floor is flat with a gradual seaward slope. Colbourn found this portion of the floor to be rippled as far offshore as 4000 feet from Puumahi Point, with ripple crests "aligned in a northwest to southwest direction." Reef walls and sandy bottom intersect at 90 degrees with no talus accumulation at the walls.

USC & GS map no. 3252 indicates that physiographically Kahana Bay seems to be the head of a submarine canyon which is indistinguishable at a depth of 17 fathoms and reappears again at 120 fathoms. Seismic reflections cited by Colbourn (1971) reveal sub-bottoms characterized by smooth topography consisting of sediment overlying a more irregular basement. He cites extensive bathymetry findings within the bar. Of especial significance to the study herein reported is evidence that "seaward transport of sediments is not confined exclusively to submarine canyons" and that much of the offshore sediment has never been on the beaches but was transported directly across underwater terraces.

A study of the physical oceanography reveals that Kahana Bay is exposed

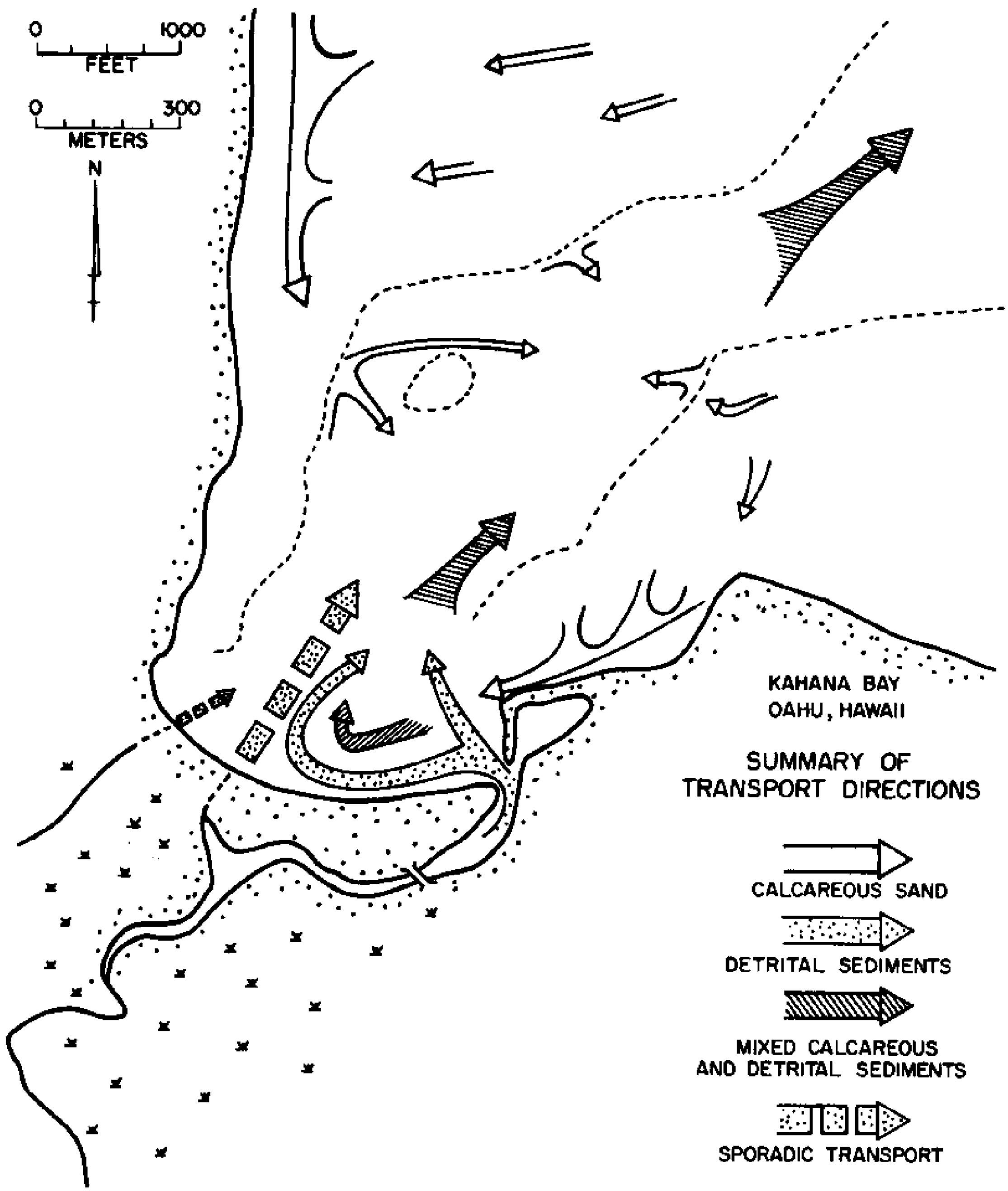


FIGURE 2.3. CIRCULATION AND SEDIMENT TRANSPORT PATTERN, KAHANA BAY (COLBOURN, 1971).

to prevailing northeast tradewinds and waves. Ocean swells lose their energy on entering the Bay and generate but little wave heights on the beach.

Field and Laboratory Observations

KAHANA BAY AS A CONTROL SITUATION. As explained in Chapter 3, first priority in the project was given to a study of the effects of sugarcane milling on coastal waters in north Kauai to grasp a unique opportunity to obtain crucial information. However, it was clearly understood, as noted in the introduction to this chapter (Chapter 2) that data on land use-water quality relationships cannot be fully interpreted without information on the range of norms in nature. To undertake to do so would be somewhat analogous to attempting to determine the weight of produce on a truck by weighing the loaded vehicle only. It is therefore the role of observations in the Kahana Bay area to supply the background data which makes it possible to interpret by a subtractive process similar data from other situations involving man's use and abuse of land and water resources.

In utilizing Kahana Bay as the principal control situation against which to evaluate the results of other land development situations--agricultural, industrial, and urban--the project staff is fully aware that both the environmental factors and the biota of coastal waters respond to other influences far more subtle than the gross land use situations selected for study. Moreover, that these subtleties are the result of differences between individual situations within the same land use category. Justification for making what the scientific purist might well consider an extremely rough preliminary evaluation, however, may be drawn from the factors considered in Chapter 5, *i.e.*, that organized society will seek to achieve its environmental goals through its institutional arrangements even if it must proceed in total darkness. Consequently, any evaluation which casts light upon the question of causes versus effects--even if only to highlight the dangers of unenlightened action or inaction--is a useful guideline to progress. Within such a rationale, Kahana Bay is judged suitable as a control station.

ROLE OF EXPERIMENTAL ACTIVITY. The project plan which guides the study herein reported calls for co-operation with other agencies or projects which might yield significant data in order that needless duplication of effort and inefficient use of financial and manpower resources be avoided. Three factors, however, make necessary a program of field sampling and *in situ* observations, together with appropriate laboratory analyses. First, although previous studies such as those of Maciolek (1972) and Colbourn (1971) are highly scientific in-depth investigations, they do not cover all of the aspects with which the Coastal Water Quality Project (CWQ) is concerned. Second, the parameters of water quality needed for one purpose seldom include all those needed for other purposes. Moreover, the spectrum of quality factors thought to be adequate water quality criteria at one point in time broadens as new types of wastes are generated or new facts on toxicity are discovered. For example, pesticides, heavy metals, nutrients, and stress on aquatic communities have only in recent years been added to the coliform organisms, solids, Biochemical Oxygen Demand (BOD), dissolved oxygen, and other less exotic or subtle factors which long defined water pollution. Consequently, even in situations where monitoring of water quality has been carried on for many years, no data are available on other constituents of water now considered critical.

Finally, in the specific case of Kahana Bay, the relatively pristine nature of the area has minimized the need for understaffed agencies confronted with more serious situations of water pollution to conduct intensive monitoring programs there. It is therefore the role of the experimental activity at Kahana Bay to fill the gaps in information on the same parameters applied to other types of land development situations in the study and with the same degree of intensity applied to the others.

SAMPLING STATIONS AND PROGRAM. On the basis of a study of literature, personal knowledge of the area, and an on-site evaluation of the situation by a team of hydrologists, oceanographers, marine biologists, and other participants in the Coastal Water Quality Project, sampling stations were selected and a sampling program adopted.

Figure 2.4 shows the location of one sampling station on Kahana Stream and five in Kahana Bay, together with biota transect lines, used in the experimental aspect of the study. The sampling program adopted calls for sampling and analysis at approximately monthly intervals.

RESULTS OF PHYSICAL AND CHEMICAL OBSERVATIONS. Because of the necessity for directing full project effort to the sugarcane industry situation in north Kauai (Chapter 3) during the fall months of 1971, the start of the experimental phase at Kahana Bay was delayed until March 1972. Consequently, the results of physical and chemical analyses available at the time of this reporting are limited. However, because there is no land development activity which would upset the natural equilibria of the area, the background data from Kahana Bay should be adequate for comparative purposes by the time data from other types of situations under study are sufficiently numerous to support valid conclusions.

Results of other investigators, as well as those of the Coastal Water Quality Project, are herein summarized. Table 2.3 presents data obtained by the Oahu Water Quality Project of the City and County of Honolulu (1971) in 1970-71 from samples taken at Kahana Bay. The OWQP sampling station was located near station 5 (Figure 2.4).

In Table 2.3, the effect of freshwater runoff during the period of heavy discharge (October 1970 - January 1971) is evident in the values of salinity. During August and September values of salinity are comparable to those observed by Maciolek (1972) in the Kahana Stream Estuary. Thereafter, they reflect a high degree of dilution by fresh water.

In the case of dissolved oxygen, it appears that as the dilution increased during the October 1970 - January 1971 period the dissolved oxygen values increasingly resembled that of the fresh water. During June 1970 to February 1971, Maciolek found dissolved oxygen to range from an average of 8.5 mg/l through a 6-foot depth of Kahana Stream to an average of 6.8 mg/l through a 10-foot depth of estuarine water. More significant is the fact that only when heavily diluted with fresh water did the dissolved oxygen at the sampling station meet the 6.0 mg/l standard specified by the State of Hawaii for Class AA waters.

Total phosphorus values present an equally interesting situation. Although most of the results were within the 0.02 mg/l standards for Class AA waters (Table 2.3), the data from the time of maximum runoff in January is in excess of the standard by a factor of nearly 2.5 and the remaining data are close to the standard so that the mean result is in excess of the standard. Also, about half of the values given in Table 2.4 did not meet the 0.02 mg/l total phosphorus standard for Class AA waters. Although the pat-

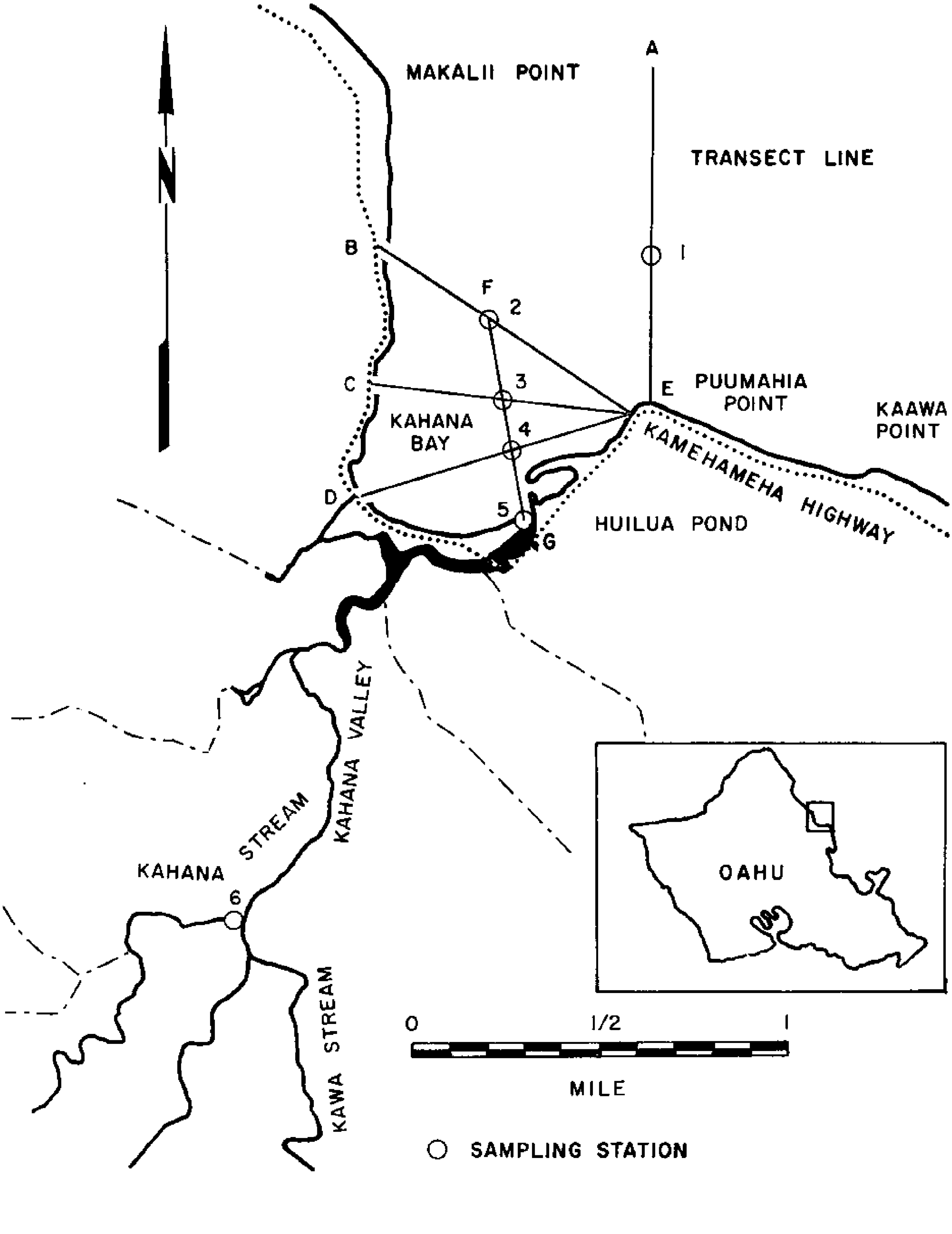


FIGURE 2.4. KAHANA BAY. LOCATIONS OF TRANSECT LINES AND SAMPLING STATIONS.

tern is variable, one might conclude that not even the ocean water (Station 1) consistently met the standards, and that the total phosphorus contribution to runoff from undeveloped land will raise the level in coastal receiving waters above that of the arbitrarily set state standards.

TABLE 2.3. ANALYSES OF WATER, KAHANA BAY[1].

QUALITY FACTOR (mg/l)[2]	1970				1971	AVERAGE
	AUGUST	SEPTEMBER	OCTOBER	DECEMBER	JANUARY	VALUE
SALINITY °/₀₀	20.78	26.44	5.61	1.97	0.56	11.07
D.O.	5.75	4.00	4.60	6.60	8.30	5.84
NO_3^- - N	0.0336	0.0682	--	--	--	--
NO_2^- - N	0.0006	0.0023	--	--	--	--
NO_4^+ - N	0.0164	0.0062	0.0287	0.003	0.0070	0.0123
TOTAL - N	0.3549	0.0720	0.2160	0.3900	0.1140	0.2293
REACTIVE - P	0.0005	0.0021	--	--	--	--
TOTAL - P	0.017	0.0114	0.0151	0.0160	0.047	0.0212
SECCHI (FT.)	7	4	3	--	--	--
pH (UNITS)	--	--	--	--	--	--
BOD	2	1.6	0.8	1.6	3.3	1.9
COLIFORM/100 ml	--	1,000	800	1,000	680,000	170,820
TEMPERATURE (°C)	25.53	26.55	22.32	21.48	21.84	23.54

[1] OWQP, 1971.

[2] UNLESS OTHERWISE NOTED.

TABLE 2.4. NUTRIENTS AND PESTICIDES IN OCEAN AND STREAM WATERS, KAHANA BAY.

STATION NO.	TOTAL SOLIDS (mg/l)	TOTAL-N (mg/l)	TOTAL-P (mg/l)	CHLORIDE (mg/l)	DDT ng/l	PCP ng/l	pH	NO_3-N mg/l	TOTAL ORGANIC CARBON mg/l	TURBIDITY APHA[1]
DATE OF SAMPLING: 03/18/72										
1	37,020	0.073	0.025	18,380	3	N.D.[2]	8.1	--	--	--
2	35,820	0.047	0.031	17,710	1	N.D.	8.1	--	--	--
3	35,700	0.041	0.030	17,710	1	N.D.	8.1	--	--	--
4	36,050	0.046	0.025	17,800	2	N.D.	8.1	--	--	--
5	--	--	--	--	3	N.D.	7.9	--	--	--
6	78	0.073	0.016	25	3	N.D.	7.4	--	--	--
DATE OF SAMPLING: 05/14/72										
1	39,630	0.081	0.015	--	<1	4	8.1	0.005	13.1	2.0
2	30,150	0.110	0.013	--	1	4	8.1	0.003	12.7	5.0
3	34,900	0.189	0.021	--	1	2	8.1	0.002	11.1	2.7
4	39,940	0.163	0.021	--	2	3	8.1	<0.001	13.7	6.5
5	5,240	0.046	0.013	--	1	13	7.5	0.005	9.4	4.2
6	85	0.040	0.012	--	--	--	--	0.023	11.7	25.0

NOTE: DDD, DDE, α CHLORDANE, γ CHLORDANE, DIELDRIN, ALDRIN, PCB, LINDANE, HEPTACHLOR AND HEPTACHLOR EPOXIDE NOT DETECTABLE.

[1]AMERICAN PUBLIC HEALTH ASSOCIATION.

[2]NOT DETECTABLE

Obviously a definitive conclusion would be premature because of the dearth of data, but it suggests one important quality factor that merits close and confirmed observation and a standard of water quality which may need revision.

Total nitrogen is somewhat more difficult to evaluate because of variable results. However, it tended to exceed the standard of 0.1 mg/l prescribed for Kahana Bay by the state standards for Class AA waters.

BOD values are generally low but there was a distinct increase as dilution increased, thus indicating that organic matter brought in from the land by surface runoff was the principal source of BOD observed. Surface runoff is also the logical source of Coliform organisms, the very large concentration (680,000/100 ml) being obviously associated with a flood flow capable of producing a dilution of bay water as evidenced by the low salinity.

Data on nutrients and coliform organisms in Kahana Bay have been observed by the State Department of Health in its routine monitoring program. Recent data on total coliform densities observed in bi-monthly samples taken along the shoreline just off the beach park, Figure 2.4, are summarized in Table 2.5. The data show that Kahana Bay tends to satisfy Class A rather than Class AA for which the Bay is classified by the state.

TABLE 2.5. BI-MONTHLY DETERMINATION OF COLIFORM ORGANISMS IN KAHANA BAY.

	TOTAL COLIFORMS (mpn/100 ml)			
MONTH	1970		1971	
JANUARY	7	--	2400	240
FEBRUARY	43	--	43	43
MARCH	93	--	240	1100
APRIL	240	93	93	1100
MAY	93	240	93	43
JUNE	--	--	43	0
JULY	240	43	1100	240
AUGUST	1100	240	240	43
SEPTEMBER	240	4	--	--
OCTOBER	240	--	--	--
NOVEMBER	460	--	--	--
DECEMBER	460	460	--	--

In the course of his study of Kahana Estuary and Stream, Maciolek established 6 sampling stations on Kahana Stream between the head of the estuary and the 300-foot contour, and two on Kawa Stream between the 50-foot contour and its conflux with the Kahana. At these stations, values of temperature, conductivity, and calcium were observed over a period of more than 20 months. The results are summarized in Table 2.6.

TABLE 2.6. SUMMARY OF PHYSIOCHEMICAL DATA OF KAHANA VALLEY[1].

STATION DESIGNATION	APPROXIMATE DISTANCE FROM ESTUARY ft X 1000	TEMPERATURE °C		CONDUCTIVITY µmhos		CALCIUM mg/l	
		MEAN	RANGE	MEAN	RANGE	MEAN	RANGE
E/M-1[2]	0	22.3	10 - 24	116[3]		8.9	4,7 - 17.3
M-2[2]	5.2	21.9	20 - 24	116	85 - 146	6.9	4.5 - 8.5
M-3, M-4	10.2, 11.6	21.5	20 - 23	104	81 - 105	5.3	3.3 - 8.5
M-5	13.5	21.4	20 - 23	101	83 - 115	5.4	4.1 - 7.0
T-1 TO T-3[2]	5.0 - 5.9	22.2	21 - 25	105	90 - 130	6.2	4.2 - 7.7

[1] AFTER MACIOLEK, 1972.
[2] M DESIGNATIONS = KAHANA STREAM, T = KAWA STREAM, E/M-1 = STREAM-ESTUARY JUNCTURE.
[3] WINTER-SPRING ONLY. SUMMER-FALL SOMETIMES >500 µmhos.

Comparing the results from Stations M-2 and T-1 to T-3, both about equidistant from the conflux of the two streams, it appears that the Kawa tributary water was slightly warmer and lower in conductivity. In the Kahana Stream, as might be expected, the water was progressively cooler and lower in conductivity and calcium as the headwaters were approached -- facts which should be borne in mind in evaluating the effect of drainage area size on the quality of water produced.

Observations of nutrients and pesticides in Kahana Stream and Kahana Bay (Station 6 and Staions 1-5, Fig. 2.4) are scheduled as a routine part of the experimental aspect for Kahana Bay. Results of the first analyses of the waters of the study area made by the Coastal Water Quality Project laboratories are presented in Table 2.4. These data, from samples taken during the dry weather period and after the winter floods had passed show Kahana Stream water to be generally lower in total phosphorus than Kahana Bay. However, the Bay waters particularly at Stations 3 and 4 exceeded the standard of 0.02 mg/l currently prescribed for Class AA coastal waters. In the case of total nigrogen, the data are inconclusive in relating the stream water with the bay waters. In all the March 1972 samples, however, the concentration was less than 0.1 mg/l standard for Class AA waters, whereas, some May 1972 samples exceeded 0.1 mg/l. In terms of total organic carbon, the stream and the bay differed but little, if any.

Pesticides were generally non-detectable with the exception of DDT which seems to be ubiqutous in all environments.

This same ubiquity of DDT appears in Table 2.7, which presents the Coastal Water Quality Project results for sediments taken from the ocean and stream at Kahana Bay. In sediments, as in waters penta chlorophenols was not detectable in March but appeared in small concentrations in all samples in May.

TABLE 2.7. NUTRIENTS, METALS AND PESTICIDES IN OCEAN AND STREAM SEDIMENTS, KAHANA BAY, OAHU.

STATION NO.	Pb (ppm)	Cu (ppm)	Zn (ppm)	Cd (ppm)	Hg (ppm)	Cr (ppm)	Ni (ppm)	DDT (ppt)[1]	PCP (ppt)[1]
DATE OF SAMPLING: 03/18/72									
1	30.7	16.6	23.0	N.D.[2]	0.11	22.8	46.1	3	N.D.
2	24.4	3.0	2.3	N.D.	0.06	6.8	10.2	1	N.D.
3	29.0	8.1	11.7	N.D.	0.03	24.5	29.4	1	N.D.
4	26.2	2.4	1.3	N.D.	0.04	5.9	16.0	2	N.D.
5	24.9	9.6	12.6	N.D.	0.04	15.0	31.4	3	N.D.
6	29.3	160.1	94.5	N.D.	0.21	147.1	349.8	3	N.D.
DATE OF SAMPLING: 05/14/72									
1	16.5	1.0	N.D.	1.3	0.09	7.6	18.1	1	4
2	4.6	136.4	75.8	N.D.	0.18	94.3	205.8	1	4
3	19.2	25.1	33.1	N.D.	0.04	50.6	45.3	1	2
4	21.6	N.D.	3.6	1.8	0.01	12.2	29.9	2	3
5	29.6	17.9	20.0	0.7	0.01	22.7	45.8	1	13
6	5.0	98.0	62.8	N.D.	0.04	47.4	298.0	--	--

NOTE: LINDANE, HEPTACHLOR, HEPTACHLOR EPOXIDE, ALDRIN, DIELDRIN, DDE, DDD, α CHLORDANE, γ CHLORDANE, PCB NOT DETECTED.

[1] PARTS PER TRILLION.
[2] NOT DETECTABLE.

Heavy metals, particularly Cu, Zn, Cd, and lead, appeared in most samples in no identifiable pattern. The circulation and migration of sediments observed by Colbourn (1971) may well account for the variation from station to station in Kahana Bay (Fig. 2.5). A significant finding is that these metals are present in appreciable concentrations in the sediments in Kahana Stream but this may be due to the parent material of the sediment. No attempt is made at this point in the report to interpret this finding. It is however, not out of line with other observations in Hawaii and justifies a program of sampling and analysis of soils from which these sediments originate that has been incorporated in the Coastal Water Quality Project schedule.

RESULTS OF BIOLOGICAL OBSERVATIONS. Biological observations of Kahana Bay were made along the transect lines shown in Figure 2.4. These lines were established to facilitate location of the sampling stations for water and sediment and for survey of benthic biota. Transect A-E (Fig. 2.4) extends due north from Mahie Point; transect B-E from bench mark 11 (next to a two-story grey house on shore) to Mahie Point and bisects the coral knoll; C-E from a square shaped cement rain water outfall pipe at the shoreline to Mahie Point; and D-E from the bridge at the northwest end of the sand beach to Mahie Point. Transect line F-G extends from the coral knoll within the Bay to the point where Kahana Stream empties into the Bay.

Sampling station 1 is located in 15 meters of water over the sand-bottomed channel. Stations 2 to 5 are positioned in a line from the coral knoll to the mouth of Kahana Stream in water depths of 7 m, 3.5 m, 3 m, and 1 m, respectively. Station 6 is located upstream at the Kahana gaging station.

Monthly water samples for chemical analysis were collected at each station one meter below the surface in a one-gallon glass container and two one-gallon plastic containers. Sediment samples were collected by divers in a plastic bag for analysis of micromollusk composition.

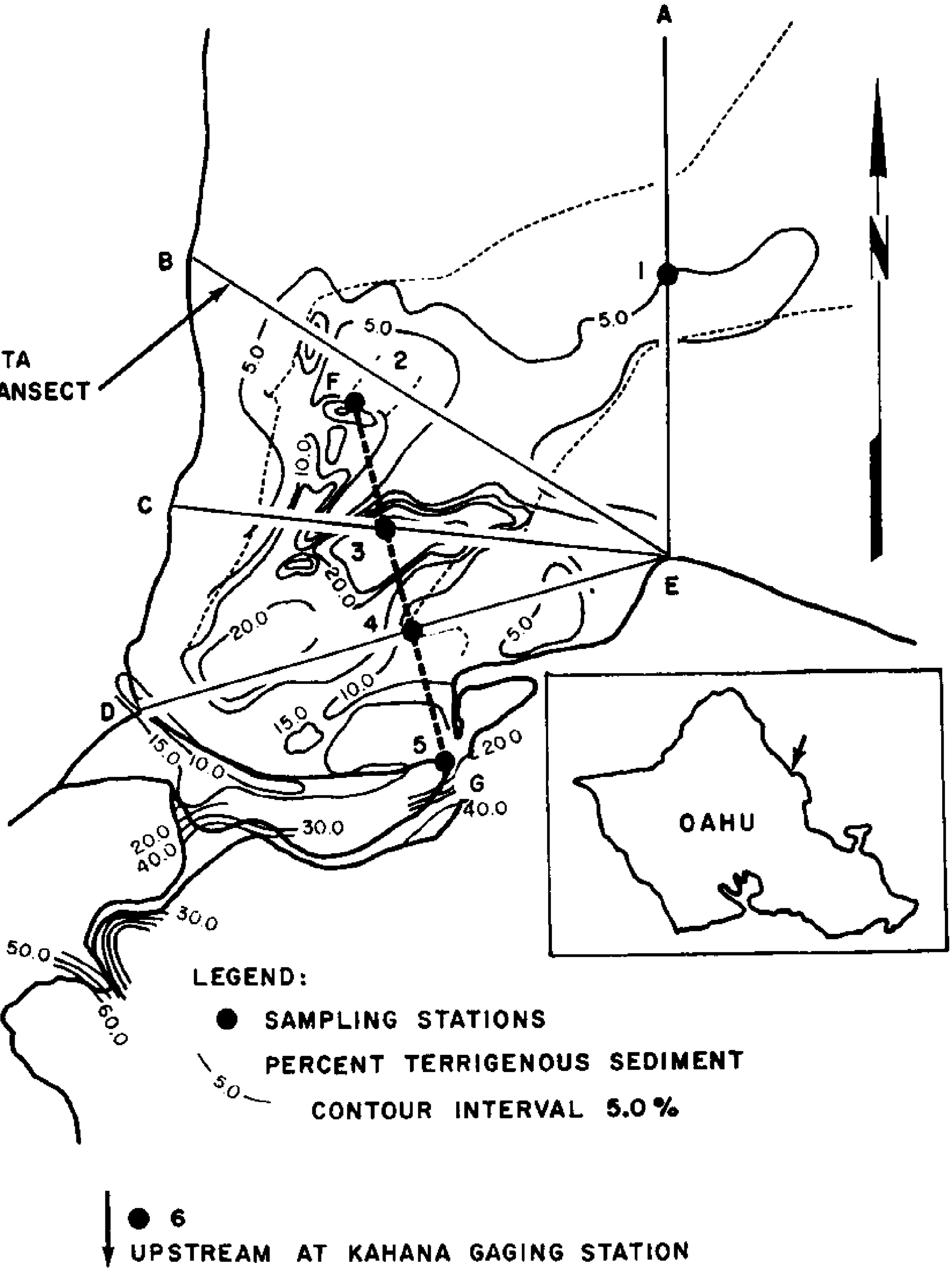


FIGURE 2.5. SAMPLING STATIONS FOR KAHANA BAY AND STREAM.

Turbidity measurements, recorded in meters as depth of clarity, were made periodically at all stations using a 12-inch diameter Secchi disc lowered over the side of a boat. The depth that the disc disappeared from the view of the observer was recorded.

Horizontal visibility on the coral knoll was measured along a transect line laid on the bottom. One diver observed the point of disappearance of a second diver as he swam away along the line.

The coral knoll was selected as the major station for the benthic biota and fish population survey. It is a well-defined small patch of coral rock completely surrounded by a sandy bottom, effectively isolating it from the fringing reefs on either side of the bay. The knoll is in the current path of both the wavedriven sea water flowing off the northwest fringing reef and the water flowing seaward from the bay proper (Fig. 2.3). Benthic measurements were also made on the seaward facing reef slope along transect line A-E. At all survey sites, the percent cover of the substrate was determined and density of abundant benthic invertebrates was measured.

The coral knoll was divided into four quadrants along the north-south and east-west compass points. In each quadrant, density of three species of sea urchins, *Tripneutes gratilla, Pseudoboletia indiana,* and *Echinometra mathaei,* was determined by the method of Batchelor (1971) which not only corrects for pattern but also indicates whether the organisms are aggregated, evenly distributed, or randomly placed.

The percent of substrate cover was estimated by using a photographic transect technique. A Nikonos camera and electronic flash unit was mounted on a rectangular metal frame. The frame holds the camera at a fixed distance from the bottom so that a uniformly illuminated area 1 m x 2/3 m is photographed. The base of the frame is just visible at the edges of the photograph for size reference. The photograph is then projected onto a piece of white cardboard ruled off in decimeters. Percent of substrate cover in each decimeter is estimated, summed and averaged. This technique also produces a permanent photographic record of the bottom.

The north-south diameter and circumference of the knoll was determined by divers using a 20-meter measuring line. The dominant substrate cover on the knoll slopes was also recorded and a list of all invertebrates seen was compiled for each site (Table 2.8).

The location, depth, clarity, and bottom type of the five sampling stations located in the Bay are shown in Table 2.9. Depth of clarity decreased gradually from the deep ocean station toward the shallower parts of the Bay. Turbidity, expressed in terms of extinction coefficient k is shown in the table. k is determined by the equation $k = 1.7/D$, where D is the maximum depth in meters at which the secchi disc is visible from the surface (Pickard, 1963). Values shown in Table 2.9 agree with those of Colbourn (1971) at similar locations. Turbid water in the inner bay probably is the result of suspension of fine material of terriginous origin from Kahana Stream. This sediment is continously resuspended by wave action in the shallower regions of the Bay and is carried seaward by tidal currents. Turbidity increases following periods of heavy rains and persists for several days. Further seaward, the bay water is mixed with clearer ocean water flowing into the deep channel. Turbidity at Station 1 is much greater than at other offshore locations along the windward coast of similar depths, where the bottom can often be seen at 50-60 feet.

TABLE 2.8. TAXONOMIC LIST LOCATION, AND RELATIVE ABUNDANCE OF INVERTEBRATES OBSERVED ON THE CORAL KNOLL DURING THE STUDY PERIOD.

PHYLUM	SPECIES	COMMON NAME	LOCATION	RELATIVE ABUNDANCE
PORIFERA	UNDETERMINED	BLACK SPONGE	KNOLL SLOPES	RARE
COELENTERATA	*Pennaria tiarella*	---	KNOLL SLOPES	RARE
	Fungia Scutaria	MUSHROOM CORAL	EAST KNOLL SLOPES	COMMON
	Porites compressa	FINGER CORAL	KNOLL SLOPES	VERY COMMON
	Porites lobata	CORAL	KNOLL SLOPES & FLAT	VERY COMMON
	Montipora verrucosa	CORAL	KNOLL SLOPES & FLAT	COMMON
	Montipora verrilli	CORAL	KNOLL SLOPES & FLAT	COMMON
	Montipora flabellata	CORAL	KNOLL FLAT	RARE
	Pocillopora meandrina	CORAL	KNOLL SLOPES & FLAT	VERY COMMON
	Pocillopora damicornis	CORAL	KNOLL FLAT	COMMON
	Pavona varians	CORAL	KNOLL SLOPES & FLAT	RARE
	Cyphastrea ocellina	CORAL	KNOLL FLAT	RARE
	Leptastrea purpurea	CORAL	EAST KNOLL SLOPES	COMMON
	Psammocora stellata	CORAL	KNOLL FLAT	RARE
ANNELIDA	*Lanice conchilega*	SPAGHETTI WORM	KNOLL SLOPES	COMMON
MOLLUSCA	*Conus quercus*	OAK CONE	KNOLL SLOPES & FLAT	COMMON
	Octopus species	OCTOPUS	KNOLL FLAT	VERY RARE (1)[1] (BUT REPORTED COMMON)
ARTHROPODA	*Stenopus hispidis*	BANDED SHRIMP	KNOLL SLOPES	VERY RARE (1)
	Dardanus species	HERMIT CRAB	KNOLL FLAT	VERY RARE (1)
	Panulirus marginatus	SPINY LOBSTER	KNOLL SLOPES	COMMON
ECHINODERMATA	*Tripneustes gratilla*	SEA URCHIN	KNOLL FLAT	VERY COMMON
	Echnometra mathaei	SEA URCHIN	KNOLL FLAT	VERY COMMON
	Pseudoboletia indiana	SEA URCHIN	KNOLL FLAT	VERY COMMON
	Echniometra oblonga	SEA URCHIN	KNOLL FLAT	RARE
	Echinothrix calamaris	SEA URCHIN	KNOLL SLOPES	COMMON
	Echinostrephus aciculatus	SEA URCHIN	KNOLL FLAT	COMMON
	Heterocentrotus mammillatus	SEA URCHIN	KNOLL SLOPES	RARE
	Ophiocoma erinaceus	BRITTLE STAR	KNOLL FLAT	VERY COMMON
	Actinopyga mauritiana	SEA CUCUMBER	KNOLL SLOPES	RARE

[1] (1) = NUMBER SIGHTED.

TABLE 2.9. LOCATION, DESCRIPTION, AND PHYSICAL MEASUREMENTS AT SAMPLING STATIONS.

STATION	DEPTH (m)	DEPTH OF CLARITY (m) JUNE 6, 1972	EXTINCTION COEFFICIENT	BOTTOM TYPE	LOCATION
1	15.0	9	.2	CLEAN CALCAREOUS SAND	100 m NORTH OF REEF SLOPE ALONG TRANSECT LINE A-E[1]
2	7.0	5.5	.3	MIXED SAND AND TERRI-GINOUS MATERIAL	JUNCTION OF TRANSECT B-E AND F-G, JUST SHOREWARD OF CORAL KNOLL
3	3.5	3.5	.5	MIXED SAND AND TERRI-GINOUS MATERIAL	JUNCTION OF TRANSECT C-E AND F-G
4	3.0	3.0	.6	MIXED SAND AND TERRI-GINOUS MATERIAL	JUNCTION OF TRANSECT D-E AND F-G
5	1.0	---	---	MIXED SAND AND TERRI-GINOUS MATERIAL	MOUTH OF KAHANA STREAM AT EAST END OF SAND BEACH
6	---	---	---	---	AT GAGING STATION IN KAHANA STREAM

[1] REFER TO FIGURES 2.4 & 2.6 FOR LOCATION OF TRANSECT LINES.

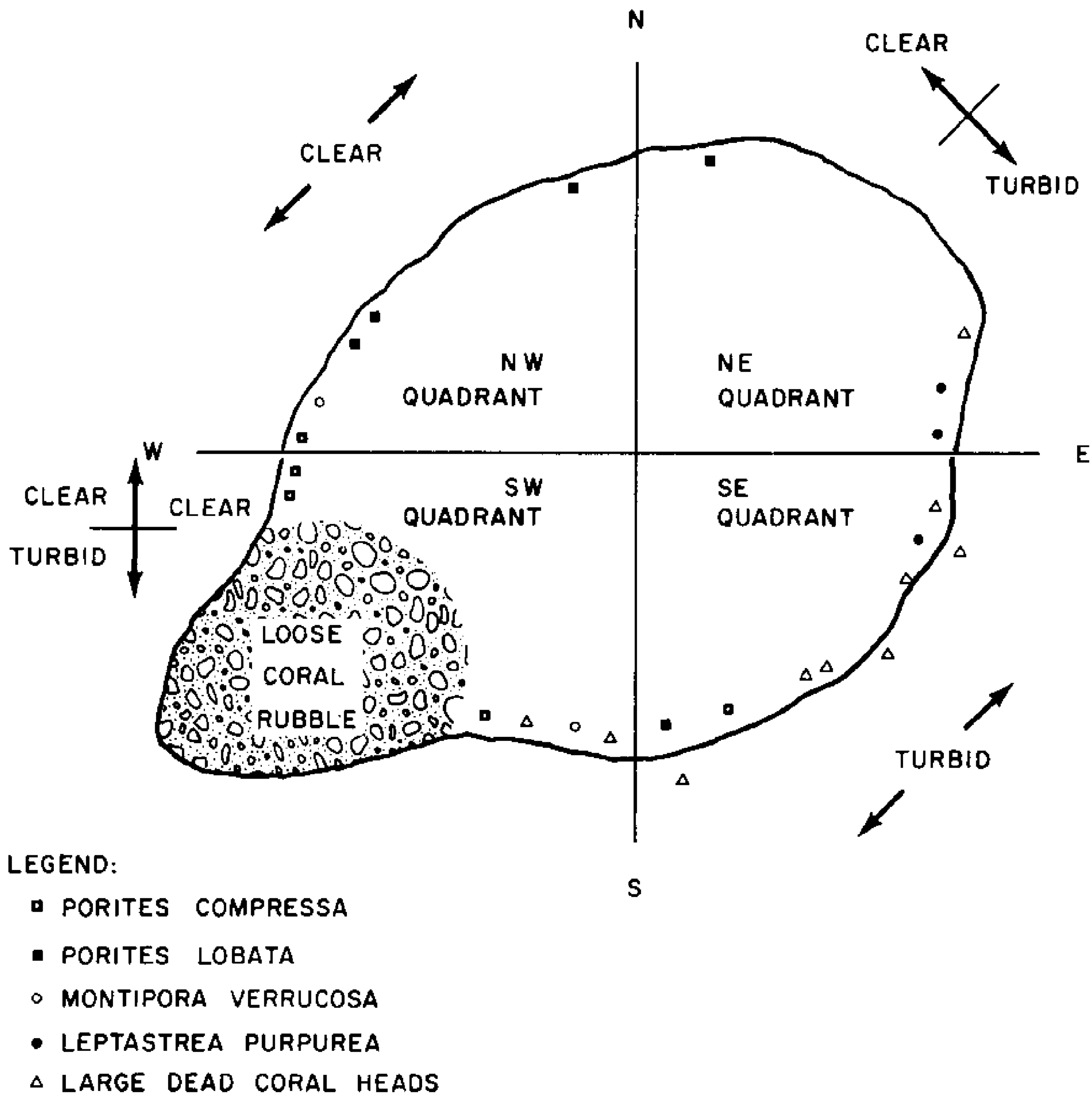


FIGURE 2.6. DETAILS OF CORAL KNOLL OUTLINE.

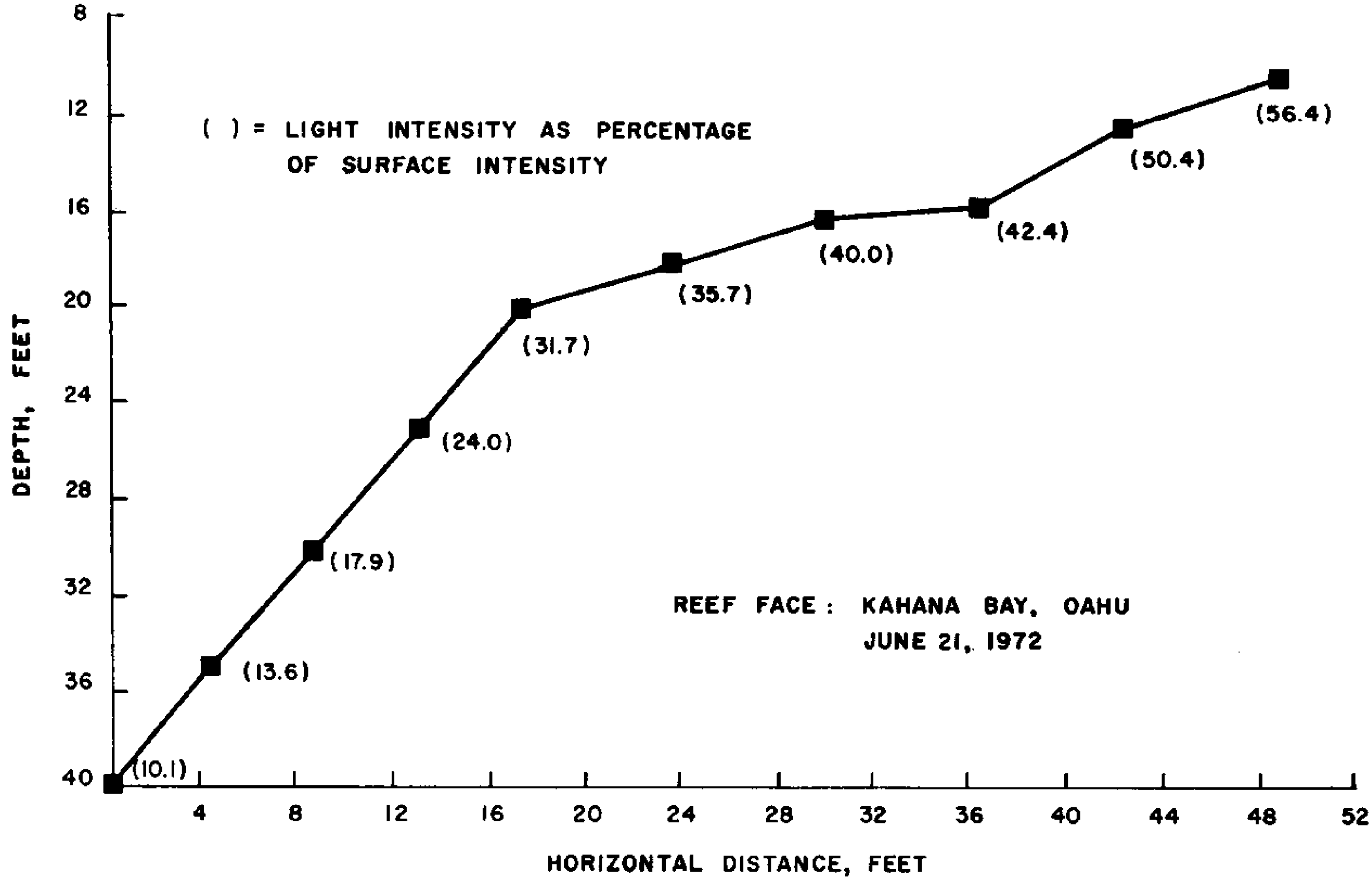


FIGURE 2.7. DEPTH PROFILE STATION KA-1 REEF FACE, KAHANA BAY, OAHU, JUNE 21, 1972.
( ) = LIGHT INTENSITY AS PERCENTAGE OF SURFACE INTENSITY.

Horizontal visibility on the coral knoll varied from 20 m to as little as 5 m during the survey period. The east and south slopes of the knoll were always more turbid than the rest of the perimeter (Fig. 2.6), reaching a visibility minimum of one meter during one dive.

A vertical transect was laid on the seaward reef slopes along transect line A-E. Depth, slope angle, and light intensity at sampling points every 2 meters along the transect line are shown in Figure 2.7. The reef slope begins in 40 feet of water and rises sharply from the flat sandy bottom of the channel. The slope then ascends at an angle of about 45° to about 20 feet and then continues at a much shallower angle. At about 10 feet, the reef becomes almost horizontal and continues shoreward as an extended reef flat.

At the base of the slope and extending upward about 4 feet much fine loose sediment overlies a region of loose corel rubble. Above this base the slope consists of hard uneven calcareous rock of a coral and coralline algae origin. Less than 10 percent of live coral cover was observed at most stations. A zoanthid, *Zoanthus* sp., was the dominant encrusting organism between the 25 and 40-foot depths. Some vertical zonation of coral species was evident with *Montipora verrucosa* ranging between 12 feet and 40 feet, *Porites lobata* between 15 and 30 feet, and *Pocillopora meandrina* from 25 feet and increasing in number especially on the upper reef slope and reef flat.

The base of the roughly circular coral knoll (Fig. 2.6) is about 20 feet deep, completely surrounded by the sandy bottom of the bay channel. The diameter along the north-south transect line was measured at 220 m and the circumference, 660 m. The calculated area of the knoll is 37,994 m^2. The edges of the knoll slope up at about 20-30° on the west and north and at about 45° on the east and south to an extensive, reef flat between 6-8 feet in depth. During periods of heavy trade winds, storms, and low tides, larger waves coming directly in the channel from the open ocean continually break over the coral knoll. This constant wave action has shown its effect, producing a long tongue of loose coral rubble extending leeward and shoreward from the southwest quadrant. About 15 percent of the periphery of the knoll is intermittently covered with large heads of coral, mostly *Porites compressa* and *Porites lobata*.

Locations of the larger coral heads around the perimeter are indicated in Figure 2.6. *Porites compressa*, a rather fragile, branching finger coral, is confined largely to the leeward southwestern slopes, on either side of the rubble tongue, while *Porites lobata*, a more resistant, lobed, encrusted coral dominates the more seaward regions of the clear western slopes. Large patches of *Leptastrea purpurea*, an encrusting coral that grows in flat plates, covers huge dead coral heads on the turbid eastern slopes. Heads of dead and heavily eroded coral heads as large as 4-6 feet high and 6-8 feet in diameter are also common along the eastern and southern slopes. Between these isolated live and dead heads, the slopes consist of rather irregular pockmarked limestone rock of coral and coralline algae origin. This sparce and intermittent distribution of coral suggests that conditions for growth and resettlement of coral are marginal. Turbidity and heavy wave action are probably largely responsible.

Fresh water entering the Bay from the stream during periods of extremely heavy rainfall may also be a growth limiting factor. Banner (1968) reported the death of coral reefs in Kaneohe Bay to a depth of 2-3 feet below tide level due to a 4-foot layer of fresh water which build up in that Bay during almost a week of very calm weather and excessive rains. Similar conditions could prevail in Kahana Bay on rare occasions although the phenomenon has never been documented.

The table-like upper reef flat of the coral knoll is remarkably uniform in appearance. It is flat and pockmarked with small holes, the result of the characteristic digging activity of the sea urchin, *Echinometra mathaei*. Occasional rubble and sand-bottomed channels a few feet wide and deep cut across the reef flat region with no apparent consistent directionality. The dominant calcium depositing substrate organism on the reef flat is an alga (species to be determined) which covered as much as 60 percent of the bottom in measured quadrats. The average coralline alga cover in a 1-meter by 20-meter quadrat, located in the northwest quadrant, was 20 percent.

Density of three species of sea urchins in the four quadrants of the coral knoll was measured in detail. Measurements in the southwest quadrant in the region of the loose coral rubble tongue show a strikingly different pattern of distribution than on the rest of the knoll. *Pseudoboletia indiana* was the dominant urchin in this quadrant, but so rare in the other quadrants that adequate measurements could not be made. *Echinometra mathaei*, the dominant urchin in three quadrants and over the entire knoll, was completely absent on the coral rubble tongue.

A species list of all invertebrates observed and their location is shown in Table 2.8.

Within the estuarine and stream sections of Kahana Stream, Maciolek (1972) found eleven species, including eight native species, of diadromaus organisms. The distribution and abundance of these in the juvenile or adult stages are summarized in Table 2.10. Their presence, Maciolek notes, must indicate that larval and post-larval stages of the same fauna must be present in migrating to and from the ocean.

OTHER SITUATIONS REPORTED

EPA Studies (Oahu)

In 1967-68 the federal Water Quality Protection Administration, now the Environmental Protection Agency (EPA), made a study ("The Hawaii Sugar Industry Waste Study," 1971) of the quality of runoff from an undeveloped area in Central Oahu for comparison with similar runoff from a sugarcane production area. The details of this study are discussed in Section IV of Chapter 3, hence are introduced here only as they relate to Kahana as an undeveloped area. Excerpts from the EPA results which correspond to those of others are summarized in Table 2.11.

Manoa Stream

In 1971-72 students at the University of Hawaii under the direction of Dr. R.H.F. Young, one of the Associate Investigators of the Coastal Water Quality Project (see Table 1.1, Chapter 1, p. 8), made a study (1972) of the amount and quality of runoff from Manoa Stream at various points above the University campus. Details of this study are summarized in Chapter IV, p. 174, but one sampling station was established on Aihualama

TABLE 2.10. DISTRIBUTIONS AND RELATIVE ABUNDANCES OF DIADROMOUS MACROFAUNA IN THE KAHANA (OAHU) STREAM-ESTUARY SYSTEM. 1970-71.

DIADROMOUS SPECIES	E-7	E-5	E-4	E/M-1	LOWER VALLEY M-2; T-1, 3	MID-VALLEY M-3,4,5,6
MOLLUSKS						
Neritina granosa - N	0	0	0	0	0	+
Theodoxus vespertina - N	?	?	?	+	0	0
CRUSTACEANS						
Macrobrachium grandimanus - N	+++	++++	++++	++++	++++	++
Macrobrachium lar - I	0	0	0	++++	++++	++++
Macrobrachium rosenbergii - I	0	0	0	++	+	0
Atya bisulcata - N	0	0	0	0	+	+++
FISHES						
Chonophorus genivittatus - N	++	+++	++++	+++	++	0
Chonophorus stamineus - N	0	0	0	+	++	+
Sicydium stimpsoni - N	0	0	0	0	++	0
Eleotris sandvicensis - N	0	+	+++	++++	++	0
Kuhlia sandvicensis - N	++++	++++	++++	++++	++	0

NOTE: N = NATIVE, I = INTRODUCED
0 = ABSENT, + = RARE, ++ = OCCASIONAL, +++ = COMMON, ++++ = ABUNDANT

TABLE 2.11. SUMMARY OF QUALITY FACTORS, UNDEVELOPED LAND.

QUALITY FACTOR OBSERVED (mg/1)[1]	AREA OF OBSERVATION		
	KAHANA VALLEY (CWQ)	NORTHWEST OAHU (EPA)	MANOA VALLEY (UNIV. OF HAWAII)
TOTAL SOLIDS	78	56 - 570	103 - 190
SUSPENDED SOLIDS	--	10 - 240	7.4 - 108
CHLORIDES	25	--	19 - 11
TOC	11.7	5 - 71	--
TURBIDITY	25.0	--	2.8 - 59
pH (UNITS)	7.4	5.6 - 7.1	6.9 - 7.0
NO_3 - N	0.023	0.04 - .92 (KJELDAHL)	0.74 - 2.3
TOTAL - N	0.04 - 0.07	0.03 - 4.1	0.20 - 0.27
TOTAL - P	0.01	0.02 - 1.68	0.27 - 0.66
TOTAL COLIFORMS (mpn)	--	--	14,000 - 24,000
FECAL COLIFORMS (mpn)	--	--	150 - 720
DDT (ppt)[2]	3	--	--
OTHER PESTICIDES	N.D.	--	--

[1]UNLESS OTHERWISE NOTED.
[2]ppt = PARTS PER TRILLION.

Stream above its conflux with Waihi Stream, another of the system which feeds Manoa Stream to monitor the discharge from an undeveloped area. This area is located within the H. L. Lyon Arboretum and is not readily accessible to the public because of regulation of public entrance and the rugged terrain between the sampling station and the Koolau Crest at about elevation 2000 feet above sea level. The area is heavily forested, subject to intense rainfall, and comprises an area of about 95 acres, in comparison with 520 acres in the EPA findings are worth reporting because of the overall dearth of information on the quality of discharges from undeveloped land. These data are also incorporated in Table 2.11. It represents the range of dry weather and wet weather flows.

Summary of Water Quality Data

A summary of the quality of water discharged from the three areas of undeveloped land reported is presented in Table 2.11.

In evaluating Table 2.11, it should be recalled that the data were obtained from different size drainage areas; that the EPA studies covered a period of more than one year; but two sampling periods, both in the spring during the relatively dry season. Nevertheless, with the exception of NO_3-N reported for the Manoa Valley site to exceed total nitrogen, the data generally show a similar pattern, which hopefully, may be sufficiently different from the pattern of runoff from other types of land development eventually to make possible some value conclusions in the context of the objectives of the study (Chapter 1).

chapter 3

Coastal Water Quality and Sugarcane Wastes

BACKGROUND AND CONCEPTS

Introduction

The growing, harvesting, and milling of sugarcane is Hawaii's most important private industry. As the state's oldest continuous industry, it dates back to 1835 and has been a mainstay of Hawaiian economy for over 100 years. Like others with more than a century of history, the sugarcane industry began its waste disposal as a matter of operational convenience at a minimum of cost and continued with a minimum of expensive modification until there was some compelling reason to change. Irrigation tailwater and washwater and bagasse from the milling operation were discharged to coastal waters via natural watercourses or simple flumes. Reasons for changing this historic practice developed only in recent years as a concern for the quality of the environment and the welfare of the ecosystems of nature suddenly emerged as a social and political factor. This concern raised a broad spectrum of questions and generated an important number of polarized groups of people. Questions ranged from the effect of nutrients, agricultural chemicals, sediments, and bagasse on the habitat and integrity of aquatic communities, to social and cultural relationships which fundamentally underlie the American economy, if not indeed all of western civilization. Individual viewpoints ranged from those of the serious scientist to those of the emotional zealot and the predicted consequences of waste management practices in almost any context ranged from esthetic shock to total disaster.

To the scientific community, the development and use of land for sugarcane culture represents one of the many situations in which too little is known concerning what water quality factors move from whence to where, by what routes and vectors, and with what ultimate consequences. This spectrum of unknowns, together with the prominence of the sugarcane industry in Hawaii, suggested to the planners of the Coastal Water Quality project of the Sea Grant Program of the University of Hawaii that a high priority should be given to a study of the influence of sugarcane growing, harvesting, and milling on the quality of coastal waters. To this end, and in line with the objectives of the project outlined in Chapter 1, a study area was sought which might represent a reasonably typical situation involving particularly the quality relationships of sugarcane wastes.

As it turned out, evaluation of the influence of the sugarcane industry on coastal water quality was given top project priority because there developed an unprecedented opportunity to observe "before" and "after" conditions on the island of Kauai in two situations. The most urgent of these situations from the standpoint of timing involved the Kilauea Sugar Company on the north coast of Kauai, which had decided to discontinue its sugarcane culture and milling activities at the close of the 1971 harvesting season, after more than 90 years of continuous operation. In this case, traditional waste discharge practices had been but little modified through the years, although use of agricultural chemicals and milling techniques had generally kept pace with contemporary practice.

The second situation involved the McBryde Sugar Company on the south coast of Kauai which had made extensive changes in its waste management practices subsequent to a 1968 study of the coastal water quality made by the federal government at several locations in Hawaii, including the south coast of Kauai. In both instances the sugar companies had extensive records of past and current practice and were willing to cooperate with the Coastal Water Quality Project in the study.

Information less extensive in nature but useful in final interpretations of the study was obtained from a small scale situation reported by the EPA (cited in Chapter 2) in which the quality of runoff water from sugarcane fields in northern Oahu was compared with that of adjacent undeveloped land.

For reasons of clarity of presentation, a general concept is developed and the three foregoing situations are presented sequentially in detail in this chapter.

General Concept of Sugarcane Waste Generation

A general and idealized concept of sugarcane culture as a waste generating system is depicted schematically in Figure 3.1. Here three types of discharge to the ocean are identified:

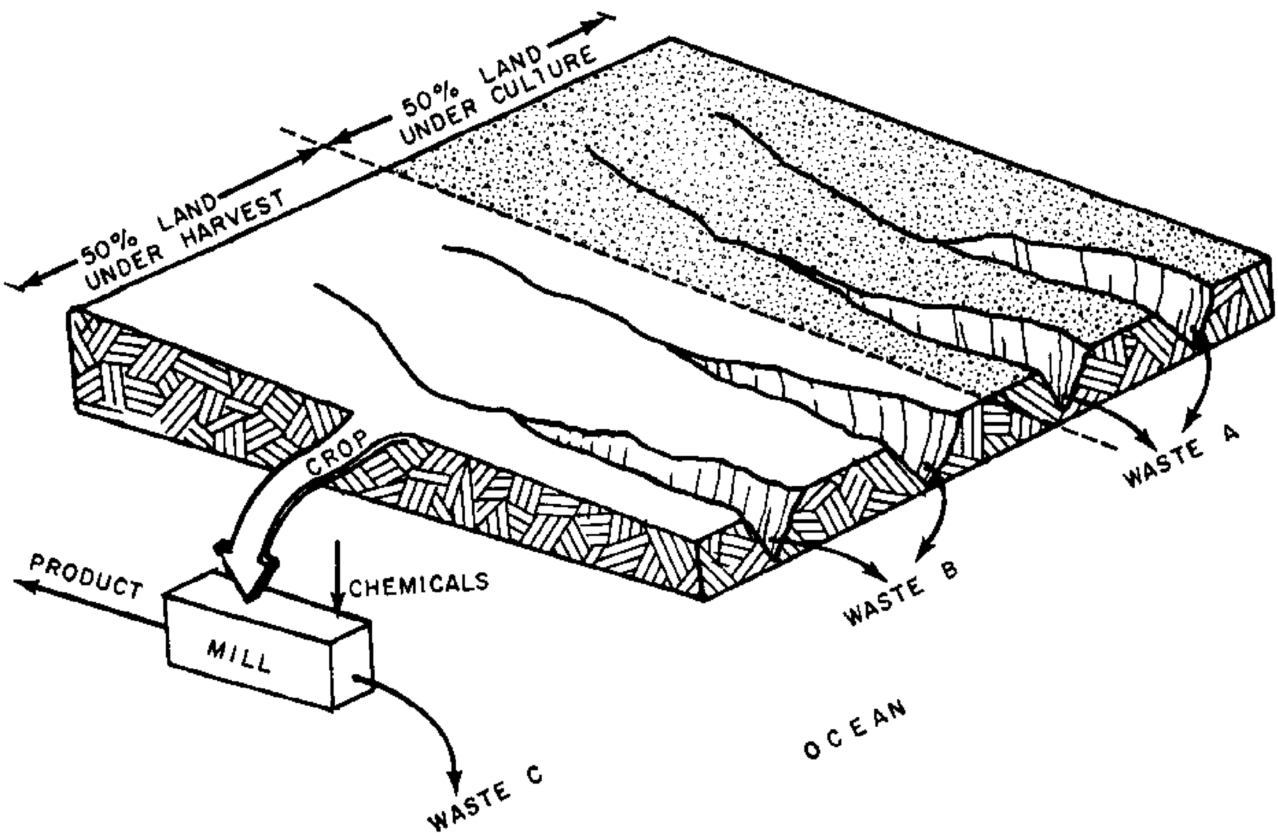


FIGURE 3.1. SUGARCANE INDUSTRY AS A WASTE GENERATING SYSTEM.

1. Discharge from the land area under active irrigated crop culture (Waste A, Fig. 3.1)
2. Discharge from the land area undergoing crop harvesting and replanting (Waste B, Fig. 3.1)
3. Discharge from the milling operation (Waste C, Fig. 3.1).

Each of these three discharges has distinguishing characteristics which define its actual or its potential ability to affect the quality of the coastal water into which it flows as well as the quality of the coastal water environment. The most obvious of these characteristics are summarized in Table 3.1.

TABLE 3.1. CHARACTERISTICS OF WASTES GENERATED BY SUGARCANE CULTURE AND MILLING.

WASTE	TYPE OF DISCHARGE	ACTUAL OR POTENTIAL CHARACTERISTICS OF WASTE GENERATING SYSTEM OR DISCHARGED WATER
WASTE A (FIG. 3.1)	DISCHARGE FROM LAND AREA WITH GROWING CROP OF IRRIGATED SUGARCANE	1. SOIL SURFACE RECEIVES FERTILIZERS AND PESTICIDES.
		2. SOME OF LAND AREA CONTRIBUTING SURFACE RUNOFF IS NOT SUITED TO CULTIVATION, HENCE UNDER NATURAL VEGETATIVE COVER.
		3. CULTIVATED SOIL SURFACE MAY BE SOURCE OF SEDIMENTS, AGRICULTURAL CHEMICALS, AND DEBRIS TRANSPORTED TO OCEAN BY SURFACE RUNOFF OR RAIN OR IRRIGATION TAILWATER.
		4. NON-CULTIVATED AREA MAY BE SOURCE OF SEDIMENTS DUE TO EROSION BY RAINFALL, AND OF NATURAL OR MAN-DISCARDED ORGANIC DEBRIS UNDERGOING BIODEGRADION.
		5. WATER INFILTERATING THE CULTIVATED SURFACE MAY CARRY NITRATES AND OTHER SOLUBLE CHEMICALS TO THE OCEAN VIA PERCOLATING WATER.
		6. DISCHARGED WATER TYPICALLY REACHES THE OCEAN AT MULTIPLE POINTS OF DISCHARGE, HENCE IT IS DISPERSED AND LIMITED IN CONCENTRATION BY THE GEOMETRY OF THE SYSTEM.
WASTE B (FIG. 3.1)	DISCHARGE FROM LAND AREA UNDERGOING CROP HARVESTING AND REPLANTING	1. LAND SURFACE IS ESPECIALLY VULNERABLE TO SCAVENGING OF SOIL PARTICLES AND ASSOCIATED CHEMICALS BY SURFACE RUNOFF OF RAIN WATER.
		2. SAME AS ITEM 2, WASTE A (ABOVE).
		3. " " " 4, " " " .
		4. " " " 5, " " " .
		5. " " " 6, " " " .
WASTE C (FIG. 3.1)	DISCHARGE FROM MILLING OPERATION	1. SOIL PARTICLES, BAGASSE, AND CHEMICALS DISCHARGED FROM WASHING AND MILLING OPERATIONS.
		2. DOMESTIC SEWAGE FROM MILL MAY BE MIXED WITH MILLING PROCESS DISCHARGES (ITEM 1).
		3. NORMAL DISSOLVED SOLIDS IN WATER SUPPLY MAY BE SOMEWHAT CONCENTRATED BY EVAPORATION OF WATER DURING PROCESS.
		4. WASTE WATER IS DISCHARGED TO OCEAN AT A SINGLE POINT OF CONCENTRATION RATHER THAN DISPERSED BY A MULTI-POINT DISCHARGE SYSTEM.

Of the three types of discharge depicted in Figure 3.1 and outlined in Table 3.1, Waste C, the mill discharge is likely to be the most constant in its composition. The amount of dirt brought in with the cane varies, of course, with the extent to which the field being harvested is muddied by rain and the method of harvesting. Bagasse, however, is a function of mill load with more being burned during wet weather, hence the variability of natural phenomena is also a factor in solid waste discharge. The continuity of at least the esthetic effects of bagasse and suspended solids in coastal waters depends largely upon the oceanographic aspects of the receiving water and the continuity of the mill waste discharge.

Harvesting and milling operations in the sugar industry as a whole is essentially a year-round continuous activity. At Kilauea these operations were continuous throughout most of the year, *i.e.*, for about 10 months, mid-January through mid-November on a 5 1/2 day per week basis. Within this period waste generation through harvesting and milling may have been more steady than from the other two source categories which depended more heavily upon intermittent rainfall patterns, and also upon a combination of agronomic practices.

The source of most of the mill waste discharges stems from the sugarcane lands throughout the plantation, and also applications of fertilizers and other agricultural chemicals (pesticides, etc.) to those lands; but that through the mechanical harvesting and milling operations of man these "diffused" sources are transformed into a concentrated "point" source. Other diffused sources of sediments and debris stem from natural processes on non-sugarcane lands which make up the greater proportion of the total lands in the area.

Seasonal and annual variability in the nature of Wastes A and B is much more profound than Figure 3.1 and Table 3.1 might suggest. For one thing, the symmetry of land under culture and under harvest never exists as depicted in Figure 3.1. Even if the figure represented a real situation, one need only harvest the crop from the upper half of the area one year and from the lower elevations the next year to change the entire waste generating system by reason of geometry as well as of the cropping function indicated.

Variation in rainfall might be expected to have the most profound effect on sugarcane land during the period between the removal of one crop and the development of a good soil cover by the succedding crop. Similarly, its least effect might be expected during the period when the cane is changing little in its ground cover characteristics. However, during this more settled period, variations in the rate of application of fertilizer and other agricultural chemicals may be necessary to optimize the crop yield. Therefore, there is not likely to be any prolonged period when Waste A is relatively constant in the load of quality factors it transports to the ocean. This, then, leads on to the general concept that the ocean itself is the major integrator of wastes from the sugarcane industry over any appreciable period of time and to the suggestion that the diversity and continuity of its biological communities may be the measure of the true effect of sugarcane culture on coastal water quality.

Without further elaboration on the general concepts presented, it is evident that to evaluate the relationship between coastal water quality and land development for sugarcane culture in a real situation, several aspects must be investigated, including:

1. The geographic, topographic, and geological relationships of the plantation area.
2. Past and present land management and chemical use practices.
3. The operational aspects of the milling process.
4. The hydrologic and water management aspects of the situation, including the amounts of water discharged as various waste streams.
5. The oceanographic factors which govern the ultimate fate of wastes entering the coastal water.
6. The amount, concentration, and variety of constituents, including sediments, carried by the wastewater discharges.
7. Changes in the constituents of the coastal water and in its sediments and biota resulting from wastewater discharges from the

sugarcane industry in the situation under study.

8. Soil characteristics and variability.

These several aspects were used as guidelines by the Coastal Water Quality Project staff in evaluating experimental findings and existing information in the situations discussed under both the "before" and "after" conditions of operational practice.

NORTH COAST OF KAUAI (KILAUEA SUGAR COMPANY)

Geographical and Environmental Aspects

LOCATION OF STUDY AREA. The study area is located along the northeast coastline of the island of Kauai, Hawaii. As shown in Figure 3.2, it includes both the Kilauea Sugar Company lands bordering the ocean between Moloaa Bay and Kalihiwai Bay (a distance of approximately 11 miles) and the coastal waters from Moloaa Bay to Hanalei Bay. In addition, it encompasses most of the watershed area which affects the quality of coastal waters in the area. Thus, it includes a total of 22,070 acres of land area, 13,333 of which were controlled by the Kilauea Plantation Company during the "before" period of the study, although only 4,688 acres of plantation lands were in sugarcane cultivation. From south to north the lands extended from the boundary of the state conservation district, which includes the Anahola, Halelea, and Moloaa Forest Reserves, to the Pacific Ocean.

Kuhio Highway connects Kilauea with the Kauai's principal city of Lihue (26 miles) and the island's main port of Nawiliwili (30 miles). About one-fourth of the lands of the study area are between the Kuhio Highway and the coast, the remainder being mountainward of the road.

The mill used in processing sugarcane by the Kilauea Sugar Company is located within the plantation community of Kilauea near Kuhio Highway and about two miles from the ocean and Kilauea Point (see Fig. 3.3, p. 47).

PHYSIOGRAPHIC AND GEOLOGICAL FEATURES OF STUDY AREA. Considered geologically, Kauai is the oldest island in the main Hawaiian group. It is volcanic in origin and lava flows dip radially in all directions from the principal volcanic center near Mt. Waialele. A long period of exposure to climatic forces has weathered rocks into soil material and dissected land areas with streams, deep valleys, and gulches. Major watercourses are the Kilauea and Kalihiwai Rivers and Niu and Moloaa Streams (see Fig. 3.4) and about 20 lesser watercourses which intermittently help to drain the surface water and some ground water directly to the ocean.

In the Kilauea plantation area and its watersheds, rocks of both the Waimea Canyon and Koloa volcanic series are represented. The Waimea Canyon series represents the thin dipping pahoehoe and aa (clinker) lava flows of the original dome of the Kauai volcano. These flows of basalt are both porous and permeable but the porosity and permeability of these materials in the Kilauea area is highly variable. Because the flows were frequent and overlapping, soils were not formed between flows and surface drainage did not become well established until cessation of volcanic activity. Eruptions of the volcano were not explosive and hence little ash was erupted. As a result there are few soils, sediments, or ash beds associated with the early lava flows. Dikes are far less pervious than the flows they

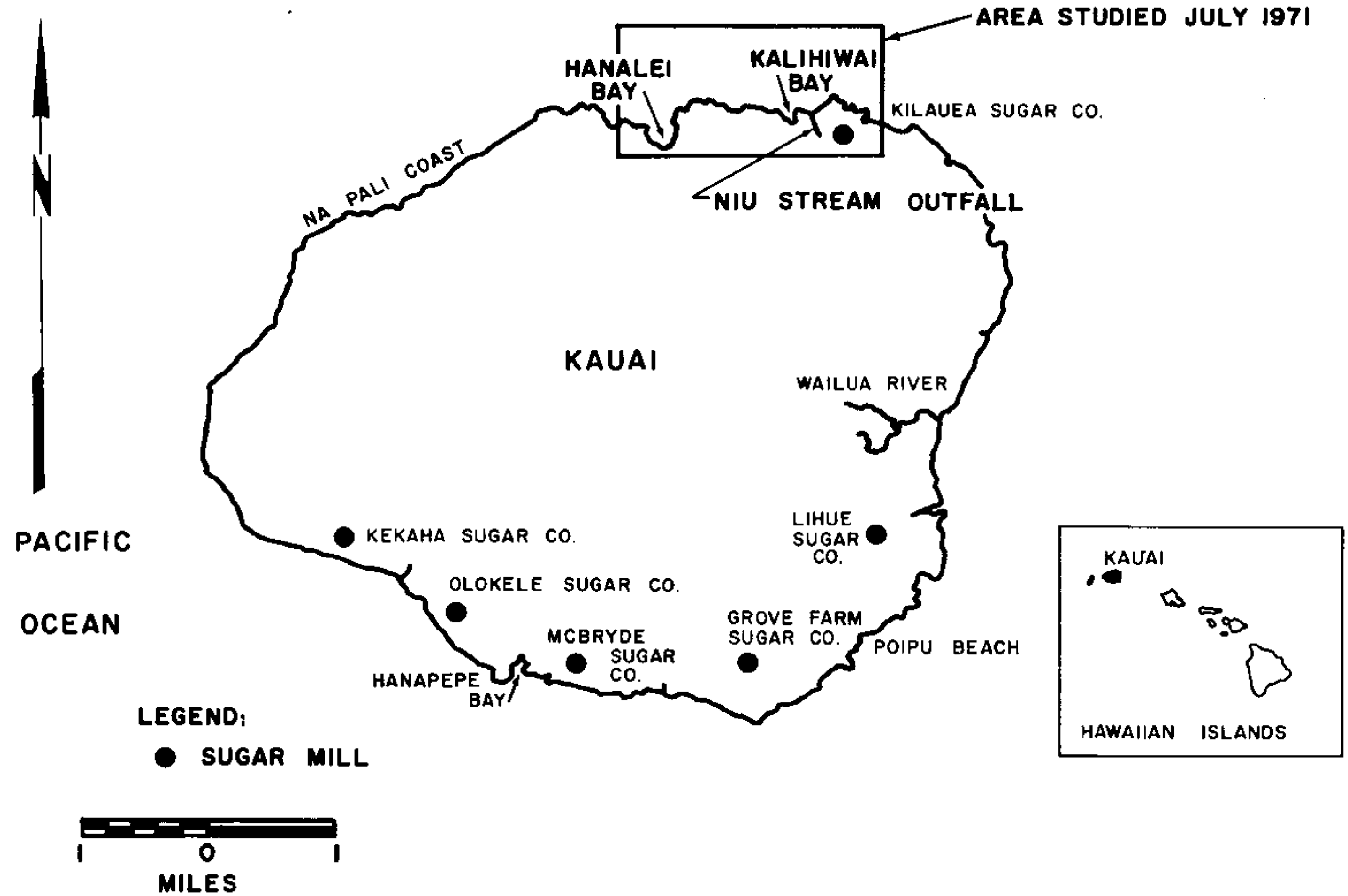


FIGURE 3.2. MAP OF STUDY AREA.

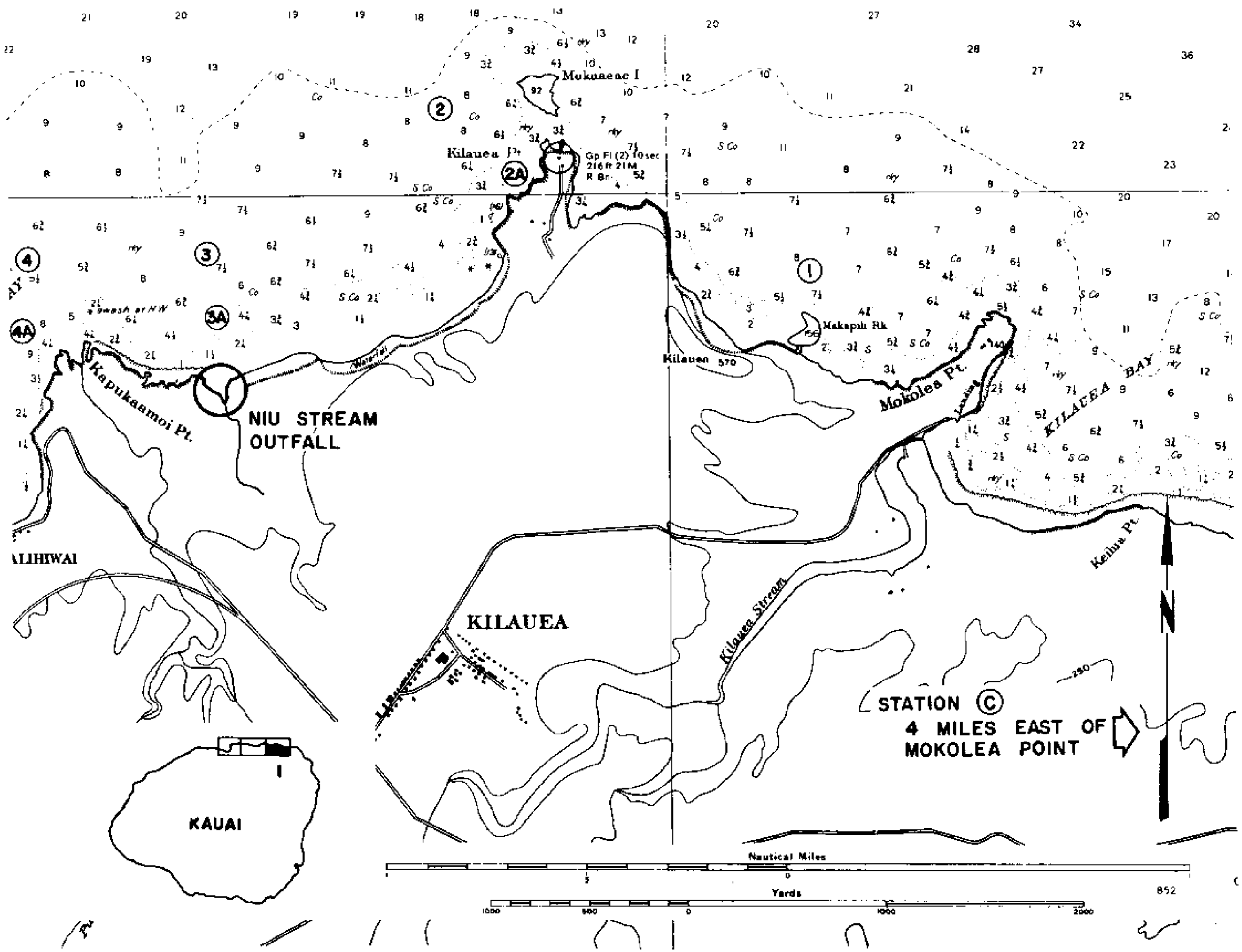


FIGURE 3.3. DETAIL OF OFFSHORE STATION LOCATIONS 1 - 4.

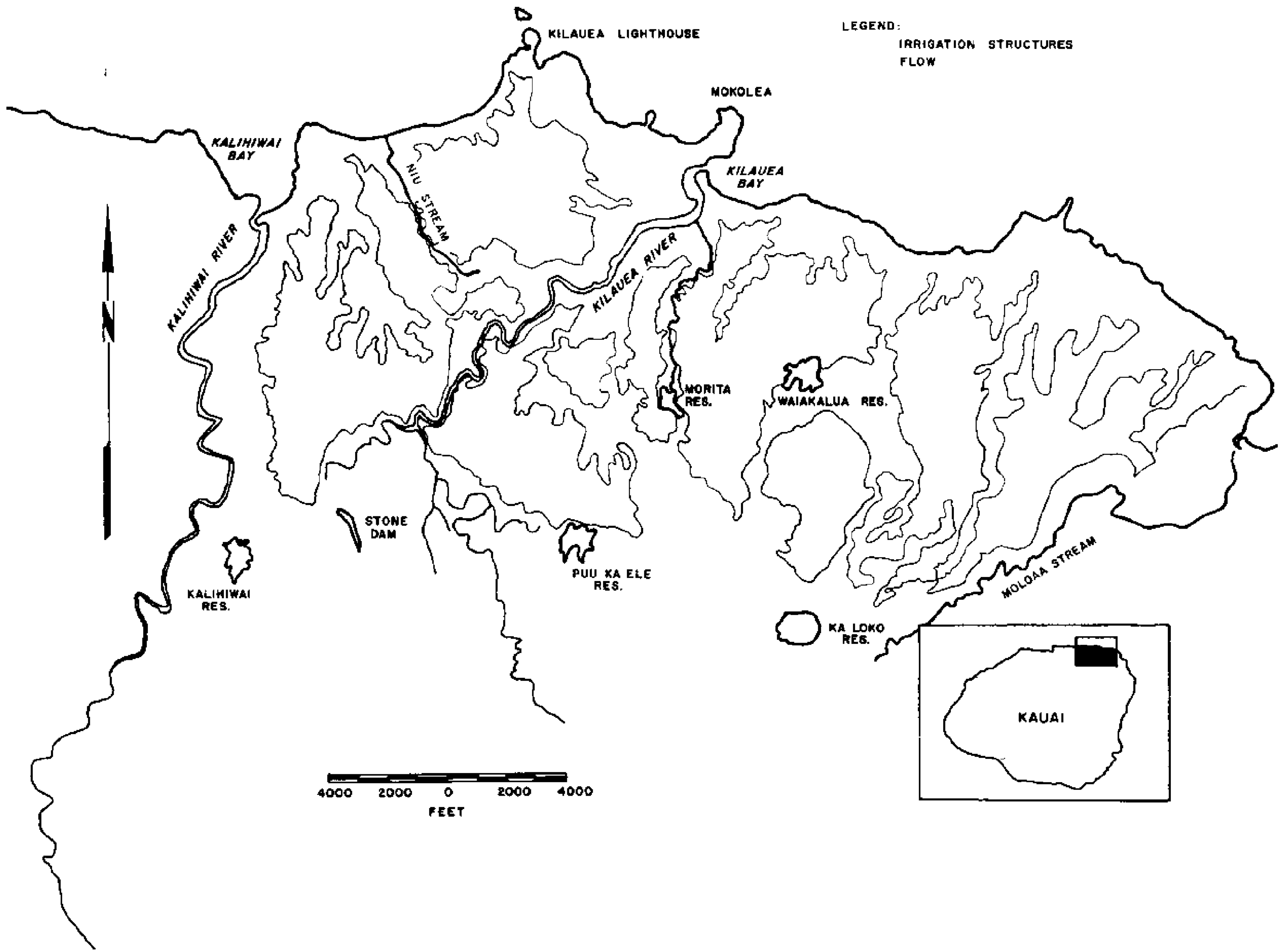


FIGURE 3.4. PRINCIPAL DRAINAGE SYSTEM, KILAUEA PLANTATION AREA.

cut and divides the porous lava masses into numerous compartments.

The original northeast flank of Waimea Canyon dome was thoroughly eroded and the tops of certain mountains and several sharp-edged ridges remain near Kilauea marking the original surface. The eroded Waimea Canyon dome has been thickly mantled by Koloa series flows which are, in general, thick, massive, and poorly permeable with some interbedded ash layers. The depth to the base of the Koloa series is not known in most areas. In two instances holes drilled to 325 and 340 feet below sea level did not reach the base of the flows.

Stream erosion subsequent to the emplacement of the Koloa flows produced the steep-walled valleys which now characterize the Hanalei, Kalihiwai, and Kilauea Rivers and Moloaa Stream. Marine erosion has simultaneously eroded the seaward edge of the Koloa series flow into sheer cliffs. Valleys which were cut during past ages when the sea level was lower than at present have been filled with sediments to make narrow alluvial plains.

The configuration of the coastline within the study area is shown in Figures 3.3 (p. 47), 3.5 (p. 50), and 3.6 (p. 51). Most of the approximately seven miles of coast between Hanalei Bay and Kilauea Bay is outlined with broad, fringing reefs backed by long stretches of narrow sand beaches. From Kilauea Bay to Mokolea Point (Fig. 3.3), the shoreline is largely sandy beach with a fringing reef extending along the entire length. Background land slopes are generally gentle with declivities of 0 to 10 percent. Between Mokolea Point and Makapili Rock, the coastline is characterized by sheer cliffs and a general absence of beaches. There is some sandy beach shoreward of Makapili Rock, perhaps due to the disruption of longshore current processes by the shadowing effect of the rock outcrop. Generally from Makapili Rock to Kilauea point (Fig. 3.3) the shoreline is rugged. There is one small stretch of beach west of Makapili Rock. Background declivities are greater than 80 percent slope. The stretch of coast from Kilauea Point to Kapukaamoi Point (Fig. 3.3) is characterized by broad sandy beaches with a background of steep cliffs of greater than 80 percent slope. Between Kapukaamoi Point and Niu Stream, the point of discharge of mill wastes from the Kilauea Sugar Company, there is a small fringing reef.

The shoreline of Kalihiwai Bay (Fig. 3.5) is backed by a broad sandy beach and gently rolling slopes. Moberly and Chamberlain (1964) describe the beach as an arcuate beach about 1500 feet long that is the bay head barrier of Kalihiwai River. The beach width varies with the season. Sand moves out in the winter and comes back during the summer. Kalihiwai Beach generally has a low slope with at least one berm that is often cusped. Beach sand is medium to coarse-grained and largely detrital.

The coastal area between Kalihiwai Bay and Puu Poa Point (Figs. 3.5 and 3.6) is mostly sandy beach. A broad, fringing reef extends along the stretch of coast almost continuously from Puu Poa Point into Hanalei Bay. The length of coastline between Kalihiwai Bay and Honono Point is backed by cliffs with greater than 80 percent declivity.

SOILS OF THE STUDY AREA. The land within the study area is highly variable in characteristics, reflecting the complex relationships between geology, climate, and soils of the area. These characteristics dictate, in turn, to a large extent, the pattern of land utilization and the nature of waste discharges from the land. Elevations used for sugarcane culture are in the

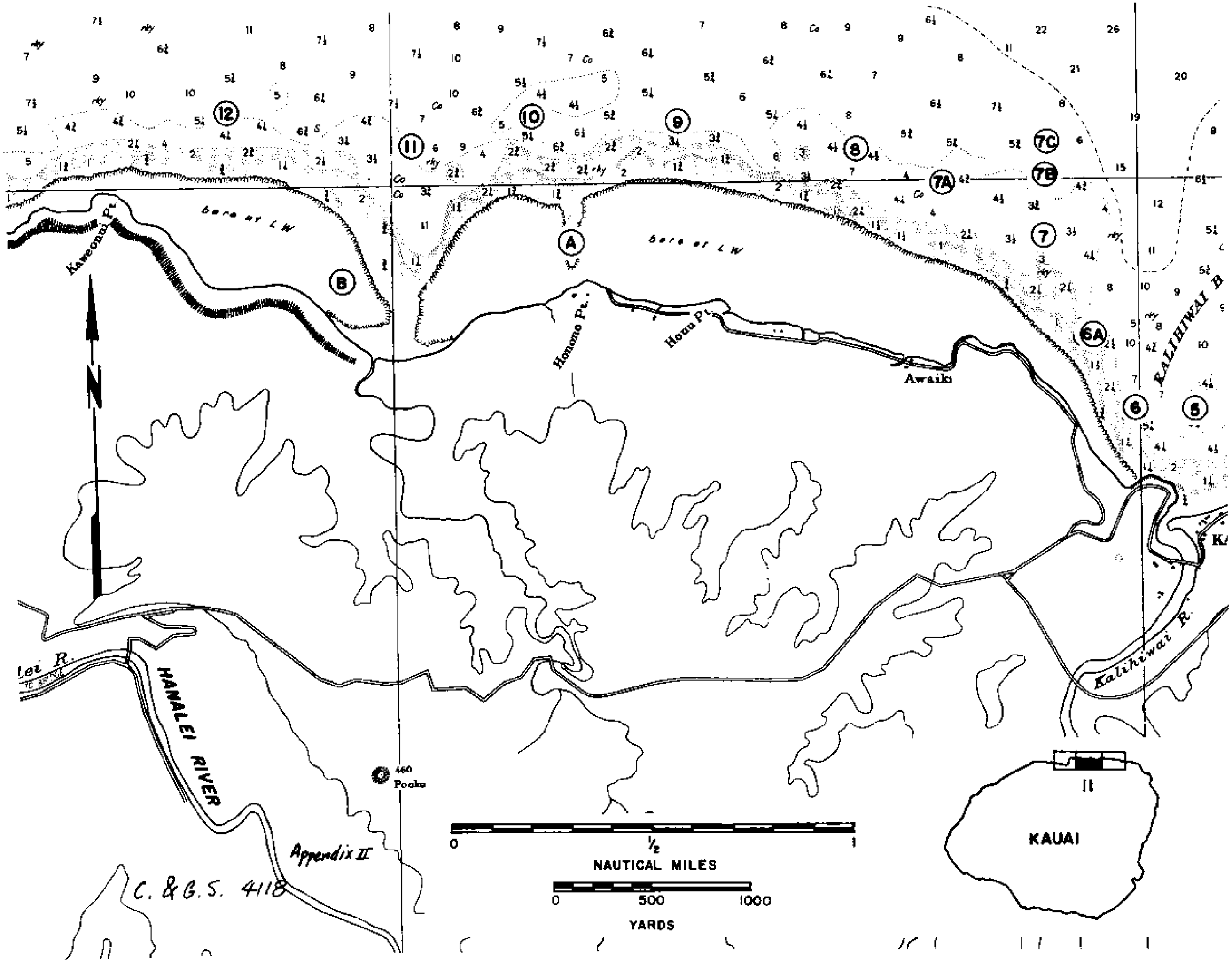


FIGURE 3.5. DETAIL OF OFFSHORE AND REEF STATION LOCATIONS 5 - 12.

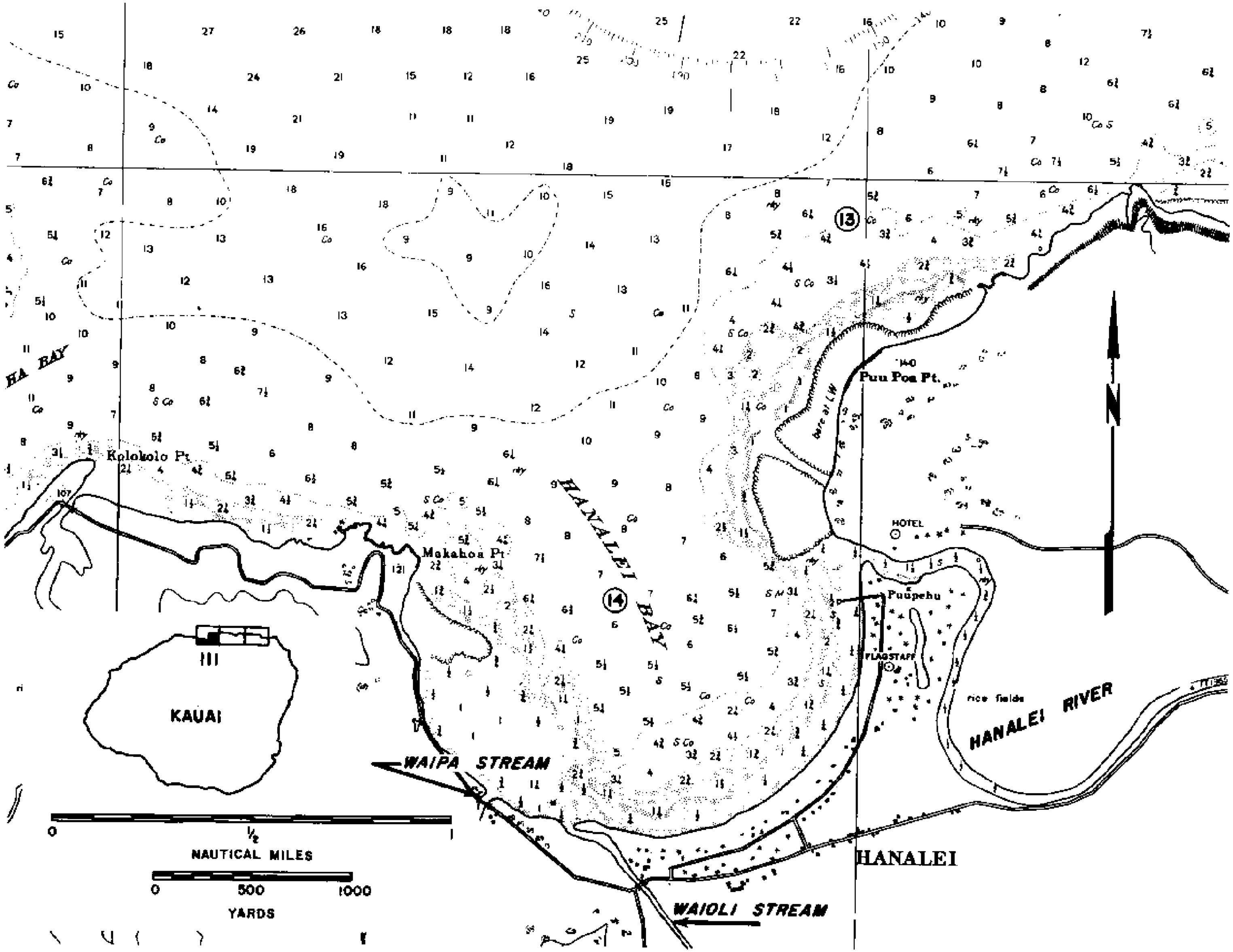


FIGURE 3.6. DETAIL OF OFFSHORE STATION LOCATIONS 13 AND 14.

ranges of from 200 to 600 feet above sea level. The canefields by Hawaiian standards are relatively flat, hence, the area has been adaptable to the use of heavy machinery and equipment.

Most of the cultivated soils occurring on Kilauea Sugar Company lands are oxisols which developed *in situ* from weathered basaltic lavas of the Koloa Volcanic Series (Pleistocene). Within this order are the following series: Lihue, Kapaa, Puhi, Makapili, Pooku, and Halii. Two other orders, Ultisols and Inceptisols, are represented by the Ioleau and Hanamaulu series. Unlike the oxisols and the Ioleau series (which was also derived from residual basic igneous rock), the Hanamaulu series have developed from alluvial materials. The distribution of these soils in the Kilauea area is presented in Figure 3.7.

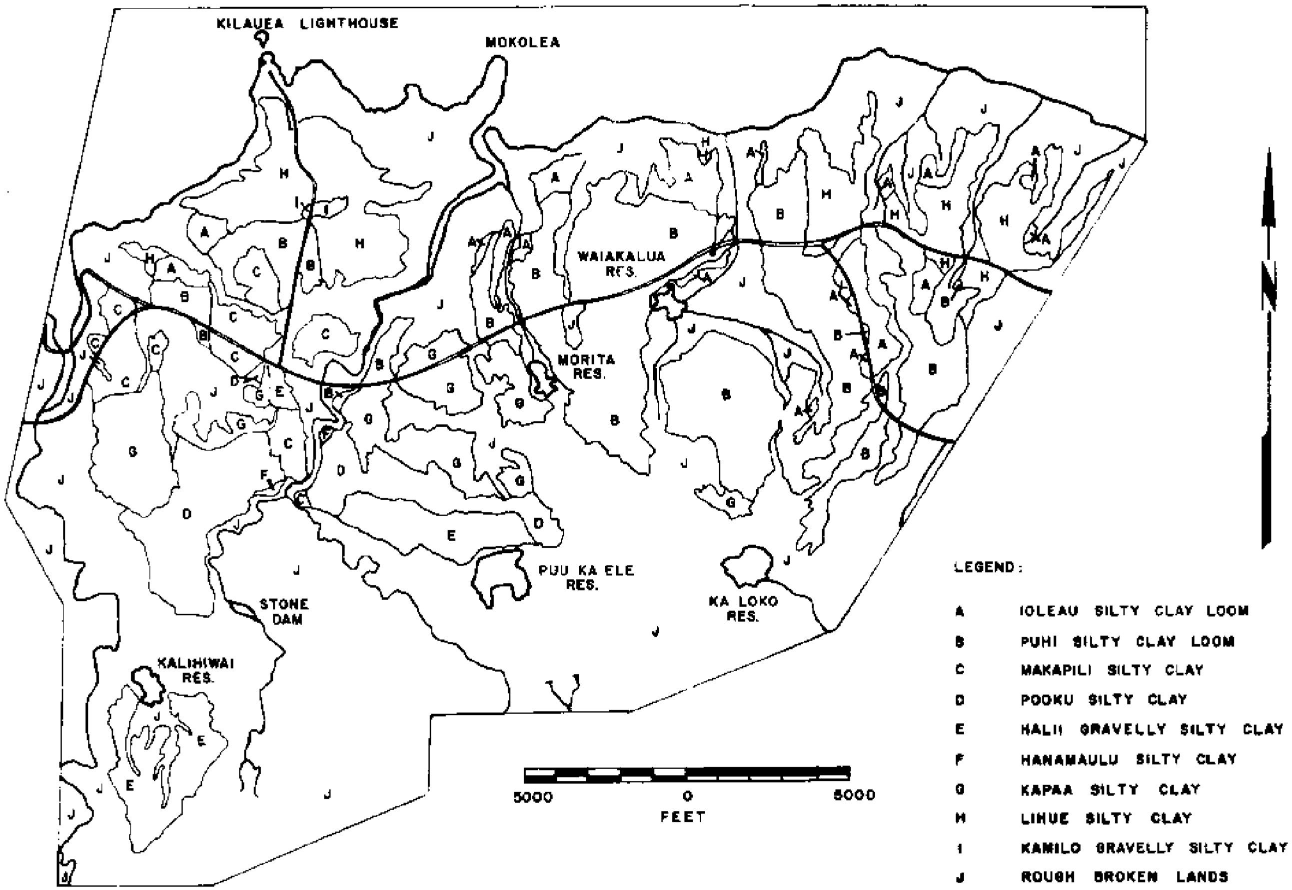
In general, the soils of the area are leached of bases and silica, extremely weathered, and acidic throughout their profiles. Topsoil ranges in pH from 4.2 (Hanamaulu and Pooku soils) to 5.5 (Lihue series). Physically, these soils are non-stony, deeper than 30 inches, have good structure, high amounts of water stable aggregates, and are fairly well suited to machine tilling, especially at slopes of less than 20 percent. Subsoil permeabilities are said to range from "slow" to "moderately rapid."

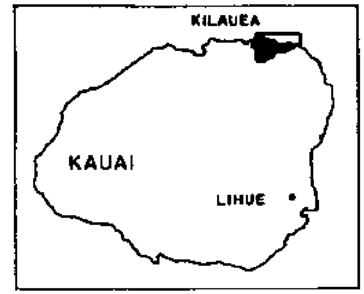
Characteristics of the soils in the Kilauea area, which are cultivated by the Kilauea Sugar Company are summarized in Table 3.2, together with other pertinent information useful in estimating erosion losses or at least the relative hazard of soil loss by surface erosion. Actual erosion losses, of course, depend upon topographic, vegetative, and land management practices as well as upon the soil characteristics, slopes, and climatic conditions indicated in the table.

HYDROLOGICAL AND WATER MANAGEMENT ASPECTS. The Kilauea Sugar Company plantation is located in an area characterized by a mild semi-tropical climate. Owing to the marine influence and the prevailing northeast trade winds, there is little diurnal or seasonal variation in temperature. The mean annual temperature at sea level is reported to be approximately 75°F, with seasonal fluctuations seldom exceeding ±10°F from the mean. Variations in temperature at the study site are largely a function of elevation.

Because the plantation area has a northerly aspect, mountain shadows have a minimum effect on the length of daylight. Cloud cover and fog, and hence humidity increases with elevation. Average daylength varies from a maximum of 13.4 hours during June to a minimum of 11 hours during December. The prevailing winds are northeast trades which often cause orographic rains during the winter months when cyclonic storms pass over Kauai frequently producing heavy rainfall that may cause both soil erosion and crop damage.

The most pronounced feature of the climate of the plantation area is the progressive increase in rainfall over short distances from coastal to inland areas as a result of orographic phenomenon. Thus, the mean annual rainfall on the plantation ranges from nearly 200 inches at the head of the Pohakuhonu Stream and Halaulani Stream watershed, to approximately 40 inches at the ocean shoreline (U.S. Geological Survey, 1961-1969; U.S. Weather Bureau; and Cox, 1954). However, the effect of rainfall in eroding soil and in transporting the various wastes cited in relation to Figure 3.1 (see p. 42) is a function of such things as rainfall intensity and distribution, natural vegetative cover, and water management and agricultural practices. Similarly, the effect of the constituents found in the various waste discharge





LEGEND:

A	IOLEAU SILTY CLAY LOOM	HUMIC FERRUGINOUS LATOSOL
B	PUHI SILTY CLAY LOOM	HUMIC FERRUGINOUS LATOSOL
C	MAKAPILI SILTY CLAY	HUMIC FERRUGINOUS LATOSOL
D	POOKU SILTY CLAY	HUMIC FERRUGINOUS LATOSOL
E	HALII GRAVELLY SILTY CLAY	ALUMINOUS HUMIC FERRUGINOUS LATOSOL
F	HANAMAULU SILTY CLAY	HUMIC LATOSOL
G	KAPAA SILTY CLAY	ALUMINOUS HUMIC FERRUGINOUS LATOSOL
H	LIHUE SILTY CLAY	LOW HUMIC LATOSOL
I	KAMILO GRAVELLY SILTY CLAY	LOW HUMIC LATOSOL
J	ROUGH BROKEN LANDS	

FIGURE 3.7. SOILS OF THE KILAUEA AREA.

TABLE 3.2. KILAUEA SUGAR COMPANY CULTIVATED SOILS: CHARACTERISTICS AND CAPABILITIES.

SOIL SERIES[2]	FAMILY	TOTAL AREA (%) [3]	ELEVATION (FEET)	RAINFALL (IN/YR)	RUNOFF	EROSION HAZARD	EFFECTIVE SOIL DEPTH (INCHES)	WATER HOLDING CAPACITY IN SOIL (INCHES)
1. HALII GRAVELLY SILTY CLAY 3-8% SLOPES	TYPIC GIBBSIHUMOX CLAYEY, FERRITIC, ISOTHERMIC	3.0	300-1000	100-200	VERY LOW	SLIGHT	OVER 60	---
2. HALII GRAVELLY SILTY CLAY 8-15% SLOPES	SAME AS ABOVE	0.6	" "	" "	LOW	SLIGHT TO MODERATE	" "	---
3. HANAMAULU SILTY CLAY 3-8% SLOPES	OXIC HUMITROPEPTS FINE, OXIDIX, ISO-HYPERTHERMIC	0.1	200-1000	90	VERY LOW	NONE TO SLIGHT	" "	7.0 FOR 5 FT
4. IOLEAU SILTY CLAY LOAM 2-6% SLOPES	ORTHOXIC TROPOHUMULTS CLAYEY, OXIDIC, ISO-HYPERTHERMIC	3.9	100-750	40-65	LOW	SLIGHT	25-36	3.6-5.4
5. IOLEAU SILTY CLAY LOAM 6-12% SLOPES	SAME AS ABOVE	3.5	" "	" "	MODERATE	MODERATE	15-25	2.0-3.6
6. IOLEAU SILTY CLAY LOAM 12-20% SLOPES, ERODED	" " "	1.9	" "	" "	HIGH	MODERATE TO SEVERE	15-25	2.0-3.6
7. KAPAA SILTY CLAY 3-8% SLOPES	TYPIC GIBBSIHUMOX CLAYEY, GIBBSITIC, ISOTHERMIC	8.9	200-800	75-100	VERY LOW	SLIGHT	OVER 60	---
8. KAPAA SILTY CLAY 8-15% SLOPES	SAME AS ABOVE	2.1	" "	" "	LOW	"	" "	---
9. KAPAA SILTY CLAY 15-25% SLOPES	" " "	0.8	" "	" "	MODERATE	MODERATE	" "	---
10. LIHUE SILTY CLAY 0-8% SLOPES	TROPEPTIC EUTRUSTOX CLAYEY, HALLOYSITIC, ISOHYPERTHERMIC	14.0	0 -800	40-60	VERY LOW	NONE TO SLIGHT	USUALLY TO DEPTH OF FOLLAGE	3.2 (VARIABLE)
11. LIHUE SILTY CLAY 8-15% SLOPES	SAME AS ABOVE	3.6	" "	" "	LOW	SLIGHT	SAME AS ABOVE	SAME AS ABOVE
12. LIHUE SILTY CLAY 15-25% SLOPES	" " "	0.9	" "	" "	MODERATE	MODERATE	" " "	SAME AS ABOVE
13. LIHUE GRAVELLY SILTY CLAY 0-8% SLOPES	" " "	0.7	" "	" "	VERY LOW	NONE TO SLIGHT	" " "	SAME AS ABOVE
14. MAKAPILI SILTY CLAY 0-8% SLOPES	TYPIC ACROHUMOX CLAYEY, FERRITIC, ISOTHERMIC	8.7	100-350	70-80	" "	SLIGHT	60	7.5
15. MAKAPILI SILTY CLAY 8-15% SLOPES	SAME AS ABOVE	0.8	" "	" "	LOW	"	"	"
16. POOKU SILTY CLAY 0-8% SLOPES	TYPIC ACROHUMOX CLAYEY, FERRITIC, ISOTHERMIC	8.8	250-1000	80-150	VERY LOW	NONE TO SLIGHT	"	---
17. POOKU SILTY CLAY 8-15% SLOPES	SAME AS ABOVE	2.2	" "	" "	LOW	SLIGHT	"	---
18. POOKU SILTY CLAY 15-25% SLOPES	" " "	0.2	" "	" "	MODERATE	MODERATE	"	---
19. PUHI SILTY CLAY LOAM 3-8% SLOPES	TYPIC UMBRIORTHOX CLAYEY, OXIDIC, ISO-HYPERTHERMIC	24.6	175-500	80-150	LOW	SLIGHT	"	7.0
20. PUHI SILTY CLAY LOAM 8-15% SLOPES	SAME AS ABOVE	9.9	" "	" "	"	"	"	"
21. PUHI SILTY CLAY LOAM 15-25% SLOPES	" " "	0.8	" "	" "	MODERATE	MODERATE	"	"
		100.0						

[1] THE ABOVE DATA WAS COMPILED FROM THE FOLLOWING SOURCES: a) DETAILED LAND CLASSIFICATION - ISLAND OF KAUAI, LSB BULLETIN NO. 9, 1967, b) SOIL CONSERVATION SERVICE, "HAWAII TECHNICAL GUIDE, TABLE OF SOIL CHARACTERISTICS AND QUALITIES."

[2] NATURAL DRAINAGE OF ALL SOILS CLASSIFIED AS "WELL DRAINED."

[3] TOTAL CULTIVATED AREA: 4,668 ACRES. ACREAGE PERCENTAGES PLANIMETERED AND ADJUSTED FROM SOIL SURVEY AIR PHOTOS SCALE (1/1559.6). PERCENTAGES FOR NOS. 6 AND 9, COLUMN 1, ALSO INCLUDE SMALL ACREAGES FROM MORE SLOPING PHASES.

streams (see p. 110) on coastal water quality is related to the volume of wastewater discharged. For this reason it is necessary to make estimates of several of the hydrologic aspects of the study area by evaluating such data as are available.

Some concept of the seasonal variation in rainfall may be gained from Table 3.3 prepared by the Kilauea Sugar Company from data obtained from rain gages located on the plantation.

TABLE 3.3 MONTHLY AVERAGE RAINFALL FOR TWO RAIN GAGE STATIONS OF KILAUEA SUGAR COMPANY: 1949-1958.

MONTH	GAGE F300 (INCHES)	KALIHIWAI GAGE (INCHES)
JANUARY	5.4	8.5
FEBRUARY	3.6	6.4
MARCH	6.7	14.2
APRIL	8.1	11.3
MAY	5.3	9.5
JUNE	2.1	4.6
JULY	2.5	8.3
AUGUST	5.1	7.7
SEPTEMBER	2.3	5.1
OCTOBER	6.1	8.7
NOVEMBER	5.5	10.6
DECEMBER	6.1	9.2
MEAN ANNUAL RAINFALL	57	104

There are nearly two dozen rainfall gages located on or adjacent to sugarcane growing areas of the Kilauea plantation. However, there are only a few gages in the mountain areas. Therefore, rainfall in the principal individual watersheds of the area must be estimated. Three isohyetal maps published in 1954 (Cox, 1954), 1959 (Taliaferro, 1959), and 1969 (Smith, 1969) cover the plantation area. Figure 3.8 presents one such map used by the Kilauea Sugar Company in making its estimates and reports. Such maps are judged to be applicable because although the total rainfall has varied from year to year by a factor sometimes greater than three, the overall average has remained essentially constant from 1948 to 1969. Moreover, the rainfall contours for high rainfall in the mountainous areas were based on estimates and there is no better bases for estimates today than there was in past years.

The mean rainfall input to the Kilauea plantation, based on the isohyetal maps, averaged 87 mgd. This is equivalent to an average rainfall value of 88 inches per year over the entire plantation area of 13,333 acres. The percentage of this rainfall that appeared as runoff might be estimated from rainfall records which show the mean annual rainfall to average approximately 150 inches per year for the Pohakuhonu and Halaulani Stream watershed, or 23,100 acre feet per year. The flow of this stream system averages approximately 19,200 acre feet per year according to U.S.G.S. records (1961-1969). Thus the rainfall-runoff coefficient is computed at the relatively large value of 0.83. However, this coefficient reflects not only direct surface runoff but also ground-water seepage, some of which may originate outside of the basin. Whether such a value is reasonable or not is difficult to assess. Cox (1954) has noted that "infiltration is

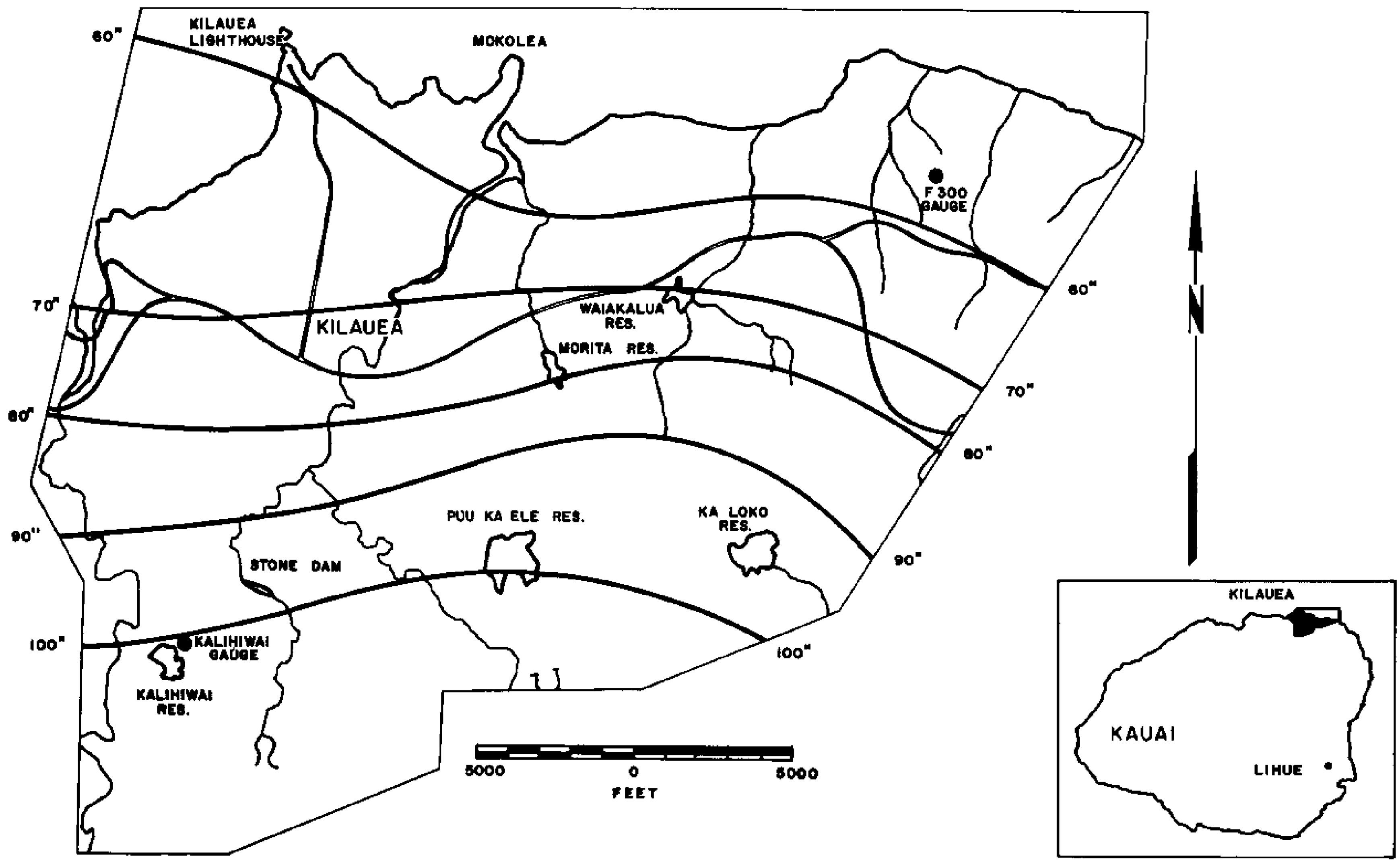


FIGURE 3.8. ISOHYETAL MAP OF THE KILAUEA AREA.

poor in much of the plantation area because of the low permeability of the underlying rock." Table 3.2, however, indicates that the soils themselves are well drained and that the range of runoff is low to moderate. Ground water discharge accounts for most of the dry weather flow of the Pohakuhonu and Halaulani Streams. Moreover, high mountain dike water is reported to contribute to the ground-water flows in Kauai in unknown quantities (Cox, 1954 and Clark, 1935). Therefore it is possible that some of the watershed flow originates outside the watershed boundaries, but for the present study this possibility is not considered in the water balance determinations. Rainfall directly on the reservoirs and ditches, and runoff intercepted by a ditch system near the coastal area are neglected because the intercepted water is calculated essentially to equal evaporative losses.

The irrigation system for the Kilauea Plantation prior to its cessation of operations is shown schematically in Figure 3.9 and geographically in Figure 3.10. All of the surface water involved except that from two sources either originated on the Kilauea Plantation or flowed by natural watercourses (or if not diverted would have flowed by such courses) to the plantation. The two diverted sources were the Moloaa and Hanalei Ditches. The Moloaa Ditch was diverted from the Kaluaa Stream (not shown) before its conflux with the Moloaa Stream (not shown) and was discharged into the Ka Loko Ditch which in turn discharged into the Ka Loko Reservoir. The flow in the Moloaa Ditch was not measured; however, the data from USGS continuous recording flow gaging station which had been in operation from 1933 to 1968 on the Ka Loko Ditch downstream of the Moloaa Ditch discharge point were used. The Hanalei Ditch carried water diverted from the adjacent Kalihiwai River, purchased from Lihue Plantation.

As shown in Figure 3.9, the irrigation system was comprised of four collection reservoirs, Ka Loko, Puu Ka Ele, Stone Dam, and Kalihiwai, and two holding reservoirs, Waiakalua and Morita. In addition, Ross Ditch discharged water into Koalau Ditch. Ka Loko and Puu Ka Ele Reservoirs and Ross Ditch were connected by varying degrees to Puu Ka Ele Stream, thereby essentially eliminating the possibility of determining the contribution of surface runoff from the individual drainage areas.

Although Pohakuhonu Stream above Stone Dam was diverted to Kalihiwai Ditch, there was a USGS continuous recording gage was in service on the diversion from 1961 to 1967. Therefore, with this flow record, in addition to flow data from the USGS gages on both Halaulani and Pohakuhono Streams before they flow into Stone Dam, a surface runoff value can be calculated. From the difference between the recorded mean annual flows of the two USGS stations on Kalihiwai Ditch, the flow in the pipeline serving the Kilauea Sugar Mill and adjacent property was calculated to be 2.9 mgd, thus, yielding an estimate of the mill waste discharge.

Miscellaneous flows of 0.4 mgd into Puu Ka Ele Reservoir and 0.2 mgd into Kalihiwai were estimated by Kilauea Plantation personnel. The water purchased from Lihue Plantation conveyed in Hanalei Ditch was not measured by a continuous flow recorder but was reported (Kilauea Sugar Co., Ltd., 1963) to have amounted to 7 mgd except for the months of June, July, August, and September at which time it was estimated to be 5.5 mgd, yielding an annual average of 6.5 mgd. The remaining flows shown in Figure 3.9 into the four collecting reservoirs and Ross Ditch were measured by USGS continuous flow recorders for various time intervals beginning in 1933. During 1967-68 all of the USGS stations were discontinued except for the two located on Poha-

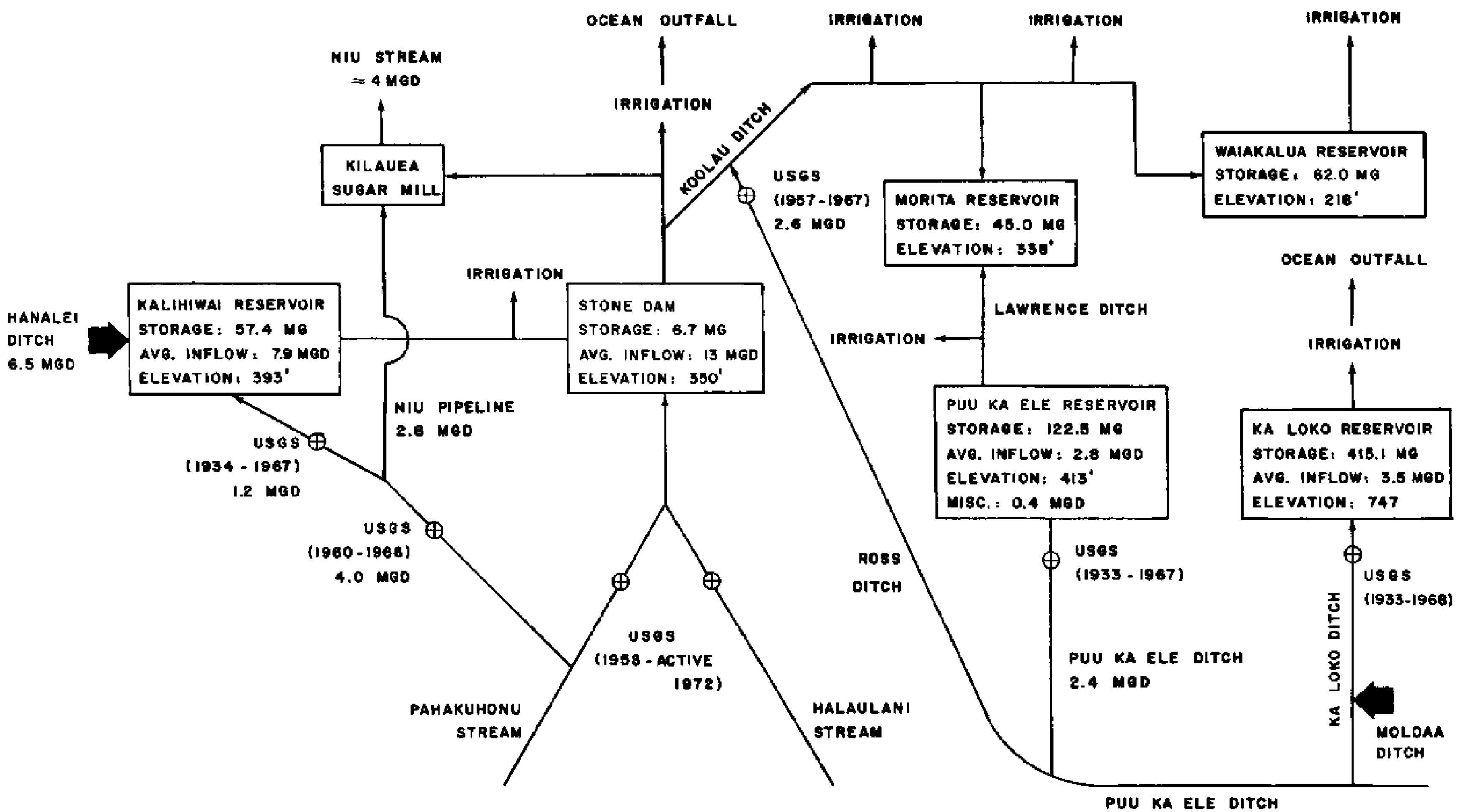


FIGURE 3.9. IRRIGATION WATER SYSTEM FOR KILAUEA PLANTATION. INFLOW FROM USGS RECORDS 1961-1966 KILAUEA PLANTATION RECORDS.

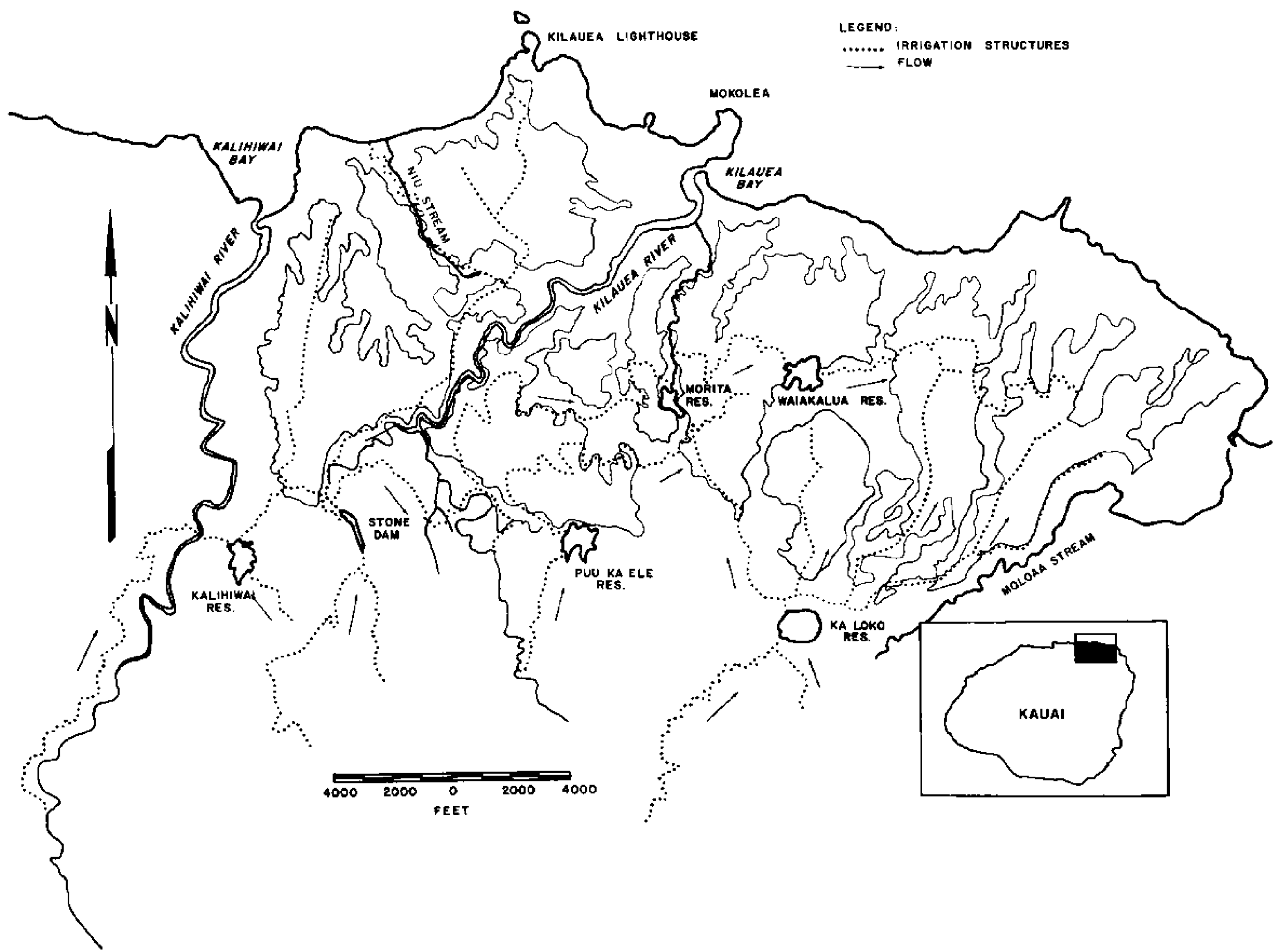


FIGURE 3.10. IRRIGATION SYSTEM FOR KILAUEA SUGAR PLANTATION.

kuhono and Halaulani Streams above Stone Dam. Thus the only stream drainage areas on the plantation with flow records and without interconnection with unknwon flow systems are these two remaining USGS gages cited above. The watershed area of the Pohakuhonu and Halaulani Streams at the gaging station are 1113 and 735 acres, respectively. A swampy area, however, is located between the two gaging stations, hence it is impossible to identify the actual line of demarcation between the two watershed areas. Therefore, for practical purposes, the two areas totaling 1848 acres are herein considered as one.

The total quantity of irrigation water flowing into the four collection reservoirs and Ross Ditch amounted to an average of 29.3 mgd for the period 1961 to 1966 and to 31.5 mgd over the entire period of record from 1933 to 1967. Therefore, it seems reasonable to consider 30 mgd as representative of the average flow entering the Kilauea Plantation irrigation system throughout the period that might reasonably be expected to have influenced the coastal water quality as it existed when the study began. To estimate the amount of this flow which was discharged into the ocean as irrigation tailwater, it is necessary to consider the acreage of sugarcane under irrigation and the water requirements of growing cane.

In 1969, Kilauea Sugar Plantation reported (Smith, 1969) that 3200 of its 4668 producing acres were under irrigation. Furrow irrigation with level ditches and aluminum flumes accounted for 1700 acres. Ames Boom-O-Rain sprinklers of 600 gpm capacity were used on the remaining 1500 acres. Because by 1971, a changeover from sugarcane to sorghum was already in progress, the pre-1969 irrigation practice (Smith, 1969) of 1700 and 1500 acres in furrow and sprinkler systems, respectively, is herein used for comparative purposes.

Estimates of sugarcane water requirements were based on the following parameters (Ekern, 1972):

a. The net water requirement of sugarcane versus evaporation is in the ratio of 1:1
b. Furrow irrigation is 30 percent efficient and sprinkler irrigation is 60 percent efficient
c. Of the approximately 70-inch average rainfall on the sugarcane fields, 30 inches can be effectively used by the sugarcane.

Evaporation pan data from four areas on the Kilauea Plantation indicate that evaporation losses in the canefield ranged from 60 inches per year near the mountain region and nearly 80 inches per year near the coastal area to give an average of approximately 75 inches per year in the sugarcane growing areas. Based on these measurements, the 3200 acres of irrigated sugarcane would require an average of 27 mgd of water. This compares favorably with the estimate of 30 mgd input to the irrigation system and is therefore assumed to be a reasonable check on the method of estimation.

The portion of the Kilauea Plantation that was not in agricultural crops, and hence discharged surface runoff directly to the ocean without being intercepted by reservoirs or irrigation ditches, amounted to approximately 3750 acres. The average rainfall in this area is nearly 60 inches per year, with an estimated surface runoff coefficient of 0.7 (based on the first approximation of 0.83 coefficient measured at higher elevations having twice as much rainfall). These measurements and estimates then result in a value of 12 mgd surface runoff to the ocean from the uncropped land area of the plantation.

An irrigation ditch was diverted through the Kilauea Sugar Mill during the harvesting season and discharged into Niu Stream. A portion of the irrigation water as well as the piped water from the Kalihiwai Ditch was used in the mill's operation. The wastewater effluent from the mill contained various quantities of silt, bagasse, cane trash and stalks, fly ash, factory restroom waste, traces of oils and lubricants, sugar, and residual chemicals used in the milling process which included magnesium oxide, lime, caustic soda, soda ash, and sulfuric acid. The wastewater and debris were flumed adjacent to the diverted irrigation ditch with several overflows to the ditch for approximately 3800 feet to an outfall that converged with the diverted irrigation water at Niu Stream. The average flow of Niu Stream during mill operation was estimated by Kilauea Plantation personnel to be about 5 mgd for nine months of mill operation or an average of approximately 4 mgd annually.

An overall hydrologic budget for the Kilauea Sugar Plantation is shown in a block diagram in Figure 3.11. It summarizes evaluations made in previous

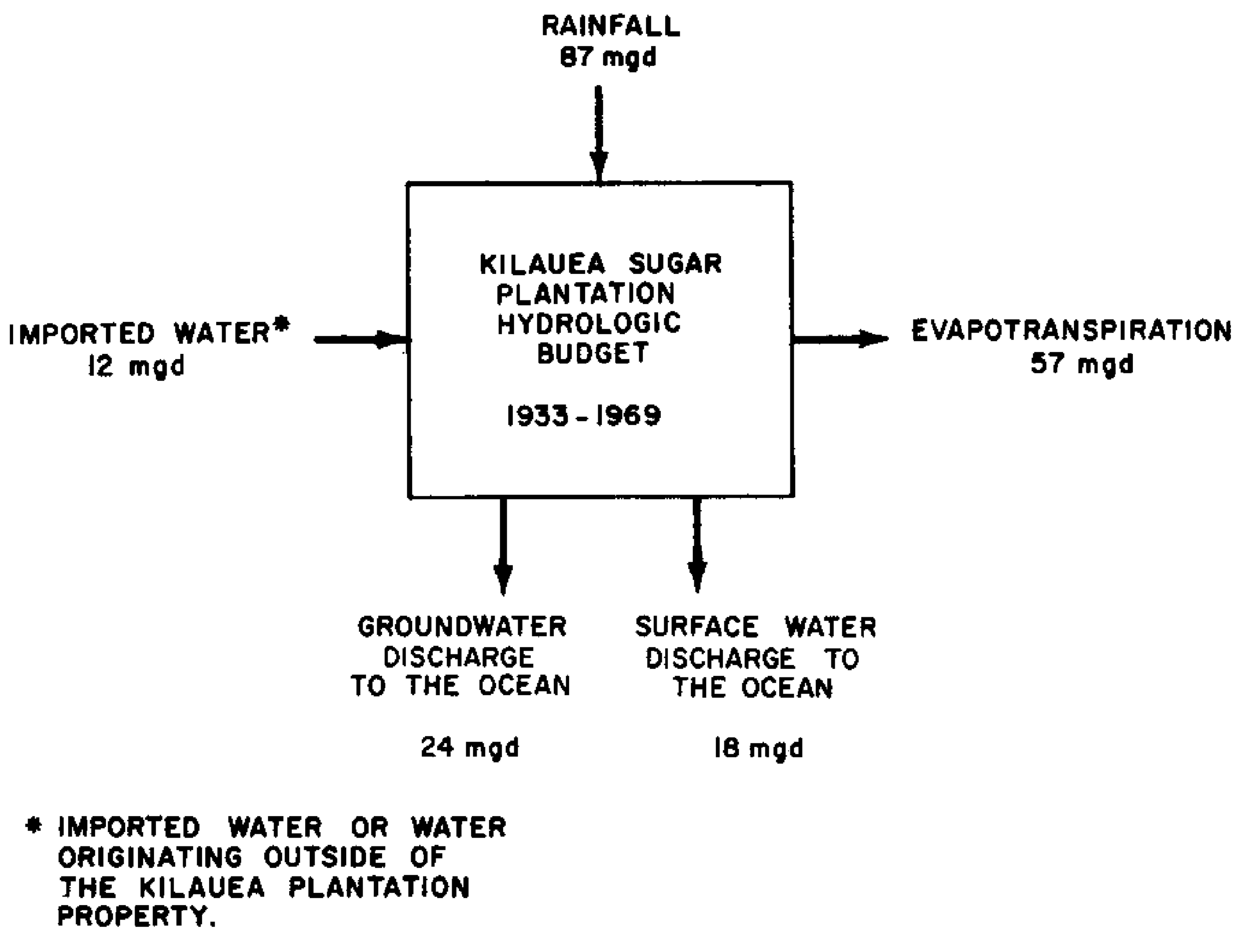


FIGURE 3.11. KILAUEA SUGAR PLANTATION HYDROLOGIC BUDGET (1933-1969).

paragraphs and estimates of evaporation and loss via ground-water transport. Inputs to the budget are the rainfall of 87 mgd within the plantation boundaries (13,333 acres) and the 12 mgd denoted as imported water. The imported water value includes the 6.5 mgd purchased from Lihue Plantation, 3.5 mgd flowing into Ka Loko Reservoir, and a prorated portion of the influent to Puu Ka Ele Reservoir estimated at 2.0 mgd.

Outputs from the system include surface runoff, evapotranspiration, and ground water discharge into the ocean via outcropping strata of springs which feed Kilauea River and other streams in the plantation area. Surface runoff is estimated at 16 mgd, including the mill usage. Evapotranspiration is estimated as follows: based on a sugarcane net water requirement to pan evaporation ratio of 75"/year, the 4668 acres of sugarcane required 26 mgd of water. No firm evapotranspiration data are available for the miscellaneous vegetative cover on the 8,665 acres of Kilauea Sugar Company property in forest reserve, gulches, and wasteland. However, assuming that the same quantity of rainfall is utilized by the plants as by sugarcane (30"/year), transpiration from the non-crop area would have amounted to 19 mgd. Evaporation from vegetative-intercepted rainfall is difficult to estimate. However, assuming that 15 percent of the pan evaporation rate applies to intercepted water, based on general experience elsewhere, the loss of water from 13,333 acres by this route would be some 11 mgd. Thus, an estimate of 56 mgd output via evaporation and transpiration is made. For lack of a more accurate basis of estimation, the remaining 27 mgd of input is ascribed to losses via ground-water discharge as springs along the cliffs overlooking the coastline which flow into the Kilauea River and other streams.

Although the hydrologic budget values estimated and summarized in Figure 3.11 are estimates only, they do give some reasonable scale to the various wastewater streams reaching the ocean from the Kilauea Sugar Company during its later years of operation, *e.g.*, 1969. For reasons further elaborated in "Oceanographic Factors" (p. 62) an appreciable error in values presented is of little significance in the final analysis of coastal water quality as a function of the Kilauea operation.

Ground water was discovered in 1971 within the project area at an exploratory well (Kilauea Well 1125-11) located about 1500 feet south of Kilauea town and about 12,000 feet from the shoreline at a ground elevation of 390 feet. The depth of the well is 790 feet or 400 feet below mean sea level. The static water level stood about 16 feet above mean sea level and the water quality is excellent having 12 mg/l for chloride and 62 mmhos at 25°C for conductivity. The water temperature is 73 to 75°F and is within the common range for Hawaii ground water. The driller's log indicates thick formations of clayey soils, extending throughout the tope 260 to 275 feet. The well yield was reported inadequate when the well was tested at the 500 foot depth. However, after extension to its final depth, the well yielded 1000 gpm with a 12-foot drawdown and the recovery was rapid as is the usual case in most Hawaiian well production. Additional ground-water data will be needed before the ground-water hydrology can be established for the project area.

OCEANOGRAPHIC FACTORS. Niu Stream which carries the mill wastewater was long considered the obvious cause of an extensive plume of discolored water along the shoreline area. Figure 3.10 indicates that the coastline near the Niu Stream outlet is also the area where any irrigation tail water from the plantation lands west of Kilauea River might be expected to reach the ocean, the remainder being more dispersed via smaller streams discharging east of Kapuhi Point. Therefore, the oceanographic conditions in the study area, particularly near the mouth of Niu Stream, were considered to be an important aspect of the coastal water quality situation in the study area. Moreover, the sediment-laden plume itself presented an opportunity to observe in a qualitative fashion the dispersal patterns of the discharged wastes.

The northern coastline of Kauai is exposed to predominantly northeast tradewinds which are the most persistent source of wave energy for the area. Waves generated by these tradewinds are present almost all year round, with the largest waves occurring from April to November (Inman, Gayman and Cox, 1963). The 4 to 12-foot waves typically have periods of 5 to 8 seconds and approach from the east-northeast. An intermittent source of wave energy is the winter swell which is caused by the Aleutian and mid-latitude lows. The waves are most intense from October through May and produce wave periods of from 10 to 17 seconds and waves that are 8 to 14 feet in height which may approach from the northwest, north, or northeast.

There are few data on currents in the Kilauea area and none on inshore observations. A small number of measurements from other locations off the northern coast of Kauai show alternating tidal motions approximately paralleling the trend of the shore. It would appear that currents off the northshore are complex. The ocean bottom drops rapidly to deep water, a sharp point exists to the east, and an abrupt embayment to the west causing offshore currents that are non-steady and surf conditions that vary widely.

Some data on currents are reported in the literature. Laevastu, Avery and Cox (1964) reported a westerly current off Hanalei on 24 July 1963 and northwest to west current with speeds as great as 1.8 knots at the time of high tide off Kilauea and Anahola on 25 July 1963. Wyrtki, *et al.*, (1969) reported "prevailing diurnal tidal currents superimposed on weak flow from the east" from paddle-wheel current meter studies off Kilauea Point from October 25 to November 12, 1968. Both of these reports deal with currents at a considerable distance offshore.

In addition to the complex current patterns, there are equally or even more complex patterns inshore where the nearshore environments is subject to random horizontal eddies. Moberly and Chamberlain (1964), for example, noted a strong alongshore current to the east during periods of high waves in Kalihiwai Bay. Observations of the vividly colored plume which was generated by Niu Stream each working day soon after startup of washing and milling operations at the Kilauea Sugar Company mill were made by members of the staff of the Coastal Water Quality Project. With the assistance of the Civil Air Patrol and the photography class of Kauai Community College, aerial color photographs were made of the plume on weekdays during the 1 to 11 November, 1971. The results, of which Figures 3.12 and 3.13 are examples, showed that the plume exhibited widely variable and random patterns, primarily influenced by a lateral eddy motion of various scales. There was no evidence of correlation with tide or wind. The plume went strongly west on one day, weakly east on two days, showed little overall direction on three days, and strongly east on one day. The strong east and strong west motions occurred on consecutive days, illustrating the randomness of the pattern (and the eastward motion was against the stronger tradewind). Regardless of the direction the main plume took, some discolored water was alwyas seen extending eastward as far as Kilauea Point, probably indicating a quasi-permanent eddy behind this sharp projection of the coastline. For the pur-

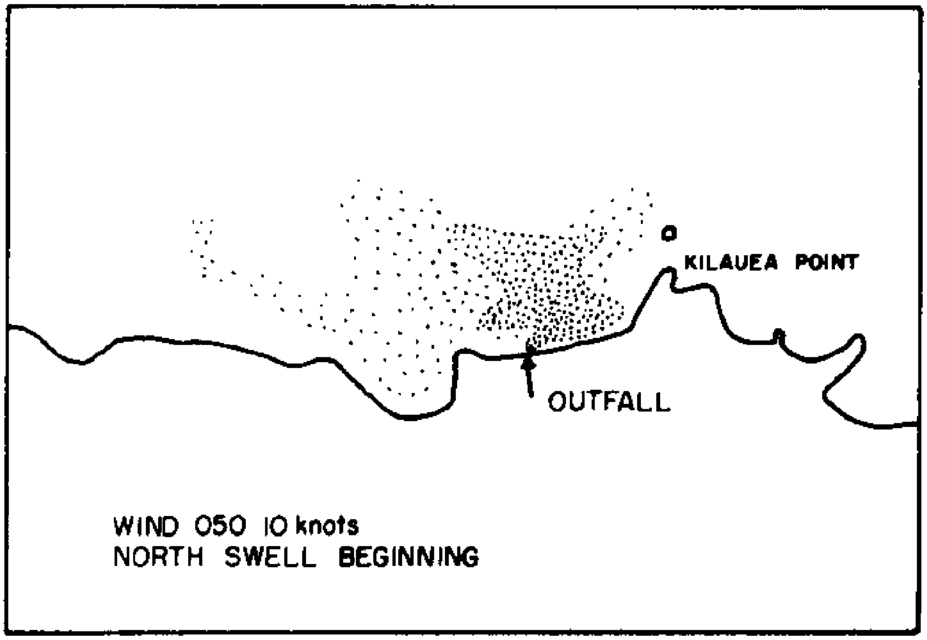


FIGURE 3.12. EASTWARD DRIFT OF PLUME ON NOVEMBER 4, 1971.

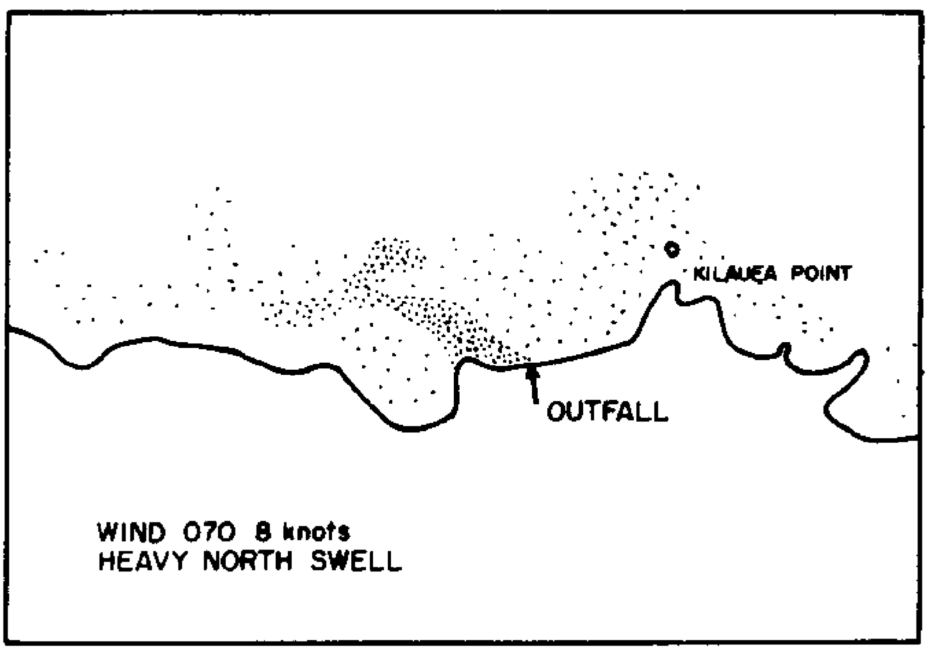


FIGURE 3.13. WESTWARD DRIFT OF PLUME ON NOVEMBER 5, 1971.

poses of the study it was concluded that there is no regularity in the plume pattern which might be reflected in regularities of bottom effects; hence, such effects should be visible in both directions from the outfall, and not just westward as suggested by casual observations by local informants.

Land Use and Agricultural Practice

BRIEF HISTORY OF KILAUEA SUGAR COMPANY. Kilauea Sugar Company was the third of seven sugar companies to begin operations on Kauai, being established in 1877. Table 3.4, compiled from data furnished by the Company (Smith, 1969

TABLE 3.4. CHRONOLOGICAL HISTORY OF KILAUEA SUGAR COMPANY.[1]

1877 - THE FIRST SUGARCANE WAS PLANTED BY E.P. ADAMS AND JOHN ROSS AS PART OF A RANCHING OPERATION WITH ABOUT 6000 HEAD OF CATTLE AND 3000 ACRES OF LAND.

1880 - THE FIRST CANE WAS HARVESTED THREE YEARS AFTER THE FIRST PLANTING, WITH YIELDS OF ABOUT 4 TO 5 TONS RAW SUGAR PER ACRE.

1881 - KILAUEA INSTALLED THE FIRST RAILROAD IN HAWAIIAN SUGAR INDUSTRY TO HAUL CANE FROM THE HARVEST FIELDS TO THE MILL.

1910 - THE GASOLINE TRACTOR WAS INTRODUCED AT KILAUEA REPLACING THE STEAM PLOW.

1937 - THE FIRST CANE CLEANER WAS INSTALLED AND EXPERIMENTAL TRUCKING WAS INITIATED.

1941-45 - (WORLD WAR II YEARS). THE HAWAIIAN SUGAR INDUSTRY EXPERIENCED LABOR SHORTAGES DUE TO MILITARY SERVICE AND WAR-RELATED INDUSTRIAL EMPLOYMENT OF FORMER PLANTATION WORKERS.

MECHANIZATION BEGAN DURING THE WAR YEARS AND SHORTLY THEREAFTER LABOR UNIONS WERE ORGANIZED. MECHANIZED HARVESTING, IRRIGATION, AND MILLING MACHINERY WERE ADOPTED AS A MEANS OF INCREASING PRODUCTION AND SOLVING LABOR PROBLEMS.

1942 - KILAUEA CONVERTED FROM HAND HARVESTING TO COMPLETE MECHANICAL HARVESTING.

1956-71 - LABOR FORCE DECLINED FROM 277 TO 161 EMPLOYEES AT KILAUEA.

1971 - IN NOVEMBER 1971 KILAUEA SUGAR OPERATIONS CLOSED DOWN PERMANENTLY AFTER 94 YEARS OF CANE PRODUCTION.

1972 - IN JANUARY 1972 C. BREWER COMPANY ANNOUNCED (HONOLULU STAR BULLETIN, 1972 AND ADVERTISER, 1971) THE SALE OF 8,578 ACRES COMPRISING KILAUEA SUGAR COMPANY LANDS FOR A SUM REPORTED TO BE IN EXCESS OF $30 MILLION.

[1] SMITH, 1969; KILAUEA SUGAR CO., 1905-68; AND HONOLULU STAR BULLETIN, 1972 AND ADVERTISER, 1971.

and Kilauea Sugar Co., 1905-68), summarizes the major events in the history of Kilauea Sugar Company which significantly changed its operational procedures throughout the 94-year period during which it grew and milled sugarcane.

During the earliest period of the plantation's development, there was emphasis on labor-intensive agriculture within a framework of plantation self-sufficiency. After World War II, however, there was more technological input and a switchover to relatively capital-intensive agriculture. At the same time, the increasing cost of land, labor, and capital in the face of relatively stable sugar prices and increasing competition from sugar beet and alternative sources of sweetners all made sugarcane culture at Kilauea decreasingly attractive as an investment to its owners, C. Brewer and Company, a subsidiary of International Utilities Corporation.

Prior to 1942, harvesting operations were essentially by hand and harvested cane was hauled to the mill by field trains. The company began experimental trucking to the mill. Table 3.4 shows a history of increasing mechanization and decreasing labor input on the plantation. As more and heavier machines were used in the fields, however, soil losses became a greater problem than experienced in earlier years.

PRODUCTIVITY OF PLANTATION. Table 3.5 shows that in 1969 Kilauea experienced

TABLE 3.5. SUGAR COMPANIES ON KAUAI (1969 DATA).*

NAME	YEAR FOUNDED	CANE ACREAGE	TONS SUGAR	TONS RAW SUGAR PER HARVESTED ACRE
KILAUEA SUGAR COMPANY	1877	4,801	15,549	6.48
LIHUE PLANTATION CO.	1894	15,881	66,110	8.32
GROVE FARM COMPANY	1835	10,354	40,086	7.74
MCBRYDE SUGAR COMPANY	1899	5,947	32,358	10.88
OLOKELE SUGAR COMPANY	1941	4,806	30,698	12.78
GAY AND ROBINSON	1880	2,570	17,555	13.66
KEKAHA SUGAR COMPANY	1868	7,904	54,691	13.84

*SOURCE: HAWAIIAN SUGAR PLANTERS ASSOCIATION. *SUGAR ON KAUAI.* 1969.

the lowest yield of raw sugar per acre of the seven plantations on Kauai. This is primarily a result of its unfavorable location in the windward northeast corner of the island (see Fig. 3.2). In this area the fields are exposed to high, gusty winds, salt spray, an irregular pattern of rainfall, and a limited level of solar radiation, due to frequent cloud cover. This last factor is particularly critical in the production of sugarcane with a high sugar content. In general, production increases when the land area is less exposed to the regular northeast tradewinds and receives more sunlight. These conditions are generally termed a function of "leewardness" of the plantations. Kilauea is the least leeward and Kekaha the most leeward of the northeast tradewinds on Kauai. Table 3.5 shows that in 1969 the Kekaha Sugar Company lands were the most productive of the seven plantations.

Productivity of the Kilauea Sugar Company plantation during 1958 to 1970 is shown in Figure 3.14. The tendency to increase the yield of sugar per ton of cane during the mid-1960's is evident in the figure.

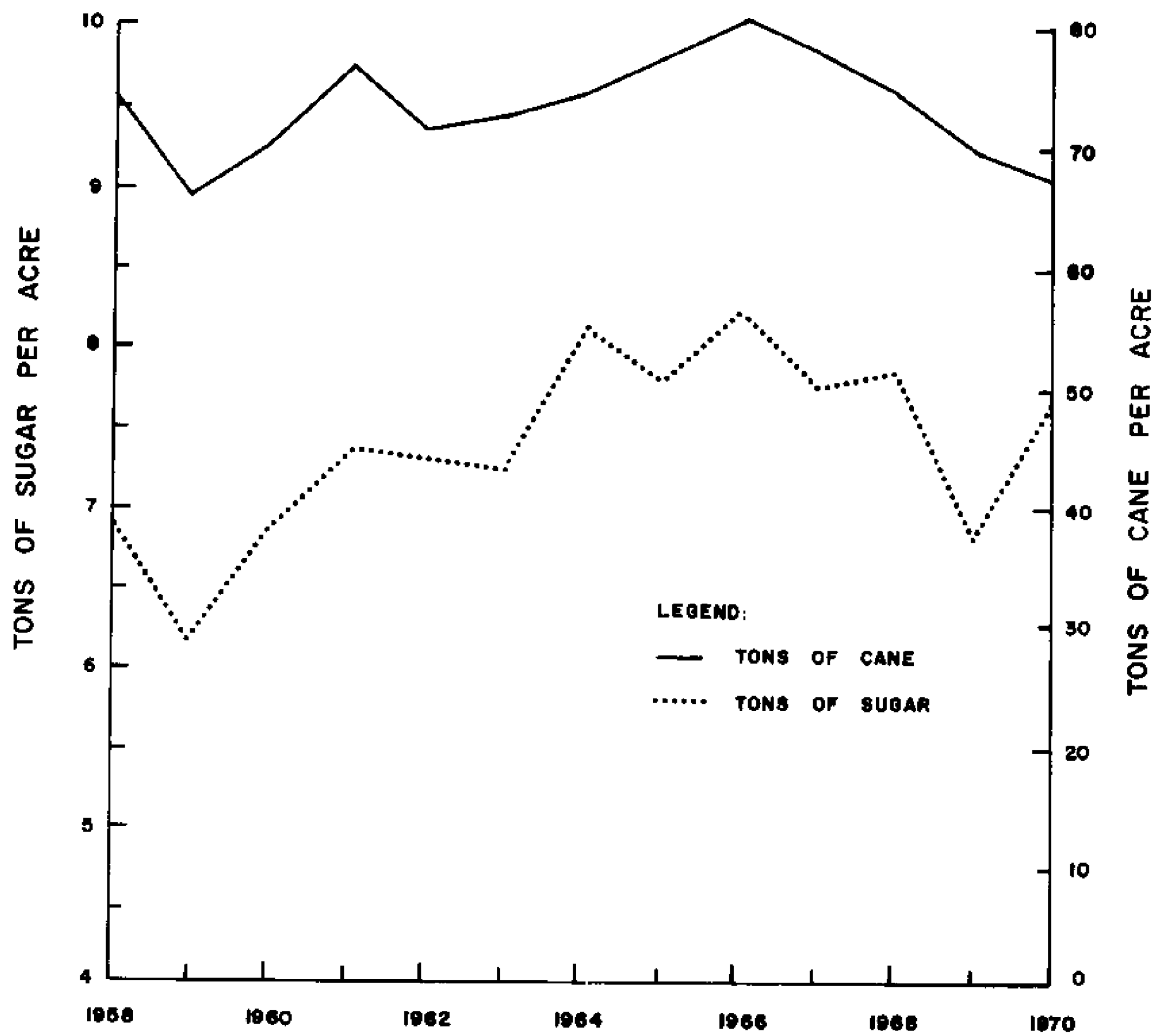


FIGURE 3.14. YIELD PER ACRE OF CANE AND SUGAR FOR KILAUEA SUGAR COMPANY, LTD., 1958-1970.

LAND TENURE: OWNERSHIP AND USE. Of the total 22,070 acres in the study area, land controlled by Kilauea Plantation Company total 13,333 acres, or 60 percent of the total. Lands in sugarcane cultivation totaled 4,644 acres, or 21 percent of the total area and 35 percent of the Company controlled lands. The 8,737 or 40 percent of the total area not controlled by the Company are classed as State Conservation Districts being in use as state forest reserve and watershed. For purposes of the study, the entire 22,070 acres are considered as a watershed and the land uses within that watershed as affecting the coastal water quality of the study area.

At the end of 1969, Kilauea Sugar Company controlled 13,333 acres, as previously noted, which included the 4,668 acres planted to sugarcane. Of this planted land, the Company owned in fee 2,999 acres and leased 1,678 acres.

During 1970, the Company began leasing phased-out sugarcane lands to Metcalf Farms for growing seed corn and feed grain sorghum. The process of converting cane lands to other crops was begun as sugar crops were harvested during the last two years of the plantation's operation. By January 1971, the Company had only 2,908 acres in sugar of which 2,014 were held in fee, and had leased to Metcalf Farms a total of 1,626 acres for sorghum or corn crops.

By the end of 1971 when the plantation ceased operations, lands leased to Metcalf Farms totaled 4,146 acres of which 3,836 acres were held in fee by Kilauea Sugar Company.

For purposes of this study, land ownership and use through 1969 are particularly relevant. The final two years of the plantation's operation from 1969 to 1972 is a phasing-out period during which sugarcane acreage continually decreased as final crops were harvested. Thus, the last two years of the plantation's operation do not represent normal lifetime practices of sugarcane cultivation which are the major concerns of the overall study. The general pattern of land ownership and use as of December 31, 1969 are shown in Figure 3.15 and Table 3.6, respectively.

Land uses other than sugarcane cultivation, include pasture operated by Gay and Robinson and leased from Kilauea Sugar Company. In 1969, Gay and Robinson leased 3,404 acres (Table 3.6).

Other land uses include camps, industrial areas, roads, lots, building sites, reservoirs, ditches, flumes, orchards, experimental plots, and miscellaneous uses which total 627 acres. Land leased to Gay and Robinson for pasture plus land classified as Waste and Forest Reservoir (conservation district) total 8,038 acres.

Table 3.7 shows that about 35 percent of the total land area controlled by Kilauea Plantation was used for sugar production. The remaining 65 percent was in other uses, including pasture, forest, and wasteland.

From Table 3.6 it may be seen that the factory of mill area was a small percentage, less than 0.68 percent, of the total land area used by the Kilauea Sugar Company. The factory was, however, a highly capital intensive use of land which concentrated diffused sources of cane-land wastes in a single location and discharged them into the ocean at a single point, Niu Stream (Fig. 3.1).

SUGARCANE CULTURE PRACTICES. Intervals between plantings of sugarcane are normally limited to three crops; the original planted crop followed by two ratoons. Cultivation practices depend upon whether farming is flat culture or deep furrow and irrigated or dryland farming. In either cultural practice, the first operation after harvest is to "subsoil" compacted areas, such as harvesting truck roads, windrow areas, and line heads and ends of irrigation systems. This is done to a depth of about 20 inches by a tractor-drawn subsoiler. The fields are then leveled or graded where necessary, and rocks or other extraneous material removed from the field.

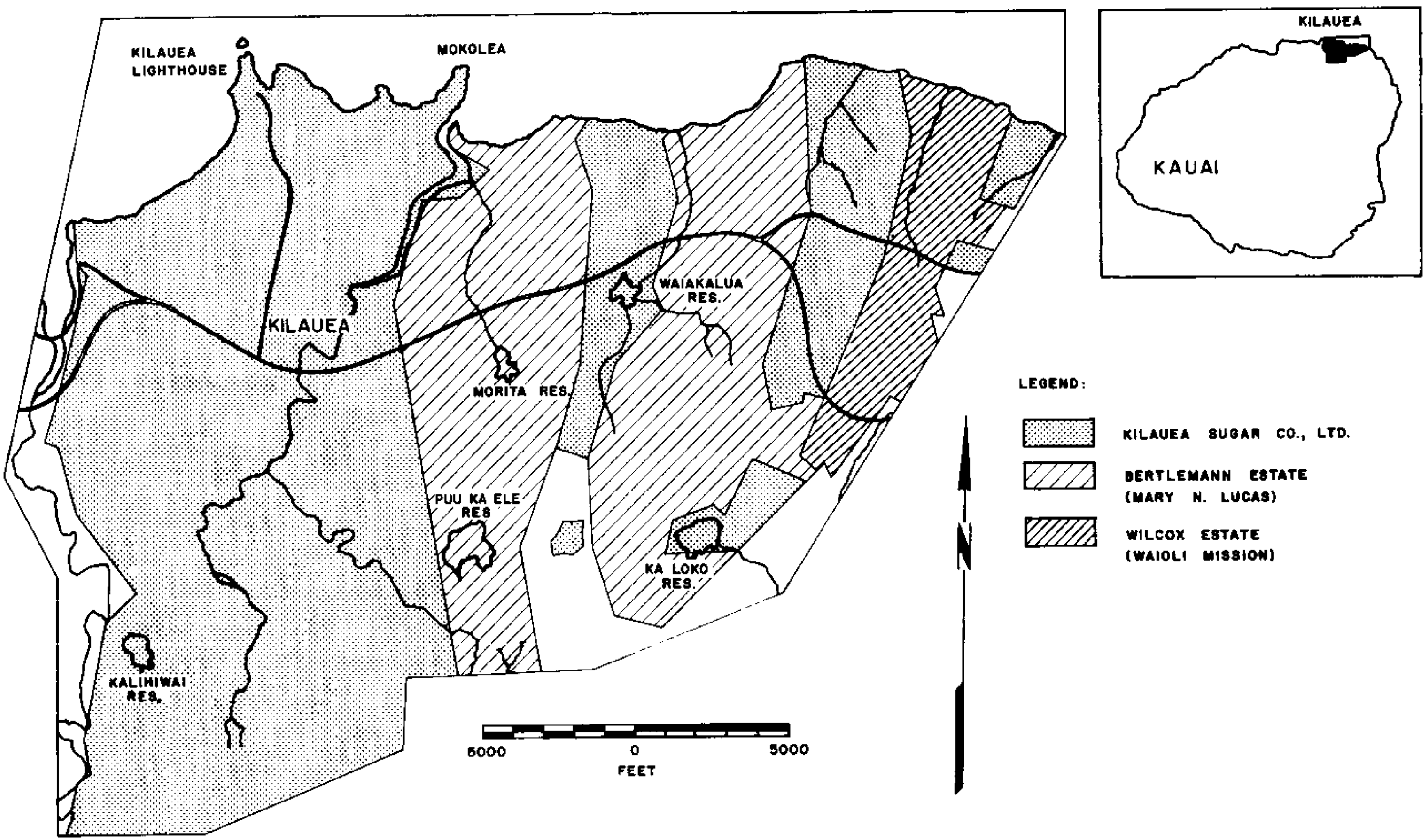


FIGURE 3.15. LAND OWNERSHIP PATTERN OF THE KILAUEA SUGAR COMPANY.

TABLE 3.6. LAND USE WITHIN THE KILAUEA SUGAR COMPANY AREA, 1970.

	USE CATEGORY	OWNED ACRES	LEASED ACRES	TOTAL ACRES	% OF TOTAL
1.	PASTURE (GAY AND ROBINSON)	2,292.6	1,110.9	3,403.5	25.52
2.	CANE	2,990.2	1,678.1	4,668.3	35.02
3.	WASTE (GULCHES, ETC.)	1,789.3	749.3	2,538.6	19.03
4.	FOREST RESERVE	1,772.1	324.0	2,096.1	15.72
5.	ROADS	111.7	68.9	180.6	1.36
6.	RESERVOIRS, DITCHES, AND FLUMES	95.1	84.4	179.5	1.35
7.	CAMPS, FACTORY AREA	88.5	0.8	89.4	0.68
8.	FALLOW	65.4	25.2	88.6	0.67
9.	MISCELLANEOUS USAGE	37.1	0	37.1	0.28
10.	MACADAMIA (PROPOSED, BUT NOT PLANTED)	22.1	2.0	24.1	0.18
11.	EXPERIMENTAL PLOTS	17.8	0.7	18.6	0.14
12.	LOTS AND BUILDING SITES	5.6	0	5.6	0.04
13.	OTHER AGRICULTURAL USES	1.8	1.2	3.0	0.02
	TOTAL	9,287.5	4,045.1	13,333.0	100.00

TABLE 3.7. MAJOR USES OF KILAUEA SUGAR COMPANY CONTROLLED LAND.

USE	ACREAGE	PERCENT OF TOTAL ACREAGE
SUGAR	4,668	35
PASTURE, FOREST, WASTE	8,039	60
OTHER (MIXED)	537	4
MILL SITE	89	1
TOTAL	13,333	100

For flat culture the subsoiling operation is followed by a Rex pulvimixer which rotovates the area. The cane lines are then subsoiled to a depth of 20 inches with simultaneous surface application of fertilizer. In deep furrow culture, the subsoiling operation also levels the old furrows. The fields are then prepared with a line-shaper which has a fertilizer attachment to it. Hand-operated Merry Tillers are then used to furrow and cover seeds in the replanting operation and to minimize damage to the level ditches.

In the planting operation, seed cane is cut by hand into 20-inch lengths and loaded directly into side dump bins. Because Kilauea Sugar Company was on the wet side of the island, all cane seed was treated by immersion for 30 minutes in a hot (50°C) water bath. The fungicide used in this operation was P.M.A. (Phenyl Mercuric Acetate), with major usage of Ceresan L. since 1969.

Treated seeds are transported to the field and dumped loose into the bins of a two-line planter with furrowing and fertilizing attachments. This planting device, mounted on a D-6 tractor, deposits the seed along rows 5 feet in width at the rate of 2.5 sound eyes per running foot. This seed is then covered to a depth of 2 inches.

Following harvest of the planted crop, two ratoon crops are normally expected. The first operation directly following harvest of the planted crop is a combination of inter-row subsoiling and fertilizing. A tractor is used to draw 2 subsoil points which break the soil to a depth of 14 inches as close to the stool as possible without damaging it. At the same time, this equipment makes a surface application of fertilizer. On furrow-irrigated fields, the planting operation is followed by a line-shaper with a stool-shaver attachment that cuts stubble from the top of the stool and, at the same time, rebuilds the furrow to facilitate irrigation of the subsequent crop. The line heads are then furrowed out adjacent to the flumes and the line ends.

Replanting ratoon fields is accomplished as soon as possible after harvest. New plantings are carried out 3 to 4 weeks after reshaping of the fields. This relatively short interval between harvest and planting minimizes the interval of time the soil is subject to the greatest hazard of surface erosion. It also reduces the amount of herbicide needed by effecting a rapid close-in of the cropped area.

IRRIGATION PRACTICES. The general approach to irrigation of the Kilauea Sugar Company lands has been described previously in relation to hydrology and water management systems of the plantation area (Figs. 3.9 and 3.10). Basically, six small reservoirs are utilized to collect runoff via large ditches that bring water down from the mountains. The location of these reservoirs average a distance of 2 miles from the center of the plantation. Water is drawn from them as needed through a gate and an outlet ditch which is connected to field supply ditches. There are about 33 miles of unlined main ditching on the plantation.

As noted in a previous section, 70 percent of the 4,668 acres of canefields were under irrigation in 1969. Of this, 1,700 acres were irrigated with level ditches and aluminum flumes with infield cane-line or furrow grades of 1 to 3 percent. Another 1,500 acres were irrigated by 600 gpm sprinklers and 2,000 gpm guns.

The furrow irrigation practice during the summer was a 15-day cycle applying 4 to 6 inches of water per application. During the winter, 30 to 60-day intervals were commonly used.

The furrow irrigation system is only about 30 percent efficient, requires considerable manpower to install, and involves deep furrows which are not readily amenable to mechanization. On the other hand the furrows follow land contours, hence allow for good drainage with minimum of soil loss to the ocean during rainstorms.

The sprinkler system used by the Kilauea Sugar Company requires a 2-hour setting to accomplish a 2 acre-inch application at 1 acre per setting. The 2000 gpm irrigation guns require a 1-hour setting to apply 2 acre-inches to 1.75 acres.

Irrigation efficiency at Kilauea Sugar Company was doubled by the use of sprinkler irrigation in areas so managed. This permitted the use of flat farm culture and the use of mechanized planting/replanting operations. However, to offset the greater soil loss by surface erosion that characterizes the sprinkler irrigation system, additional conservation practices such as terracing and strip cropping became important.

During the final two years of operation of the plantation, some of the fields adjacent to Niu Stream were converted to sprinkler irrigation. Of the 1780 acres of sugarcane land in the Niu Stream area, 887 acres were sprinkler irrigated in 1971 and some of the irrigation water were from mill wastes.

FERTILIZATION PRACTICES. In fertilizing its cane, the Kilauea Sugar Company applied varying rates of calcium silicate and inorganic dry mix N-P-K fertilizers. Calcium silicate in the form of TVA slag or Hawaiian Cement became standard following an extensive soil and tissue testing program. The material was hauled to the field and spread over the area during soil preparation for planting. For this operation an 18-ton capacity bottom dumper equipped with a spreader device was used. Application rates were varied to meet an adequacy level of 130 pounds of silica per acre foot of soil. To meet this level, application rates ranged from less than one ton per acre to as much as three tons per acre.

N-P-K fertilizers were generally applied four times per crop from the time of planting or ratooning to the time the crop was 10 months old. Application methods varied with the stage of the crop at the time of fertilization. Methods used by the Company are shown in Table 3.8.

TABLE 3.8. FERTILIZER APPLICATION METHODS, KILAUEA SUGAR COMPANY.

APPLICATION NUMBER	PLANT CROP	RATOON CROP
1	PLANTING TRACTOR	RATOONING TRACTOR
2	HAND	HAND
3	HAND OR AIRCRAFT	HAND OR AIRCRAFT
4	AIRCRAFT	AIRCRAFT

Application rates and types of fertilizer to be applied were determined principally by crop logging and visual observation. Basic amounts used are shown in Table 3.9.

Some experiments with minor elements were carried out but none of the results were sufficient to adjust their commercial use.

WEED CONTROL. Because Kilauea Sugar Company was on the wet side of Kauai, it was confronted with a heavy weed growth and more varied weed species than other sectors of the island. Consequently, a vigorous program of systematic

TABLE 3.9. BASIC N-P-K FERTILIZER APPLICATIONS, KILAUEA SUGAR CO.

FERTILIZER	RATE OF APPLICATION LBS/ACRE/CROP
NITROGEN	180-300
PHOSPHORUS	0-200-400
POTASH	270-340

herbicide use was necessary. Major problem weeds in cane areas are paspalm, thunbergia, four o'clock, koa haole, xmas berry, lab-lab bean, Johnson grass, Job's tear, maunaloa, and balsam apple.

The weed control program was designed primarily to control weeds by pre-emergence spraying at scheduled intervals by aircraft. Use of aircraft was somewhat limited by wind conditions, field layout, and proximity of dwellings. Control of hardier species which survive pre-emergence treatment was maintained by knapsack sprayers serviced with infield nurse trucks who also sprayed roadsides and ditches. Usually a field required two pre-emergence treatments of DCMU and 2,4-D and up to three manual sprayings of Dalapon, 2,4-D, and emulsifiers before the fields closed in.

Table 3.10 summarizes the commercial use of herbicides on Kilauea Sugar Company lands over the years.

TABLE 3.10. COMMERCIAL USE OF HERBICIDES ON KILAUEA SUGAR COMPANY LANDS.

NAME OF HERBICIDE	APPROXIMATE PERIOD OF USAGE	EXTENT OF USAGE
ARSENICALS	1935 - 1950	MAJOR
OILS	1945 - 1965	MAJOR
2, 4-D	1945 - 1971	MAJOR
PENTACHLORPHENOL	1950 - 1958	MAJOR
TCA	1950 - 1958	MAJOR
DALAPON	1955 - 1961	MAJOR
MONURON (CMU)	1952 - 1958	MAJOR
DIURON (DCMU)	1955 - 1971	MAJOR
SIMAZINE	1955 - 1958	MINOR
AMETRYNE	1965 - 1970	MINOR
EMULSIFIERS	1960 - 1970	MAJOR
LASSO	1970	MINOR

The development of effective herbicide materials while the Company was in operation together with better equipment and more accurate timing of applications, and eradication of some weed species from the fields.

PEST CONTROL. Cane damage by rats and borers was a serious problem at Kilauea Sugar Company, consequently, a rat control program was carried on continuously. Warfarin-treated rolled oats were placed in covered pans at regular intervals along field edges, roadsides, and in the fields. As previously noted, fungus control required that seed cane be dipped in an appropriate chemical bath prior to planting. In 1970, as the acreage in sugarcane culture was being reduced and Kilauea Plantation lands were converted to corn and sorghum by Metcalf Farms, Inc., insecticides were applied to plant foliage and a fungicide applied to corn seed at time of plant.

Table 3.11 summarizes the pesticides used on study area lands during a 40-year period.

TABLE 3.11. PESTICIDES USED ON KILAUEA SUGAR COMPANY LANDS.

CHEMICAL	APPROXIMATE PERIOD OF USAGE	EXTENT OF USE	PURPOSE OF USE
KILAUEA SUGAR COMPANY, LTD. (SUGARCANE)			
THALIUM SULFATE	1930-45 1967	MAJOR MINOR	CONTROL OF RATS
ZINC PHOSPHIDE	1940-45	MAJOR	CONTROL OF RATS
WARFARIN	1945-71	MAJOR	CONTROL OF RATS
1080	1967	MINOR	CONTROL OF RATS
PMA (MERCURIC)	1950-70	MAJOR	FUNGICIDE
CERESAN L	1969-70	MINOR	FUNGICIDE
METCALF FARMS, INC. (CORN AND SORGHUM)			
SHELL GARDONA	1970		INSECTICIDE - CORN
SEVIN	1970-71		INSECTICIDE - CORN
METASYSTOX	1970		INSECTICIDE - CORN
SYSTOX 6	1970-71		INSECTICIDE - CORN AND SORGHUM
DIAZINON	1970		INSECTICIDE - CORN AND SORGHUM
HEPTACHLOR	1970		INSECTICIDE - CORN AND SORGHUM
MALATHION	1970-71		INSECTICIDE - CORN AND SORGHUM
MANZATE	1970		FUNGICIDE - CORN

SUGARCANE HARVESTING. The Kilauea Sugar Company employed normal harvesting routines in processing its crops. Harvesting takes place when the crop is approximately 24 months of age. Timing in cane ripening is generally programmed to avoid operating in muddy fields resulting from winter rains, hence February to October is the most common harvest season. In furrow-irrigated fields, the flume lines are removed prior to harvest and fire breaks are constructed. In sprinkler irrigated fields the towpaths are useful in constructing fire breaks and are used as cane haul roads wherever possible.

The canefield is first burned to reduce trash. The cane itself is then mechanically harvested with dozer-mounted push rakes that push the cane into windrows. It is then picked up by heavy cranes and loaded into 25-ton capacity trucks having a chain-net type trailer. At the mill, the trailers are side unloaded into a cane-storage area and fed into the mill carrier by an electric crane.

MILLING OF SUGARCANE. Cane brought in from the fields by trucks with large amounts of adhering soil as well as extraneous leaves that did not burn off is first passed through a washing operation where a system of water jets spray it on a carding drum. This removes a major portion of the adhering soil. From there the cane passes through a stool drum, another water stream, and trash extractors. These washing and preparation operations generate a waste stream that consists of wash water containing dissolved organic solids, sediments, trash, leaves, and cane stools.

The prepared cane then moves into the milling operation where it is passed through a series of cutting knives and crushed in roller mills where water is added to elute the remaining juices from the crushed stalk. This operation generates principally bagasse, a fibrous residue containing 50 percent of water by weight, and a small amount of unextracted sugars. Bagasse is composed primarily of carbon and hydrogen with a relatively high fuel value. Thus, it can be used as fuel to produce steam for the evaporators and power generation, but its exclusion from the waste stream is not 100 percent attainable.

The combined juices from the milling plant are clarified with magnesia and soda ash as precipitating agents, then filtered with a rotary drum filter. This process generates a waste comprised of organic and inorganic material in the filter cake as well as adsorbed water. Concentration of sugar from the mixed juice is done by evaporation, crystallization, centrifugal separation, and drying, which produce a wastewater stream containing dissolved sugars and blowdown water from the boilers. The mixed waste from sugarcane milling then is a transporting stream of water carrying bits of bagasse, trash, inorganic particles, and dissolved organic matter. As noted in a preceding section, the practice of the Kilauea Sugar Company throughout its period of operation was to convey this wastewater stream to the ocean via Niu Stream and a flume, producing the visible plume described in relation to the oceanography of the study area.

Potential to Affect Water Quality

RATIONALE. As a prelude to a presentation and evaluation of the results of sampling and analysis of waters, sediments, and marine biota in the study area in northern Kauai, it might be useful to summarize the factors which could conceivably affect the quality of coastal waters as a result of the activity on Kilauea Sugar Company lands both before and after the cessation of its operations in November 1971. Such a summary may be drawn from "Geographical and Environmental Aspects" (see p. 65), bearing in mind the general concepts of sugarcane waste generation outlined in "General Concept of Sugarcane Waste Generation" (see p. 42). In reviewing the summary, the reader is cautioned that it is intended to identify the opportunities for contacts between water and quality factors, as well as the transport systems involved. Whether or not water is actually altered in quality by some or all of its contacts must be determined by the scientific findings of this and other related studies.

WATERS FROM UNDEVELOPED LANDS. Much of the rainfall on the 22,070 acres of the study area occurs at elevations above that of the land cultivated by the Kilauea Sugar Company. The water that infiltrates the non-cultivated areas may be expected to become somewhat mineralized as it passes through the soil mantle and underlying geologic formations. It may emerge as:

a) Seepage which feed surface streams continuously or intermittently,
b) Perched and basal ground water discharged into the ocean through strata outcropping in the high cliffs along the coastline, or
c) Seepage which may be captured and impounded for irrigation purposes.

Only the last one of these three alternatives is related to activities of the Kilauea Sugar Company, and the effect of impoundment on quality is a minimal change in mineralization because evaporation on the 180 acres of Kilauea reservoirs essentially equals the catchment of rainfall on the water surface of these reservoirs. The effect of irrigation use of this water is considered in a subsequent section, "Waters from Sugarcane Lands," (p. 76).

Rainfall which appears as surface runoff from undeveloped land may reach the ocean via:

a) Natural watercourses which bypass agriculturally developed land, or
b) Natural watercourses or irrigation ditch overflows from crop land.

In the first instance, any effect of the runoff on coastal water quality is that ascribable to natural undeveloped land, unless man has deposited decomposable refuse or noxious liquids in gulches and canyons on the drainage area. Natural materials may include eroded soil, organic debris, and the products of active decomposition of organic debris.

The effect of the second route is an alteration in quality as a result of sugarcane culture, as described in the next section. As noted in Table 3.7, 8,039 acres of the 13,333 acres controlled by the Kilauea Sugar Company is in the category of undeveloped land, as is the 8,737 acres of forest reserve and watershed (22,070 - 13,333) not controlled by the company. Therefore, ground and surface waters resulting from rainfall on the undeveloped land of the study area originates on some 16,776 of the 22,070 acres involved. Not all of these waters flow over Kilauea Sugar Company lands but they reach the ocean in the area deemed worthy of examination for traces of effects of the sugarcane industry. Much of what is not diverted to agricultural use or become overflows from agricultural land during heavy rainfall, reaches the ocean unaltered by the sugarcane industry.

WATERS FROM SUGARCANE LANDS. As noted in "Fertilization Practices" (see p. 72), "Weed Control" (p. 72), and "Pest Control" (p. 74), rainfall or irrigation water has the opportunity to come into contact with fertilizers, silicates, herbicides, and pesticides. Materials which are water soluble and are not degraded by biological activity in the soil or are not chemically unstable have the potential to travel with percolating water. When this happens, the materials become part of the fraction of the 24 mgd estimated in Figure 3.11 to be discharged to the ocean from Kilauea plantation as ground water.

Surface runoff of excess rainwater, sprinkler irrigation water, or tail water from furrow irrigation has the opportunity to come in contact with this same spectrum of chemicals. In addition, it has the ability to pick up and transport soil particles carrying adsorbed chemicals which are not water soluble. Thus it must be presumed that unless special measures are taken to prevent surface runoff and tail water overflow, waters from sugarcane lands may transport agricultural chemicals as well as sediments.

In the case of the Kilauea Sugar Company, Figure 3.10 shows that irrigation tail water might reach the ocean at multiple points east of Kepahi Point. Both sprinkler irrigation runoff and irrigation tail water might discharge into the ocean via Niu Stream or west of Kilauea Point.

MILL WASTEWATER. "Milling of Sugarcane" (p. 75) summarizes the water quality factors which originate in the operations described broadly as milling of sugarcane. In addition to the initial constituents of wash water, bagasse, trash, sediments, and dissolved organic matter characterize the mill waste, estimated in "Sugarcane Culture Practices" (p. 68) to be 4 to 5 mgd from the Kilauea Mill. This is discharged to the ocean at a single point via Niu Stream.

CHANGES IN POTENTIAL. In the foregoing paragraphs the potential of Kilauea Sugar Company operations to generate waste discharges to the ocean in about the year 1969 is outlined in a qualitative way. As discussed in "Field and Laboratory Observations" (p. 78) the study group had only a brief opportunity to analyze discharges prior to closedown of operations in 1971. Thus only transient conditions during a phasing-out period were monitored. Tables 3.10 and 3.11 show that a considerable range of herbicides and rodenticides were used during the 1935-1971 period of operation. It is also noted in "Sugarcane Culture Practices" (p. 68) that a mercuric compound was used as a fungicide prior to 1969. This suggests, that the ocean itself, particularly its sediments and biota, may be the long-term integrator of the effect of sugarcane wastes and of their potential to alter water quality. Similarly, changes in the biota of the ocean and its esthetic aspects may measure the effect of discontinuing the sugar plantation operations and so indicate the value of various waste control measures in terms of coastal water quality. However, in evaluating changes in the potential of the lands previously controlled by Kilauea Sugar Company, Ltd., and especially in evaluating the extent to which observed changes are related to the sugarcane industry, it is necessary to re-examine from time to time the land development and land management practices in the area.

As of June 1972 when the improved conditions of the North Kauai Coastal Waters (see p. 78) were observed, 4100 acres of the 4500 acres previously in sugarcane were either already in sorghum production or being planted with sorghum as rapidly as possible. Included in this total acreage sere some fields of corn, notably at the higher elevations where sugarcane was produced without irrigation because of natural high rainfall. The remainder of previously cultivated land, some 400 acres, will be returned to pasture land under natural cover, generally because it is either too steep or too wet for efficient utilization in sorghum production.

In assessing the potential of sorghum culture as a contributor of quality factors to the coastal waters, it must be recognized that sorghum culture on

Kauai is still experimental in that the optimum management routines have not been established. Nevertheless, it is known that irrigation will be by efficient overhead sprinklers, that sorghum requires only 70 percent as much water as sugarcane, that plant crops mature in 90 to 120 days and ratoons in 70 to 90 days, and that 3 or 4 ratoons may be feasible. It is also known that pesticides such as Sevin, Systox, and Malathion are needed to control aphids and midges which attack sorghum, that herbicides such as atrazine and ametryne are necessary, that nitrogen is regained in greater amounts for sorghum than for sugarcane, and that continued use of calcium silicate on the soil may be necessary. In tilling sorghum, the ground is broken to about 6 inches in contrast with up to 20 inches for sugarcane, raw planting without furrows is characteristic of sorghum culture, and the time between harvest and replanting may be as short as one week if weather is favorable.

Especially significant major differences between sugarcane and sorghum culture are that much of the plant residue is left in the field where it is disced back into the soil. The salable harvested sorghum crop is transported elsewhere for processing other than simple heat drying of the grain. Thus the mill wastewater stream is eliminated from the three general types illustrated in Figure 3.1 (see p. 43). Of the other two streams, surface waste from irrigated and cultivated land is somewhat more difficult to intercept and control when furrow irrigation is not involved. On the other hand, sprinkler irrigation can be managed to eliminate irrigation runoff, although surface runoff from uncovered land during storms may always expected to lead to short-term discharge of sediments to the ocean.

The third type of discharge (Fig. 3.1), runoff from land under natural cover will not be altered by the change from sugarcane to sorghum culture.

Finally, the change in potential of the study area to alter water quality must be considered as being in flux. The Kilauea Sugar Company lands have been sold in parcels of various sizes to some 20 or more new owners, hence there is no certainty that the new agricultural use will not someday give way to some other type of use--possibly more intensive and possessing its own special potential to alter the quality of coastal waters.

Field and Laboratory Observations

ROLE OF EXPERIMENTAL ACTIVITY. The findings summarized thus far are based on studies of published reports, general field observations and personal interviews with officials of the Kilauea Sugar Company, as well as on documents and data furnished by the Company and on estimates made by members of the project staff. They established a framework within which to undertake the experimental work necessary to evaluate:

a) The amount, concentration, and variety of constituents, and sediments carried by the wastewater discharges, and
b) Changes in the constituents of the coastal water and in its sediments and biota where wastewaters from the sugarcane industry are discharged.

To approach these two goals, the experimental phase of the study was designed to measure the conditions existing before the closing of Kilauea Sugar Company's operations in November 1971 and to monitor environmental changes which might follow the event.

SCOPE AND NATURE OF EXPERIMENTAL PHASE. The scope of the experimental phase of the study of the Kilauea Sugar Company plantation was of necessity limited by considerations of time and budget. However, project activity was begun in July 1971, with no certainty that Sea Grant support would become available in September of that year. A program of field observations, sampling, and laboratory analyses of waters, sediments, and biota was initiated at that time with a small residue of project planning funds for the 1970-71 grant year, services donated by individual university faculty members interested in the project, the logistic and analytical assistance of State Health Department and Department of Agriculture personnel, and installations located on Kauai.

Sampling stations were selected from which to obtain data needed to identify the quality of mill influent (irrigation) water, irrigation tailwater, runoff, and wastewater from the milling process. The location of such stations is shown in figures introduced as results are reported. Such matters as size of sample, method of sampling, type of container, and special handling requirements were determined in advance so that any single sample would serve the needs of the various specialized laboratories participating in the study (see Tables 1.1, p. 8, and 1.2, p. 9). A monthly sampling program was adopted for analytical work prior to the shutdown of Kilauea plantation activities, to be followed by a quarterly monitoring program thereafter.

Sampling and observation stations used in evaluating coastal water and water environments were initially numerous (Figs. 3.3, 3.5, and 3.6) because there was no way to anticipate either the direction or the extent of effects of waste discharge via Niu Stream. On the basis of an intensive biological survey in July 1971, fewer stations were used thereafter. These are identified in various figures and tables discussed in the text. General observations were made and reported for each sampling trip as an added basis for evaluating experimental findings.

EFFECTS OF KILAUEA SUGAR COMPANY OPERATIONS ON WATER QUALITY. In the preceding sections dealing with the nature of soils, methods of sugarcane culture, and the types of agricultural and process chemicals used, there is developed a general concept of the opportunity for water to come into contact with various quality factors during use by the sugarcane industry. The extent to which such contacts do in fact alter the quality of water was explored in the experimental phase of the study at North Kauai.

The appearance of an obvious plume of sediments moving out from the Niu Stream outlet soon after the daily startup of milling operations (see p. 62) and the presence of bagasse in the ocean water and along the beaches in the discharge area was evidence that the mill wastewater stream was the most important discharge from the plantation operation which might affect the quality of the receiving coastal water. To isolate this effect of the milling operation it was necessary to sample and analyze both the mill influent water (which was also the field irrigation water) and the waste stream emerging from the mill both before and after it was mixed with bypassed water and other possible sources of Niu Stream. The results of the chemical and physical analyses are presented in Tables 3.12 and in greater detail in Table 3.13.

Table 3.12 compares mill influent and mill wastewaters on the basis of several common parameters of water quality. As explained in the footnotes, the data presented in the table come from three sources. All sampling were not done on the same date. However, the two sources of chemical data show good agreement of results even though they are grab samples taken from the

TABLE 3.12. COMPARISON OF MILL INFLUENT AND MILL WASTE WATERS.

QUALITY FACTOR	UNITS	MILL WASTE 08/03/71*	MILL WASTE 08/10/71	MILL INFLUENT 09/03/71*	MILL INFLUENT 08/10/71
BOD_5	mg/l	363	184	6.2	18
COD	"	928	463	18	84
TOTAL SOLIDS	"	3120	2082	72	132
VOLATILE SOLIDS	"	1232	--	72	--
TDS	"	656	337	62	112
TOTAL SS	"	2600	1745	8.2	20
TOTAL - P	"	4.25	0.58	0.09	0.31
KJELDAHL - N	"	1.60	0.92	0.60	0.88
AMMONIA - N	"	12.40	0.91	0.01	1.08
NITRATE - N	"	9.00	9.00	0.01-	0.7
ALKALINITY ($CaCO_3$)	"	56.4	--	31.2	--
COLOR (TRUE)	CPU	49.0	--	22	--
TURBIDITY	JTU	--	--	4	23
pH	"	6.90	5.8	7.65	7.25
TOTAL COLIFORM	MPN	600,000	>2400**	1200	>2400**
FECAL COLIFORM	"	100,000	>2400**	600	>1100**

* DATA FROM ULTRAMAR CHEMICAL WATER LABORATORY
** DATA FROM STATE HEALTH DEPARTMENT
[NOTE: ALL OTHER DATA FROM PROJECT LABORATORIES (SEE TABLE 3.13)]

waste flume on different days. They show the large increase in solids, BOD, and COD content which are to be expected from the milling process. They show also that fecal coliforms were present in the mill influent in relatively small concentrations. The much larger concentration of such organisms in the mill wastewater, however, is due to the discharge of factory restroom wastes into the mill discharge stream. Thus it is a factor peculiar to the particular situation observed and is not a quality aspect attributable to the sugarcane industry per se.

Table 3.13, like the preceding table, presents water analyses of mill influent and mill waste only during the period June to November 1971 while the Kilauea Sugar Company was still in operation. Data recorded for the dates 08/10/71 and 10/14/71, which compare mill influent with mill waste water taken directly from the waste flume, show that the milling process decreased the pH, increased the BOD by a factor of about 10, increased the total solids by a factor of from 15 to 25, introduced potassium as a quality factor, doubled the soluble phosphorus concentration, and increased COD 5 to 15 times. Only minor increase in the concentration of heavy metals and certain of the pesticides in the water apparently occurred during the milling process. Evaluation of this finding, however, is best deferred until data concerning sediments and other waters have been introduced.

TABLE 3.13. RESULTS OF WATER ANALYSES, KILAUEA SUGAR PLANTATION.

DATE OF SAMPLING	06/25/71	07/19/71			08/10/71		10/14/71		11/09/71		11/17/71	
SOURCE OF SAMPLE	AT SHORELINE	MILL WASTE OFF SHORE	OFF SHORE	OFF SHORE	MILL INFLUENT	MILL WASTE[1]	MILL INFLUENT	MILL WASTE[1]	MILL INFLUENT	MILL WASTE AT SHORELINE		GROUNDWATER SEEPAGE IN CLIFF
D.O.[3]	--	--	--	--	8.0	6.8	8.0	6.2	--	--	--	--
BOD	347	30	45	120	18	184	27	306	--	--	--	--
TOTAL - N (ORGANIC)	1.96	0.11	0.05	0.00	0.88	0.92	0.41	0.86	0.00	2.66	3.08	0.00
AMMONIA - N	--	--	--	--	1.08	0.91	0.25	0.25	--	--	--	--
NITRATE - N	--	--	--	--	0.7	9.0	0.01	0.02	0.11	0.02	0.02+	0.00
TOTAL - P	0.3	0.15	0.22	0.16	0.35	1.25	0.02	0.53	0.00	0.12+	0.12-	0.00
SOLUBLE - P	0.1	0.14+	0.16-	0.16-	0.31	0.58	0.005	0.014	--	--	--	--
SOLUBLE - K	--	--	--	--	0.0	7.0	0.0	14.0	--	--	--	--
CHLORIDES	20	19,070	18,920	18,965	30	40	9	14	10	26	15	22
COD	909	849	608	828	84	463	32	820	0.1-	268	586	0.1-
TURBIDITY (APHA)	2300	0.67	28	1.35	23	1420	2.0	HIGH	2.5	VERY HIGH	VERY HIGH	0.7
pH	5.1	8.0	7.9	8.1	7.25	5.82	7.55	6.4	--	--	--	--
TOTAL SOLIDS	3260	40,800	44,970	58,360	132	2082	126	3260	124	2904	3404	210
SUS. SOLIDS	2315	0.103	0.165	0.126	20	1745	40	2820	100	2446	3354	84
SETTLEABLE SOLIDS	12.2	0.1	0.05	0.1	0.2	2.0	0.05-	11.0	--	--	--	--
CONDUCTIVITY (μmhos/cm)	188	35,600	34,000	38,000	41	30	87	142	60	550	132	228
LEAD (μg/l)	--	--	--	--	7	8	16	22	--	--	--	--
COPPER (μg/l)	--	--	--	--	1	2	2	6	--	--	--	--
ZINC (μg/l)	--	--	--	--	5	5	5	115	--	--	--	--
MERCURY (μg/l)	--	--	--	--	(NOT DETECTABLE, *i.e.* LESS THAN 0.3 μg/l MERCURY)				--	--	--	--
DDT (ng/l)	ND[2]	2	4	ND	--	--	2.8	2.0	--	--	--	--
DDE (ng/l)	ND	ND	ND	ND	--	--	--	--	--	--	--	--
DDD (ng/l)	ND	ND	ND	ND	--	--	ND	1.4	--	--	--	--
α CHLORDANE (ng/l)	ND	--	--	--	--	--	ND	ND	--	--	--	--
γ CHLORDANE (ng/l)	ND	--	--	--	--	--	ND	ND	--	--	--	--
DIELDRIN (ng/l)	5.2	ND	ND	ND	--	--	ND	0.4	--	--	--	--
PCP (ng/l)	141	--	--	--	8	13	42.0	50.0	--	--	--	--
LINDANE (ng/l)	ND	ND	ND	ND	--	--	ND	1.1	--	--	--	--
HEPTACHLOR (ng/l)	ND	ND	ND	ND	--	--	--	--	--	--	--	--
HEPTACHLOR EPOXIDE (ng/l)	ND	ND	ND	ND	--	--	--	--	--	--	--	--
TOTAL COLIFORM (MPN)	--	--	--	--	≥2400	≥2400	(10/04/71) ≥2400	≥2400	--	--	--	--
FECAL COLIFORM (MPN)	--	--	--	--	1100	≥2400	(10/04/71) 1000	≥2400	--	--	--	--

[1] SAMPLE FROM MILL DISCHARGE FLUME PRIOR TO CONFLUX WITH NIU STREAM
[2] ND DENOTES "NONE DETECTABLE"
[3] VALUES OF ALL PARAMETERS IN mg/l, UNLESS OTHERWISE NOTED.

An unaccountably high value for zinc is reported in the mill waste on October 14, 1971. Whether this value is real or the result of some laboratory mischance can not be determined.

Table 3.13 includes a comparison between the mill influent and a wastewater sample taken at the shoreline on November 9, 1971 where flumed wastes had presumably been mixed with bypassed irrigation water and any ground water seepage which may have fed Niu Stream at that time. Here, COD, solids, and conductivity show the greatest increases, but from the data there is little evidence that Niu Stream on that occasion comprised more than mill wastes. Using solids concentration as the parameter, the same conclusion holds for shoreline samples of mill wastes reported in the table for June 25, 1971 and November 17, 1971.

A partial analysis of ground water outcropping from a cliff overlooking the ocean east of the mouth of Niu Stream is shown in the table (November 21, 1971). It shows the expected effects of passing water through the soil mantle of the earth, *i.e.*, decrease in COD and suspended solids and an increase in total solids (dissolved) and conductivity.

CHANGES IN QUALITY OF OCEAN WATER. On July 19, 1971 during a field trip for project planning purposes, samples were taken from the waste plume area of the ocean at three locations offshore from the Niu Stream (mill waste) outfall. The results of laboratory analyses of these samples are shown in Table 3.13. Only limited conclusions may be drawn from these data but they are nevertheless significant ones. For example, using chlorides as the index, it is apparent that the ocean water sampled was not diluted to any important degree by fresh-water discharges from the land. Turbidity and supended solids, however, were less than those of mill wastes by some 3 or 4 orders of magnitude. This indicates that sedimentation of suspended solids, with whatever environmental changes it might entail, was the principal effect of the sugarcane operations on the ocean water. Aesthetically, the area appeared worse than the water quality data substantiate on the sampling date because the clarity of the water made the colored sediments in shallow water readily visible, giving the inaccurate impression that the water itself was colored and turbid.

Some effects on ocean water quality, as a result of cessation of operations of the Kilauea Sugar Company are suggested by Table 3.14, which reports the findings of analyses for nutrients, heavy metals, and pesticides at several sampling stations, mostly between Kilauea Point and the west side of Kalihiwai Bay (Figs. 3.16 and 3.17). Although the data are too few to be conclusive, they do show a decrease in concentration of nutrients (P and K) after November 1971, and a very definite decrease in the concentration of lead and cadmium. At all stations, levels of lead decreased from 10 or more mg/l to non-detectable levels (>5 mg/l). Similarly, cadmium decreased from 2 mg/l to the non-detectable level (>1 mg/l). Mercury, which is detectable at 0.3 mg/l was found at Station 3 only in November 1971, but was not detected at that station in January 1972.

Of the pesticides, only DDT and PCP were detectable in specific amounts in the ocean water samples. Traces of some other pesticides were found at various sampling stations (see Footnotes, Table 3.14). Although the data are incomplete and should yield more definite information as the study progresses, the levels of DDT in the ocean water at all stations were appreciably lower in May 1972 than previously recorded in January, two months after the closing of Kilauea Sugar Company operations.

NUTRIENTS, METALS, AND PESTICIDES IN SEDIMENTS. Because many compounds, especially those involving heavy metals, pesticides, and phosphorus are more likely to be adsorbed on soil particles than dissolved in water, it was anticipated in the study that sediments rather than water might be more revealing of effects of sugarcane culture and milling on the coastal water environment. Moreover, the lesser degree of mobility of sediments tends to make them a sink in which some quality factors accumulate, rather than a

TABLE 3.14. NUTRIENTS, METALS, AND PESTICIDES IN OCEAN WATER, NORTH KAUAI AREA.

DATE OF SAMPLING	STATION NUMBER	K (mg/l)	P (mg/l)	N (mg/l)	Pb (mg/l)	Cd (μg/l)	Hg (μg/l)	DDT (ng/l)	PCP (ng/l)
11/15/71	2	575	0.04		12	2	ND		
	3	525	0.04		12	2	0.4		
	4	500	0.02		16	2	ND		
	6	500	0.03		10	2	ND		
	7	500	0.03		10	2	ND		
	12	500	0.04		10	2	ND		
1/13/72	2	500	0.03		ND	ND	ND	20	
	3	375	0.03		ND	ND	ND	26	
	4	375	0.02		ND	ND	ND	6	
	6	450	0.02		ND	ND	ND	10	
	7	450	0.03		ND	ND	ND	6	
	8	450	0.03		ND	ND	ND	5	
5/22/72	2A	850	0.01	0.064	2	ND	ND	2	7
	3	888	0.01	0.149	1	ND	ND	2	18
	4	867	0.01	0.097	ND	ND	ND	1	1
	5	858	0.01	0.143	2	ND	ND	1	7
	6	880	0.01	0.085	ND	ND	ND	1-	9
	7	867		0.119	ND	ND	ND	1	4
* AVERAGE CHEMICAL COMPOSITION OF SEA WATER		380	0.07	0.5	0.03	0.11	0.03	--	--

FOOTNOTES: DDE, DDD, HEPTACHLOR, HEPTACHLOR EPOXIDE, AND ALDRIN NOT DETECTED
LINDANE--1 ng/l, ALL STATIONS
DIELDRIN-- 1 ng/l, STATIONS 2A, 3, AND 5 ONLY
CHLORDANE--1 ng/l, ALL STATIONS EXCEPT 5, 6, AND 7

* AFTER GOLDBERG, 1963.

transport medium. For this reason and because of the possible effects of sediments on marine biota, sediment analysis was made an important aspect of the experimental phase of the study.

Sources of sediments from the sugarcane industry include irrigation tailwater, erosion of surface soil during storms, and the cane milling operation. Precautions to minimize the loss of irrigation water are normal practice in the industry, as are land management techniques to minimize soil erosion. Nevertheless, these two sources of sediments are always present. Mill wastes, however, might be expected to be a major and near continuous (9 to 10 months per year) source of sediments if such wastes are freely discharged to the ocean, as was the general practice at Kilauea.

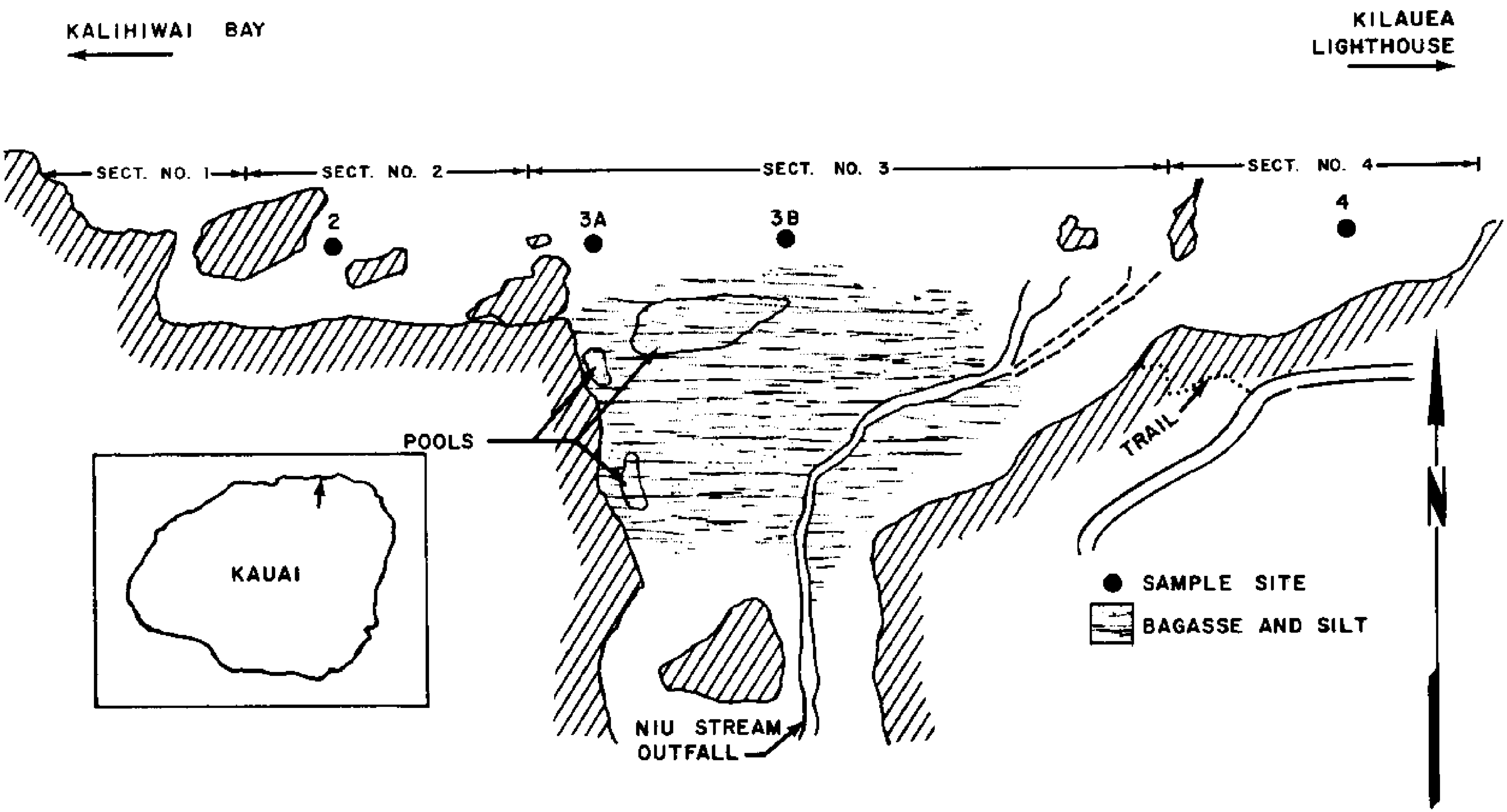


FIGURE 3.16. NIU STREAM DELTA AND BEACH SAMPLING AREA.

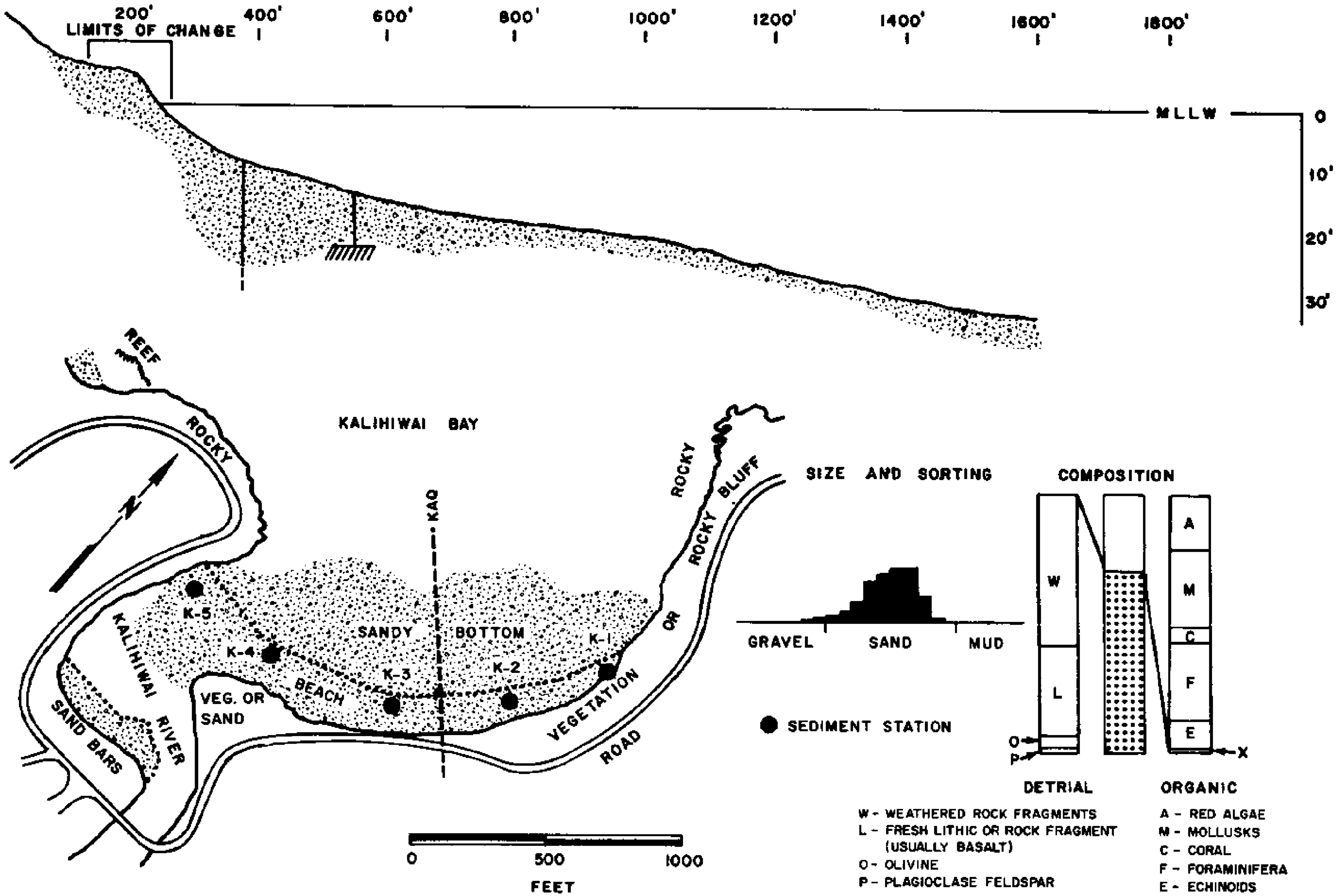


FIGURE 3.17. KALIHIWAI BAY BEACH SAMPLING AREA.

Utilizing data on the solids content of influent mill water and mill wastewater such as reported in Tables 3.12 and 3.13, a material balance was made on the basis of one day of operation of the Kilauea Sugar Company mill at a 5 mgd rate of water input. Neglecting such lesser inputs as restroom wastes, and traces of oils and lubricants, the results shown in Figure 3.18 indicate a mill discharge of 5.17 mgd carrying a total solids load of 137,600 pounds, of which 97,800 pounds is sediments brought in as soil with the harvested cane.

Preliminary analyses of selected samples were made to evaluate the agricultural chemical fraction which might be associated with sediment from mill waste or irrigation tail water. Analyses for herbicides (ametryne and atrazine) in sediment from an irrigation tail-water catch basin on McBryde Plantation, Kauai, indicated an ametryne level of 0.1 ppm. No herbicide was detected in either hydroseparator sediment or in field soil taken at the end of a 2-year cropping cycle. Sediment samples from streams and two estuaries fed by runoff from Oahu watersheds dominated by sugarcane (Wailua Plantation) did not contain either herbicide in detectable quantities.

Although insecticides are not used in sugarcane culture, analysis for chlorinated hydrocarbon insecticides was accomplished on mill wastes to establish levels of these compounds for the Kilauea mill. Sediments from the Kilauea Sugar mill waste stream on November 17, 1971 were centrifuged and the resulting sludge (36 percent solids) was analyzed for chlorinated hydrocarbons. The results, summarized in Table 3.15, show both the concentration of pesticides and the estimated weight of such materials which might be discharged with the sediments during a 200-day year of mill operation at the levels shown in Figure 3.18.

TABLE 3.15. CHLORINATED HYDROCARBONS IN MILL WASTE SEDIMENTS.

CHEMICAL	CONCENTRATION (ppt, WET WEIGHT)		TOTAL DISCHARGE PER YEAR (GRAMS)
DIELDRIN	1800		27.9
α CHLORDANE	770		6.0
γ CHLORDANE	680		5.3
DDD	540		4.2
DDT	430		3.3
		TOTAL	46.7

In October 1971, samples of sediments from the delta reach of Niu Stream and from the abutting beach and Kalihiwai Bay beach were examined for nutrient and heavy metal concentration. Location of the principal sampling stations are shown in Figures 3.16 and 3.17 and results of laboratory analyses are tabulated in Table 3.16.

Although there is no way to trace precisely the history of the sediments examined, it is logical to assume that those from Niu Stream are most heavily influenced by mill waste. Niu Stream itself would also receive and transport

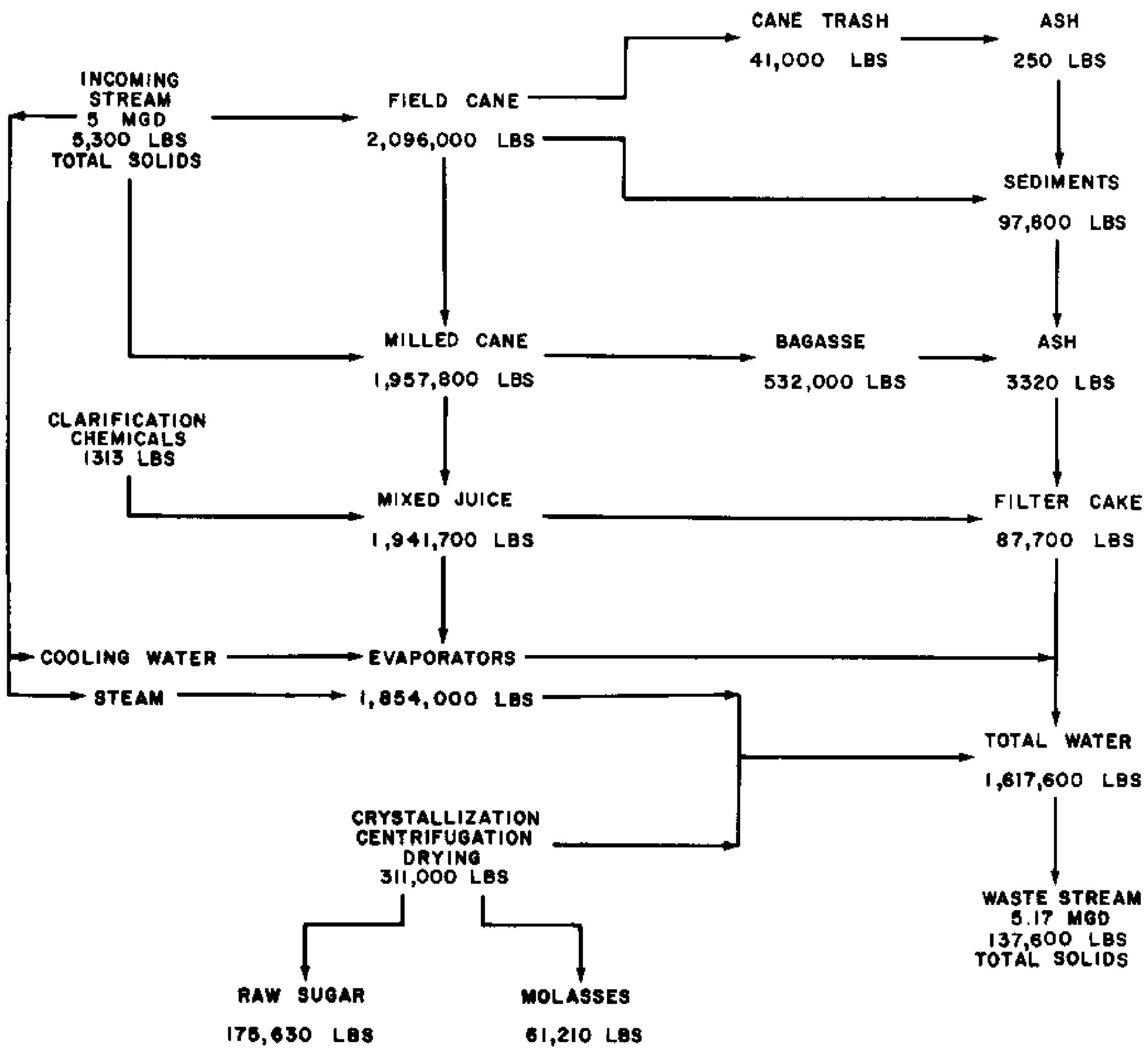


FIGURE 3.18. SUGAR PROCESSING MILL FLOW DIAGRAM AND MATERIAL BALANCE BASED ON ONE OPERATING DAY.

TABLE 3.16. METALS AND NUTRIENTS IN NIU VALLEY STREAM AND KALIHIWAI BAY BEACH SEDIMENTS, OCTOBER 1971.

SOURCE OF SAMPLE	SAMPLE SITE	CHEMICAL CONSTITUENTS (ppm, DRY BASIS)							
		K	P	N	Cd	Cu	Hg	Pb	Zn
NIU STREAM (DOWNSTREAM FROM DISCHARGE PLUME	SED. I	1050	1220	1030	16.6	120.0	0.16	37.9	98.0
	SED. II	1050	1281	1030	14.4	124.0	0.29	33.8	95.0
	SED. III	1300	1376	1257	15.7	170.0	0.16	40.9	123.0
KALIHIWAI BAY BEACH (SEE FIG. 3.17)	K1				2.6	19.8	ND	26.2	44.9
	K2				1.3	21.4	0.09	26.8	50.3
	K3				4.2	20.2	0.08	26.7	39.7
	K4				4.6	25.0	0.08	35.6	44.2
	K5				4.1	19.7	0.07	28.2	9.5
BEACH AT NIU STREAM OUTFALL (SEE FIG. 3.16)	2				2.7	7.9	0. 6	26.9	3.5
	3A				2.8	11.1	0.10	30.1	7.6
	3B				2.8	8.4	0.22	15.6	8.4
	4				3.2	12.0	0.06	28.8	7.6

solids originated from surface runoff. It is in the delta area of the stream that velocities first decrease to the degree to permit substantial deposition of mill waste sediments. The adjacent beach must then be a recipient of some of the mill wastes and surface runoff. The beach is, however, also subject to much more scavenging and eluting by ocean currents than is the delta region. Consequently, the beach might be expected to show a lesser concentration of extraneous chemicals.

The Kalihiway Bay beach area is understandably most influenced by the Kalihiwai River, although as noted in "Oceanography" (see p. 62), the plume of sediments originating in the milling operation often drifts to the west from the Niu Stream discharge point.

The foregoing postulates are only partially borne out by the data in Table 3.16. No comparative data on nutrients are available for the three locations which were monitored. Therefore, it may only be noted that the Niu Valley deposits are high in nutrients and differ little at the three sampling locations.

The Niu Valley deposits, having derived chiefly from the mill wastes, must be predominantly terrestrial in origin, which would also account for their high concentrations of copper, cadmium, and zinc. In the beach area, the admixture of marine sediments of biogenic origin, such as calcareous tests and comminuted coral, would result in a relative reduction in the heavy metal content of the total sediment sample.

The concentration of the heavy metals in the sediments of Niu Stream, as shown in Table 3.16, reflect the parent material from which they were derived.

Nutrients, metals, and pesticides in ocean sediments, both before and after closing down the Kilauea Sugar Company activities, are summarized in

Table 3.17. Although the table appears to be extensive, it fundamentally

TABLE 3.17. NUTRIENTS, METALS, AND PESTICIDES IN OCEAN SEDIMENTS, NORTH KAUAI AREA.

STATION	DATE	T-N mg/l	T-P mg/l	T-K mg/l	Pb ppm	Hg ppm	Cd ppm	Cu ppm	Zn ppm	DDT ppt*
A	07/07/71	437	294	300	17.3	ND	2.4	8.8	12.8	**
B	07/07/71	408	370	175	18.7	ND	2.0	5.6	3.8	**
C	07/22/71	355	435	150	14.8	0.16	1.9	4.8	4.8	**
1	07/22/71	136	448	575	6.2	0.18	2.5	11.4	22.0	**
2	07/19/71	212	359	325	12.3	0.22	2.5	6.8	8.9	**
3A	11/27/71	-	-	-	31.6	ND	2.2	12.3	9.5	125
4	07/22/71	299	433	275	7.8	0.22	2.0	7.5	12.9	**
4'	11/13/71	-	-	-	24.2	ND	2.5	6.4	3.5	150
5	07/06/71	190	286	325	25.6	ND	2.8	24.0	55.7	**
6	07/06/71	128	471	275	16.8	ND	1.5	16.9	38.0	**
6'	11/13/71	-	-	-	24.0	ND	2.2	16.7	37.5	79
7	07/16/71	272	293	250	16.5	0.22	1.6	5.7	5.7	**
7'	11/13/71	-	-	-	30.0	0.06	2.2	9.7	4.8	ND
8	07/16/71	244	318	125	12.6	0.18	2.1	5.0	3.8	**
9	07/11/71	190	347	250	17.8	0.15	2.4	7.8	4.2	**
12	07/27/71	217	361	75	18.9	0.18	2.0	5.3	6.4	**
12'	11/13/71	-	-	-	30.0	0.06	2.3	7.5	4.8	-
14	07/27/71	680	468	675	20.2	0.04	1.6	16.4	47.5	**
2	01/31/72	301	332	297	57.0	ND	4.5	8.1	8.2	-
3	01/12/72	237	558	559	40.0	0.04	3.5	11.8	15.7	-
4	"	193	560	545	29.9	ND	4.7	9.4	14.3	-
5	"	140	567	567	24.3	ND	1.2	15.9	37.8	-
5'	"	139	632	630	36.7	ND	5.1	19.0	39.2	-
6	"	140	608	444	40.1	ND	5.1	8.8	11.5	-
6'	"	233	575	438	45.3	ND	4.7	14.9	33.1	-
7	"	250	352	246	40.1	ND	4.6	5.2	6.8	-
8	"	346	394	376	22.2	ND	4.9	3.8	7.2	-

* WET BASIS

** IN ALL SEDIMENTS THE FOLLOWING PESTICIDES WERE NON-DETECTABLE: LINDANE, HEPTACHLOR, HEPTACHLOR EPOXIDE, DIELDRIN, DDE, DDD, DDT, CHLORDANE, AND ALDRIN. MINUTE AMOUNTS OF PCB WERE DETECTED IN STATIONS B, C, 1, 4, AND 7 reports a single coverage of a very wide area of ocean from July to November 1971 as the area of influence of mill waste discharges was being surveyed and was later followed by a single observation over a less extensive range of ocean as the necessary sampling pattern became more clearly identified.

If ocean sediments were fixed in position once they were laid down, the table might lead to the conclusion that metals and nutrients generally increased in ocean sediments after the sugar industry ceased operation. However, as noted in the brief discussion of oceanography (see p. 62), the current pattern is complex in the north Kauai area and sands move in and out of the beaches seasonally. Moreover, it is not to be expected that sediments accumulated over years of operation of the mill will be purged of any burden of constituents in a matter of two or three months. It is therefore concluded that a longer term of monitoring will be necessary before any definite pattern of change in ocean sediments can be identified, if indeed it ever becomes identifiable.

The most conclusive evidence available at the present time (June 1972) is obtained by a comparison of data in Tables 3.14 and 3.17 for the January 13, 1972 sampling date. Of the nutrients, phosphorus and nitrogen were most highly concentrated in the sediments. None of the three metals (lead, cadmium, and mercury) reported for both water and sediment samples appeared in the water at detectable levels. In the sediments, however, lead concentrations ranged from 22.2 to 57.0 ppm and cadmium ranged from 1.2 to 5.1 ppm. Mercury was non-detectable in both water and sediments. Only Station 2 had a mercury value of 0.04 ppm--scarcely more than the 0.03 ppm level of detectability.

Comparative data on pesticides in water and sediments in the ocean are fragmentary (Tables 3.14 and 3.17). Essentially no pesticide except DDT was found in either type of samples. DDT was found in 3 sediment samples in November 1971 in concentrations of 120, 100, and 60 ppt. Judging by the great disparity in DDT concentrations in mill wastewater (Table 3.13) and mill waste sediments (Table 3.15), the conclusion that sediments, rather than overlying water, is the sink for at least some of the chlorinated hydrocarbon compounds seems inescapable.

METALS AND PESTICIDES IN BIOTA. Beginning in November 1971, analyses of fish and other aquatic biota were made to determine the concentration of organochlorides, mercury, and other heavy metals in the organisms. Results of an analysis of fish collected at Station 7 (Fig. 3.3) on November 1, 1971 are summarized in Table 3.18.

From the table it is evident that all species of fish examined contained mercury, but at concentrations well below the 0.5 ppm currently suggested as a maximum concentration for human consumption.

Results of a much broader range of biota, principally from Stations A, C, and 7 are presented in Table 3.19. The table shows a general tendency for all species analyzed to be low in organochlorine pesticides, generally near or below the level of detectability. All organisms showed a small amount of mercury, generally less than 0.05 ppm. In instances where the same organism was collected from both Station C and Station 7, however, the data show some tendency for the organisms from Station C to contain lesser amounts of mercury and greater amounts of DDT than the ones from Station 7. Little data which might substantiate or refute this observation are presently

TABLE 3.18. MERCURY AND ORGANOCHLORIDES IN FISH, NORTH KAUAI.

NAME OF FISH	NATURE OF SAMPLE gm FISH	NATURE OF SAMPLE ml WATER	TOTAL Hg (ppm)
Acanthurus leucopareius	25 (WHOLE)	25	--
Acanthurus nigrofuscus	62 "	62	0.06
Acanthurus triostegus	22 (MUSCLE)	22	0.05
Canthigaster jacsator	32 (WHOLE)	32	--
Chaetodon miliaris	21 "	21	--
Diodon hystrix	45 (MUSCLE)	45	0.15
Pomacentrus jenkinsi	24 "	24	0.09
Abudefduf abdominalis	31 (WHOLE)	31	--
Parupeneus porphyreus	25 (MUSCLE)	25	0.13
Mulloidichthys samoensis	29 (WHOLE)	29	0.09
Thalassoma	38 "	38	0.14

NOTE: ORGANOCHLORINE PESTICIDES: NO DETECTABLE RESIDUES FOUND

available. However, Table 3.17 shows that on July 19, 1971, the mercury content of sediments at Station C was 0.16 ppm, as compared with 0.22 at Station 7. Neither station showed detectable DDT. No comparable observations of ocean water exist at the two stations. If mill waste and runoff from sugarcane land is the source of mercury in the biota of the area, there is some logic in the possibility that the environment at Station C might be freer of mercury contamination than that of Station 7 because Station C, as indicated in Figure 3.3 is located about one mile east of Kepuhi Roint, whereas Station 7 is near the shore on the west side of Kalihiwai Bay. Thus the former is remote from the mill waste discharge at Niu Stream and the major land drainage channel of Kalihiwai River.

There is not enough information on DDT to make any speculations. DDT is notoriously ubiquitous and is therefore probably a poor tracer material in situations such as the Kilauea Sugar Company operations.

Coastal Water Environments and Biota

SAMPLING STATIONS AND PROCEDURES. Fourteen major subtidal stations and three reef stations were initially chosen in July 1971 for sampling sediments and water and for detailed underwater observations. Six substations were also established for turbidity measurements. As noted in relation to Figure 3.5, sediment samples were collected from most of these stations during the July to November 1971 period of final operation of Kilauea Sugar Company. Ocean water samples, however, (Table 3.14) were drawn from a small number of stations. The number of sediment sampling stations were also reduced after the sugar mill shut down.

Underwater observations were made at all stations in July 1971. Three additional reef stations designated as D, E, and A1 were sampled in February 1972. The location and identifying number for all coastal stations used in the study are shown in Figured 3.3, 3.5, and 3.6. The general study area in which these stations are located in shown in Figure 3.2 and described in "Physiographic and Geological Features of the Study Area" (p. 45).

The major offshore stations are situated in depths of approximately ten meters and are spaced about equally along the Kilauea coast between Hanalei and Kilauea Bays. Reef Stations A and B lie in the path of the mill discharge plume and Reef Station C, 2 miles east of Kepuhi Point and 6 miles from the outfall, was chosen as a control. At each major station, the depth was recorded with a standard Navy depth gauge and temperature readings were taken with a standard centigrade thermometer. Dives were made on days when seas were calm and winds were light.

A one-gallon jar set in a burlap bag was lowered to the bottom and opened by divers and filled with bottom water. The sample water was analyzed on the beach at the end of the day's survey for dissolved oxygen content with a YSI oxygen meter and for salinity with a salinity titration kit (LaMotte Model POL-H). Three titrations were made and averaged for each water sample. The remainder of the samples were put into plastic bags and placed in appropriate glass or metal containers for later analysis.

Turbidity measurements were made at eighteen stations using a 12-inch diameter Secchi disc. For comparison, turbidity measurements were taken at all major stations and substations on the same day, July 15, 1971. Substations provided not only supplementary data, but they were continuously monitored.

Horizontal visibility was measured at six stations utilizing a 50-meter transect line marked every meter with tape. While one diver remained stationary on one end, a second diver moved along the line until he could no longer see the other. At two of the stations, horizontal visibility was estimated by sight.

At stations where coral was present and the visibility was not limiting, initial estimates of the percent of coral coverage were made by dropping a one m^2 quadrat along the transect line at random intervals at the same depth. The results of five to ten measurements were averaged and the area was designated heavy, medium, or sparsely covered depending on whether there was greater than 80 percent, 50 to 80 percent, or less than 10 percent coral coverage, respectively. Where no coral was visible, zero percent was recorded. In March 1972 the method of estimating coral coverage was modified (Doty, 1968) and percent of coral coverage was determined by laying 1 m^2 quadrats at randomly selected points along a 20 m transect line (see Table 3.20). The genus of coral lying under each corner and the percent coverage of the corner of the quadrat were recorded, with percent coverage calculated by the formula:

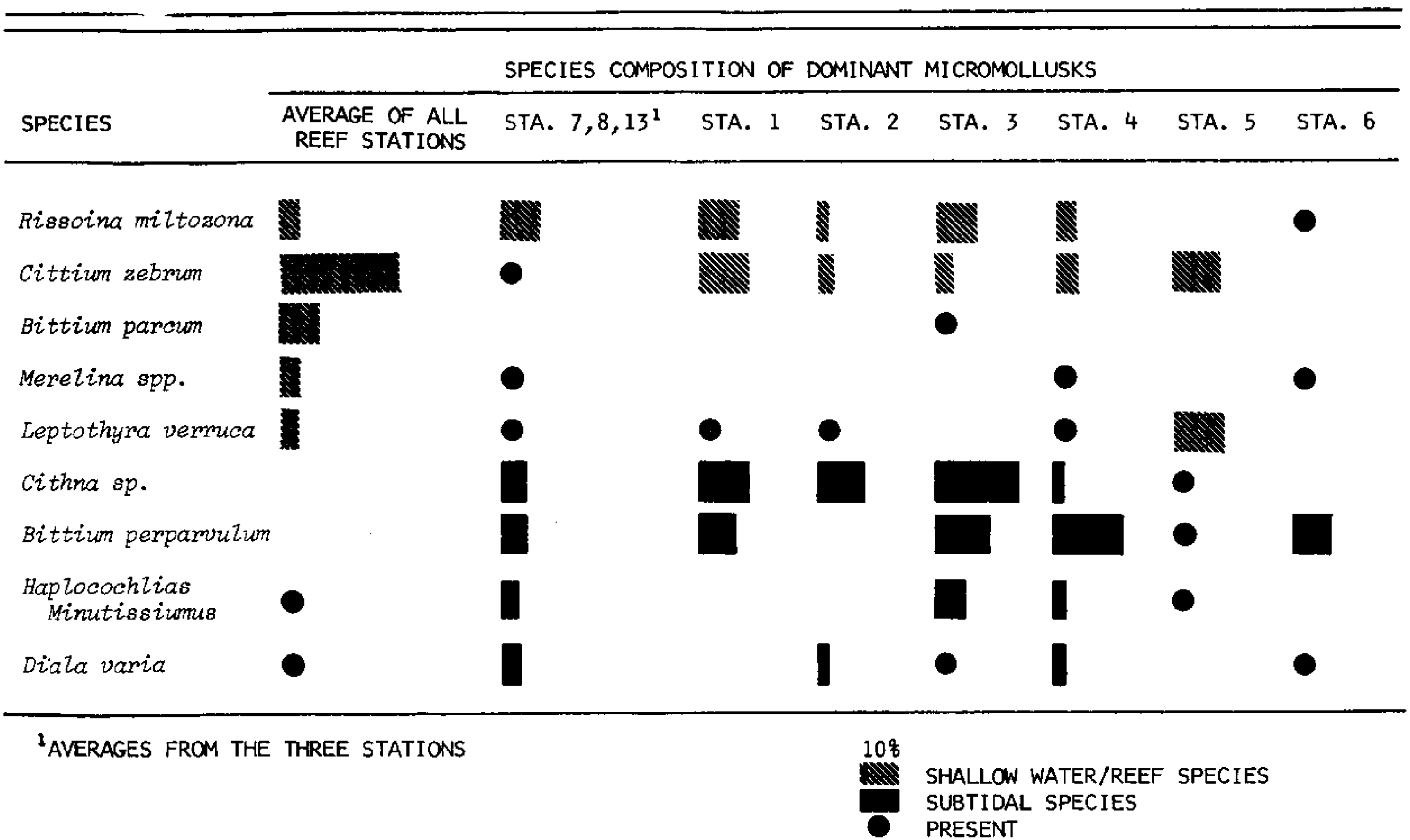
$$\text{percent coverage} = \frac{\text{No. of corners with species x}}{\text{Total no. of corners measured}}$$

Records of the presence or absence of major phyla and classes were made at each station, with special attention centered on the presence or absence

TABLE 3.19. MERCURY AND ORGANOCHLORIDES IN MARINE BIOTA, NORTH KAUAI, AND PHEASANT VISCERA FROM METCALF RANCH.

SCIENTIFIC NAME OF ORGANISM	COMMON NAME	SAMPLING STATION	ORGANO CHLORINE PESTICIDES (ppm)	TOTAL Hg (ppm)
Acanthuridae:				
Acanthurus leucopareius	MAIKOKO	A	—	—
" "	"	C	ND	<0.05
" "		7	ND	—
A. nigrofuscus		A	ND	0.07
			ND (WHOLE)	<0.05
" "			ND (MUSC.)	0.12
" "		C	ND	0.06
A. triostegus	MANINI	7	ND	<0.05
" "	"	A	ND	0.07
*Ophiuroid**		C	ND	<0.05
		A	ND	<0.05
Mollusca				
Patellidae:				
Cellana exarata	OPIHI	C	ND	<0.05
		5	0.014DDT	<0.05
		5A	<0.004DDT	<0.05
		K2*	ND	<0.05
		K4*	ND	0.06
Neritidae:				
Nerita picea	PIPI	C	<0.004DDT	<0.05
		5A	ND	<0.05
			<0.004DDT	
			<0.004 DIELDRIN	<0.05
Cephalopoda				
Vampyroteuthidae:	OCTOPUS	7	ND	--
		A	<0.004DDT	--
Arthropoda				
Crustacea	HERMIT CRAB	5	—	<0.04
	SAND CRAB	5A	ND	0.26
Algae		5	ND	—
		A	ND	<0.05
NOTE: PHEASANT VISCERA, FROM METCALF RANCH			0.01DDE 0.05 DIELDRIN	<0.05

TABLE 3.20. SPECIES COMPOSITION OF DOMINANT MICROMOLLUSKS.



of echinoderms (especially sea urchins) and fish. Fish counts were recorded at each station, with a diver swimming up and down the transect line recording the number and kinds of fish seen in 10 minutes. Algae were also collected along the transect line at each 20 meter mark established in March 1972.

Three transects were made across the reef at Stations A, B, and C during low tide. A 50-m transect line was placed on the reef parallel to shore. A one m^2 quadrat was centered over pre-selected random points and the density of sea urchins was determined. This method not only gives estimates of abundance but also of frequency and distributional pattern (Grigg, 1970).

Photographs were taken at most stations with a Nikonos II underwater camera. The focal length needed to fill one frame with one meter square was predetermined and some of the photos were taken at this focal length. This technique not only facilitates counting of organisms per unit area, but leaves a permanent pictorial record of the ocean bottom at a specific site and time.

Samples of bottom sediment at all major stations were analyzed for species composition, diversity, and abundance of micromollusks, that is, of forms less than 1 cm in length. Volumetrically, micromollusks comprise as much as one-third of the fauna on the reefs and in subtidal waters around all the islands, and thus micromollusks can be utilized as ecological indicators, as are Foraminifera and ostracods in other areas. The advantages of this technique are that it is useable in any area having unconsolidated sediments or drift, it samples most of the species present with minimal effort, and it allows quantitative and qualitative inter-area comparisons of species diversity, composition, abundance. In this study, sediment samples obtained by hand retrieval from all the major stations were subsampled in volumes of 25 cm^3. These subsamples were sorted under a binocular dissecting microscope for micromollusks which were separated, counted, and their species identified.

RESULTS OF PHYSICAL AND CHEMICAL OBSERVATIONS. Dissolved oxygen, temperature, and salinity measurements for the major offshore stations taken in July 1971 are tabulated in Table 3.21. Oxygen readings tended to be fairly constant over 9 of the 11 stations sampled. The mean oxygen tension was 5.9 ppm (standard deviation = 0.32, standard error = 0.09). Stations 3 and 7 showed readings which were significantly different from the mean (t-distribution A = 0.01). The saturation value for dissolved oxygen in sea water at 26°C and 36.1 ‰ salinity is 4.78 ml/l or 6.85 ppm (Sverdrup, *et al.*, 1942), hence, 5.9 ppm O_2 represent 86 percent saturation value.

Salinities did not change significantly from station to station except for low values at Stations 12 and 14. Station 14, situated in Hanalei Bay, indicated relatively fresher water due to discharge into the Bay from three rivers.

Turbidity, measured as depth of clarity, decreased sharply as the horizontal distance to the outfall decreased in July (Fig. 3.19). Using 15 meters as the control depth of clarity, relative turbidity increased thirtyfold from Station 1 to Station 4A (Fig. 3.19). Receiving waters more than one mile from the outfall were at maximum or control clarity. These measurements were taken on July 15, 1971 when wind and sea conditions were very calm. The discharge plume was not developed extensively compared with all the other days of that month. Off Station 7, the plume was about 300 yards wide during calm seas and extended about one mile west and 1/4 mile east of the outfall.

TABLE 3.21. DESCRIPTION OF MAJOR OFFSHORE STATIONS.

STATION NUMBER	DEPTH (m)	O_2 ppm	DEPTH OF CLARITY (m) JULY 1971	DEPTH OF CLARITY (m) MAR 1972	HORIZONTAL VISIBILITY (m) JULY 1971	HORIZONTAL VISIBILITY (m) MAR 1972	T °C / S‰	SUBSTRATE AND BOTTOM TOPOGRAPHY	LOCATION AND GENERAL DESCRIPTION
1	9	6.1	15	--	35	--	27/35.6	FLAT SANDY BOTTOM WITH LARGE AREAS OF ROCK FORMATIONS	1 MILE EAST OF OUTFALL, 300 YARDS. DEVOID OF BENTHIC FAUNA. SOME *Padina* OBSERVED, BOTTOM SURGE STRONG, SCOUR MARKS NOTED. NO BAGASSE.
2	10	6.4	7	--	--	--	26/35.2	FLAT ROCKY BOTTOM	1/2 MILE EAST OF OUTFALL, 400 YARDS WEST OF MOKUAEAE ISLAND. PLUME WELL DEVELOPED, WATER VERY TURBID. NO BAGASSE.
2A	8	—	—	12	15	20	34.9	FLAT, ROCKY	BELOW KILAUEA LIGHT HOUSE 1/2 MILE EAST OF DISCHARGE. MEDIUM CORAL MOSTLY *Montipora* AND *Porites*. NO BAGASSE, SOME SILT OBSERVED.
3	8	5.3	8.5	8	2	20	26/35.5	FLAT, ROCKY	900 YARDS SEAWARD OF NIU STREAM OUTFALL, SOME ALGAL GROWTH WINDROWS OF BAGASSE 50 YARDS LONG FLOATING ON SURFACE, NO BOTTOM FAUNA SEEN.
4	8	6.0	5.5	7	2	10	26/35.0	BARE, FLAT, ROCKY WITH LONG CREVICES RUNNING PERPENDICULAR TO SHORE	1/2 MILE TO WEST OF OUTFALL, NO FLORA OR FAUNA SEEN, LARGE AMOUNTS OF BAGASSE AND CANE STALKS.
5	10	6.0	8.0	13	3	20	25/34.5	SAND; 50 YARDS TO WEST REEF CLIFF RISING TO 5m DEPTH	EAST SIDE OF KALIHIWAI BAY, *Montipora* SEEN ON REEF CLIFF, REEF FLAT COVERED WITH MUD AND SILT BAGASSE AND CANE STALKS SEEN. LARGE NUMBERS OF BURROWS OF MUD SHRIMP *Callianassa* AT 15m.
6	11	6.0	5.0	>15	1	20	25/34.3	FLAT, SANDY; 100 YARDS TO WEST REEF FLAT	WEST SIDE OF KALIHIWAI BAY, ABUNDANT CORAL OF ALL KINDS SEEN, ABUNDANT *Dictyosphaeria* AND *Padina* GROWTH, LITTLE BAGASSE.
7	7	5.4	3.2	>15	26	35	25/35.4	ROCKY REEF WITH SAND CHANNELS PARALLEL TO SHORE	700 YARDS OUTSIDE WEST EDGE OF KALIHIWAI BAY, ABUNDANT CORAL (*Montipora*), BAGASSE AND CANE STALKS SEEN, 2-3m PLUME THICKNESS, CLARITY OF WATER INCREASED SHARPLY BELOW THIS LAYER OF SUSPENDED SOLIDS.
8	9	6.0	15	>15	32	35	26/35.8	ROCKY, RUGGED, DISSECTED BY MANY CREVICES AND CHANNELS	900 YARDS OFF THE COAST WEST OF KALIHIWAI BAY 1 1/2 MILES FROM THE OUTFALL, BAGASSE AND CANE STALKS SEEN IN TRACE AMOUNTS, ABUNDANT CORAL AND ABUNDANT FISH.
9	11	6.2	15	--	35	—	26/35.3	--	2 MILES WEST OF MILL DISCHARGE, 900 YARDS OFFSHORE. NO BAGASSE, ABUNDANT CORAL MOSTLY *Montipora*, ABUNDANT FISH.
10	NOT SURVEYED								
11	NOT SURVEYED								
12	8	6.1	15	—	--	--	25/34.5	FLAT, ROCKY, GENTLE SLOPE TO SHORE, 800 YARDS FROM SHORE REEF DROPS TO 22m	3 1/2 MILES WEST OF OUTFALL AND 600 YARDS NE OF KAWEONUI POINT, ABUNDANT CORAL AND FISH, SEA URCHIN *C. Paucispina* SEEN IN LARGE NUMBERS. AT 22m LARGE AMOUNTS OF BAGASSE PILED ALONG REEF CLIFF BASE (SEE FIG. 4). TURBID WATER AT THIS DEPTH.
13	11	--	15	--	--	--	25/—	FLAT, ROCKY, GENTLE SLOPE TO SHORE	5 MILES WEST OF OUTFALL, 700 YARDS NW PUU POA POINT, ABUNDANT CORAL, SOME CANE STALKS SEEN.
14	12	5.9	6	—	--	--	25/28.5	SOFT, FINE, BLACK MUD AT LEAST 1/2m THICK	IN HANALEI BAY 750 YARDS DUE NORTH OF THE MOUTH OF THE HANALEI RIVER, 6 MILES FROM THE OUTFALL.

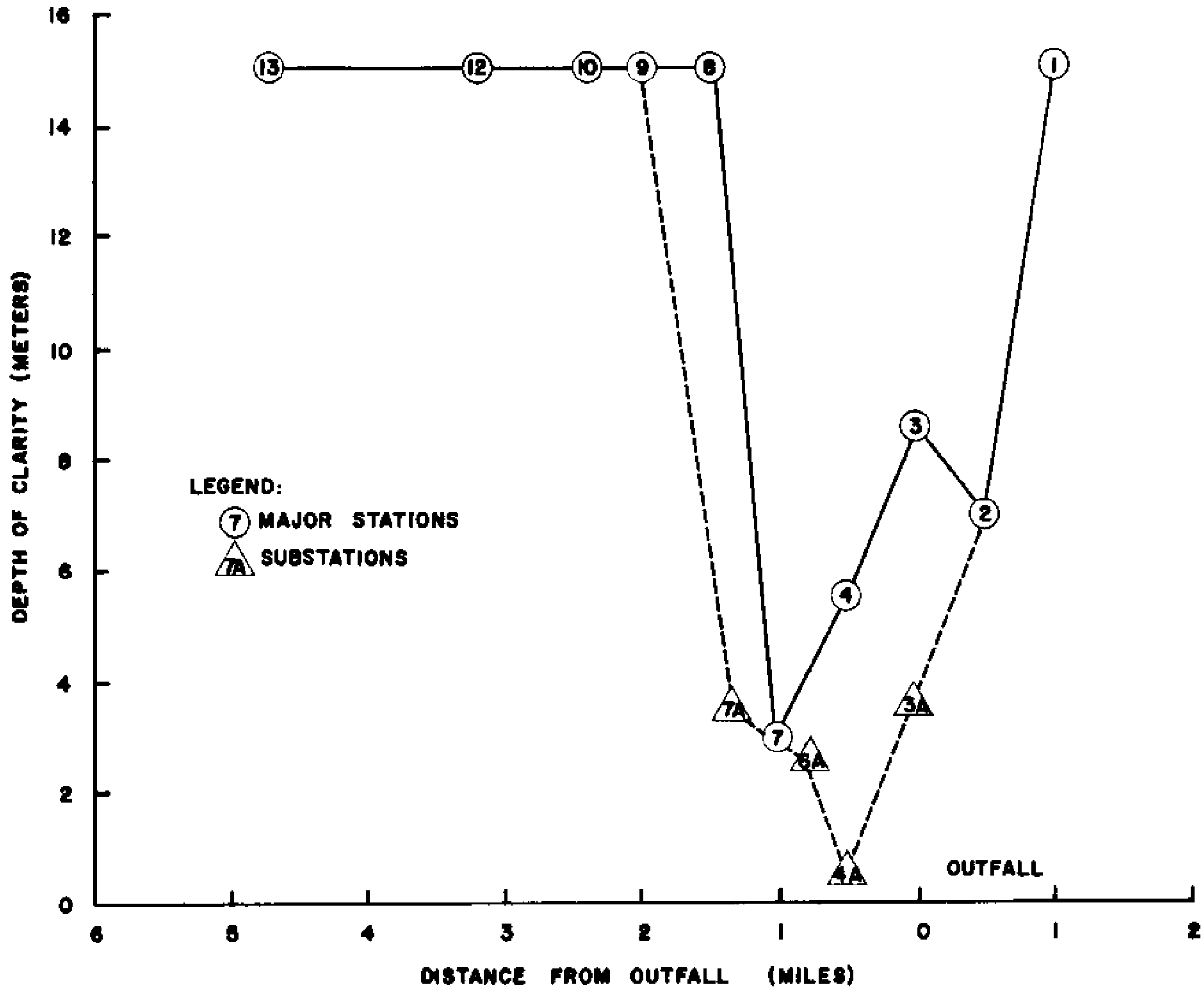


FIGURE 3.19. HORIZONTAL DISTANCE FROM NIU STREAM OUTFALL VERSUS DEPTH OF CLARITY OF OPEN OCEAN WATERS: JULY 15, 1971.

Horizontal visibility tended to increase as distance from the outfall increased. However, in one case, at Station 12 off Anini Reef, turbidity increased sharply below 10 m. A profile of the reef at Station 12 is shown in Figure 3.20. During several dives, a definite turbocline was found to exist at Stations 2, 6, and 7 with visibility rapidly increasing with depth below two to three meters.

In all the samples analyzed (Table 3.22), four common materials were found to dominate the bottom sediments: (1) terrigenous material, *i.e.*, material derived from non-marine sources, which consisted entirely of volcanic rock fragments of basaltic composition, (2) calcareous material, which consisted of coral and shell fragments by far dominated all samples while the coarser sands contained an abundance of intact forminifera and small mollusk tests in addition to the calcareous material, (3) non-calcareous organic material, which were generally indentifiable only as decaying plant and animal tissue or fecal matter, and (4) clay and mud-sized particles

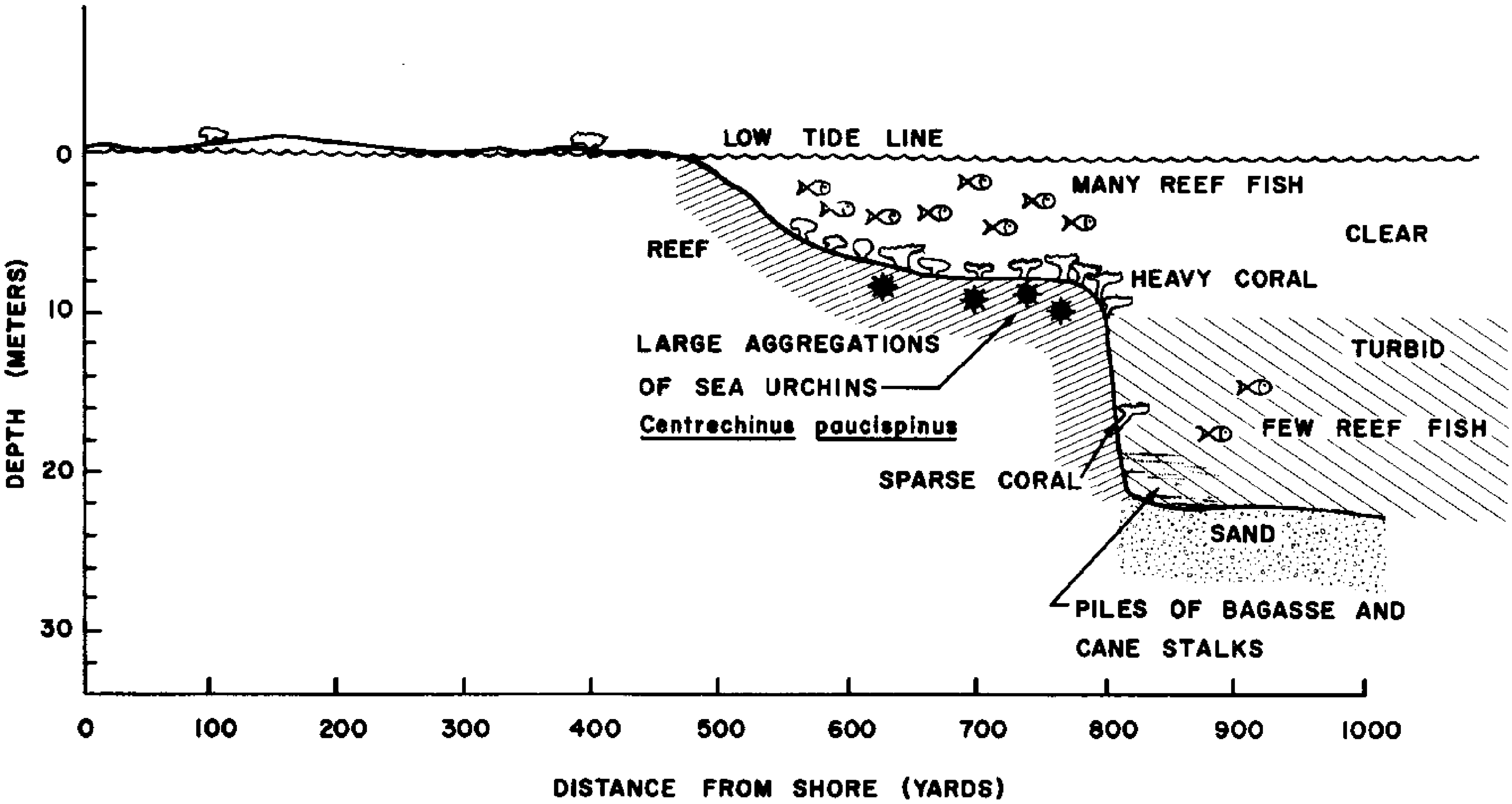


FIGURE 3.20. PROFILE OF STATION 12.

TABLE 3.22. KILAUEA WATER QUALITY BOTTOM SEDIMENT DESCRIPTIONS.

STATION	SIZE DISTRIBUTION[1] (PERCENT) COARSE	MEDIUM	FINE	COMPOSITION[2] (PERCENT) TERRIGENOUS	CALCAREOUS	ORGANIC	CLAY	DESCRIPTION
1	45	40	15	15	83	2	--	THE TERRIGENOUS MATERIAL CONSISTS ENTIRELY OF ANGULAR VOLCANIC ROCK FRAGMENTS. CALCAREOUS MATERIAL IS ANGULAR TO SEMI-ANGULAR CONSISTING OF FORAMINIFERA, MOLLUSKS, AND CORAL FRAGMENTS.
2	10	75	15	5	89	4	2	VOLCANIC ROCK FRAGMENTS ARE ROUNDED. CALCAREOUS MATERIAL IS ANGULAR, CONSISTING OF SHELL AND CORAL FRAGMENTS. ORGANIC MATERIAL AND CLAY LEND A LIGHT BROWN COLORATION TO THE SAND.
4	5	85	10	10	88	2	--	VOLCANIC ROCK FRAGMENTS ARE SEMI-ANGULAR WHEREAS THE CALCAREOUS SHELL FRAGMENTS ARE SEMI-ROUNDED TO SEMI-ANGULAR. TRACES OF FINE ORGANIC DETRITUS COLOR THE SAND LIGHT BROWN.
5	0	35	65	15	78	4	3	TERRIGENOUS VOLCANIC ROCK FRAGMENTS ARE GENERALLY SEMI-ROUNDED. CALCAREOUS MATERIALS ARE WELL-SORTED, SEMI-ROUNDED SHELL FRAGMENTS. ORGANIC DETRITUS AND CLAY-SIZE PARTICLES GIVE A DARK BROWN COLOR TO THE SAND AND ARE EASILY SUSPENDED.
6	0	45	55	20	77	1	2	VOLCANIC ROCK FRAGMENTS ARE ROUNDED TO SEMI-ROUNDED. CALCAREOUS MATERIALS, LARGELY SHELL FRAGMENTS, ARE SEMI-ANGULAR TO SEMI-ROUNDED. DARK GRAY-BROWN COLORATION IS DUE TO HIGH BASALTIC ROCK FRAGMENT CONTENT.
7	10	75	15	1	96	2	1	VERY LITTLE TERRIGENOUS MATERIAL IS PRESENT. CALCAREOUS MATERIAL CONSISTS OF SHELL AND CORAL FRAGMENTS GENERALLY ANGULAR IN SHAPE. LIGHT BROWN COLORATION IS DUE TO ORGANIC AND CLAY CONTENT.
8	60	35	5	--	1	--	--	THIS SAMPLE CONSISTS ENTIRELY OF SHELL AND CORAL FRAGMENTS AND FORAMINIFERA TESTS.
9	55	35	10	--	100	--	--	SAME COMPOSITION AS #8.
12	75	25	--	1	99	--	--	SAMPLE CONTAINS ONLY A TRACE OF ROUNDED VOLCANIC ROCK FRAGMENTS. CALCAREOUS MATERIAL IS LARGELY OF INTACT TESTS OF SMALL MOLLUSKS, FORAMINIFERA AND ECHINOID SPINES. SOME 40 PERCENT OF THE CALCAREOUS DETRITUS IS OF CORAL FRAGMENTS.
RA	30	30	40	5	89	2	4	THE TERRIGENOUS MATERIAL CONSISTS OF A SMALL AMOUNT OF VOLCANIC ASH. CALCAREOUS MATERIAL IS DOMINANTLY CORAL FRAGMENTS AND INTACT TESTS OF FORAMINIFERA AND MOLLUSKS. THIS SAMPLE SHOWS VERY POOR SORTING.
RB	65	30	5	5	95	--	--	TERRIGENOUS MATERIAL CONSISTS OF SEMI-ANGULAR VOLCANIC ROCK FRAGMENTS. CALCAREOUS MATERIAL IS WELL WASHED (NO CLAYS OR OTHER FINE MATTER) AND CONSISTS OF SHELL AND CORAL FRAGMENTS. SOME 50 PERCENT IS OF INTACT TESTS.
RC	60	35	5	1	98	--	1	THIS SAMPLE IS DOMINANTLY CALCAREOUS WITH 75 PERCENT CONSISTING OF FORAMINIFERA AND MOLLUSK TESTS. THE REMAINDER ARE CORAL AND SHELL FRAGMENTS.

[1] SIZE FRACTIONS ARE DISTINGUISHED AS COARSE (.5-2 MM), MEDIUM (.25-.5 MM) AND FINE (<.25 MM).

[2] TERRIGENOUS MATERIAL REFERS TO THAT DERIVED FROM NON-MARINE SOURCES—VOLCANIC IN THIS CASE.
CALCAREOUS MATERIAL PERTAINS TO $CaCO_3$ IN ALL FORMS, E.G., SHELLS, CORAL, ETC.
ORGANIC MATERIAL PERTAINS TO NON-CALCAREOUS ORGANIC MATTER SUCH AS FECAL MATERIAL AND/OR DECAYED PLANT AND ANIMAL TISSUE.
CLAY MATERIAL NOT ONLY PERTAINS TO CLAY MINERALS, BUT ALL CLAY AND MUD-SIZED PARTICLES (<.03 MM) THAT ARE EASILY HELD IN SUSPENSION IN WATER.

(less than .03 mm in diameter) which were held in suspension in water.

Samples obtained at Reef Stations A, B, and C are all composed of very coarse, highly calcareous grains, generally low in terrigenous material. Station A samples are very poorly sorted and have a high clay and mud content. Sediment samples from Stations 1, 8, 9, and 12 are coarse in texture and show good sorting. However, Station 1 sediment samples differ in that they contain a relatively high fraction of volcanic rock fragment. The sediment samples from Stations 8 and 9 are totally calcareous and those from Stations 2 through 7 fall into the medium and fine grain sand category and show fair to poor sorting. With the exception of Station 7, these samples show some darkening in color due to the basaltic rock fragment content. Sediments from Stations 2 and 5 have a high clay and organic matter content and are very susceptible to suspension.

In July, windrows of bagasse were observed at Station 3 and large amounts of bagasse and cane stalks were noted on the substrate clogging crevices and piled at the reef base at Stations 5, 6, 7, and 12. Trace amounts of bagasse were also seen at Stations 8, 9, and 13.

Following the cessation of mill activities in November, several changes occurred in the physical parameters of the area. Perhaps the most noticeable change was that associated with water clarity: the turbidity readings in January and March 1972 showed a definite increase in clarity of the receiving waters (Table 3.21). At Stations 3 and 4, for example, where vertical and horizontal visibilities were but 1 to 2 meters in July 1971 while the mill was still in operation, horizontal visibilities increased in March 1972 to 20 and 10 meters, respectively. The other noticeable change in March 1972 was the disappearance of bagasse from the substrate of all the stations where it had previously been noted.

NATURE OF TOPOGRAPHY AND BIOTA. The substrate of the subtidal stations is a complex of basalt outcrops, sand channels, and organic reef builders. The bottom configuration of Stations 1 to 4 (Table 3.21) is generally flat, studded with rocky (basalt) outcrops and sand pockets, with little or no coral growth (Table 3.23 and Fig. 3.21). The configuration is Stations 7 to

TABLE 3.23. PERCENT CORAL COVER, MARCH 1972.

STATION	*MONTIPORA*	*PORITES*	*POCILLOPORA*	TOTAL
2A	17.0	3.0	3.0	23.0
3	<- - - - - -	SAND	SUBSTRATE	- - - - - ->
4	0.0	0.0	0.0	0.0
5	41.5	4.5	0.0	46.0
6	45.0	8.8	5.9	59.7
7	37.0	16.0	0.0	53.0
8	51.0	5.8	1.5	58.3

NOTE: *PAVONA VARIANS* WAS SEEN IN SMALL CLUSTERS.

13 which comprise the frontal edge of the fringing reef are rugged and dissected by crevices and sand channels extending into the reef. Coral growth covers 50 to 80 percent of the substrate (Fig. 3.21 and Table 3.23). The bottom at Stations 5 and 6 inside Kalihiwai Bay is flat and sandy, with varying amounts of coral and algal growth, at Station 5 *Montipora* covers 50 to 80 percent of the substrate, and at Station 6 there is a lush algal growth in addition to coral.

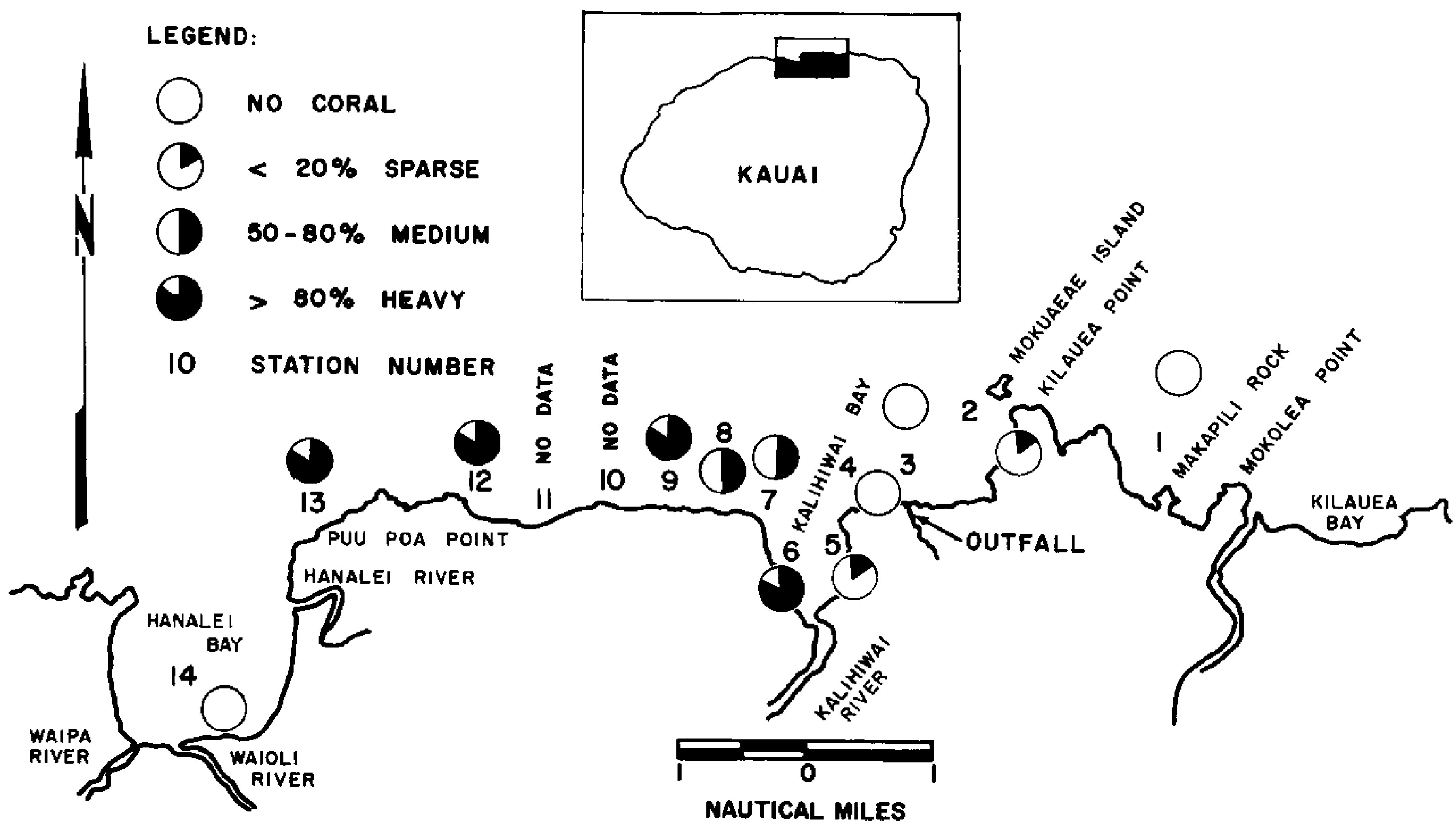


FIGURE 3.21. PERCENT OF CORAL COVERAGE AT OFFSHORE STATIONS BETWEEN KILAUEA BAY AND HANALEI BAY, 15 JULY 1971.

The major components of the biota are detailed in Tables 3.21 and 3.23. Three biotal areas are distinguishable: Stations 1 to 4 with little or no coral growth or other benthic biota and with worn molluscan shells in the sediments, Stations 5 and 6 within Kalihiwai Bay with a mixed coral/algal biota and also with worn molluscan shells in the sediments, and Stations 7 to 13 fronting Anini Reef with 50 to 80 percent coral coverage and an abundance and variety of *in situ* mollusk shell deposits in the sediments.

The sediments at Stations 1 to 4 contain few micromollusks (the average was 2.8/cm^3 of sediment in August 1971) and all of the shells except *Caecum* from Stations 1 and 2 and *Barleeia* from Station 2A were so worn as to suggest that they were deposited by transport rather than being those *in situ.* The species composition of the assemblages also indicates deposition by transport as the assemblages are composed of a mixture of subtidal and intertidal or reef forms (Table 3.20). The sediment assemblages from Stations 5 and 6 are similar in form and species composition to those of Stations 1 to 4. The shells are worn and the species composition includes both subtidal and reef species.

In contrast to the worn, transported assemblages of micromollusks from Stations 1 to 6, the assemblages from Stations 7 to 13 reflect a situation where the mollusks have apparently been deposited *in situ:* the shells are fresh and unworn, there is an abundance of shells in the sediments (the average for Stations 7, 9, and 12 is 10.7 shells/cm^3 of sediment), and the faunal composition indicates a variety of microhabitats. This variety is reflected in the proportions of the orders of gastropods represented and is compared with the composition of the fauna from a similar situation off Waikiki Reef, Oahu as shown in Figure 3.22. Stations 8 and 12 in this series of stations are anomalous, however. Station 8 is in a sand channel scoured by wave action which apparently precludes the deposition of shells and Station 12 is located at a break in the reef front and this assemblage is composed of a misture of worn reef shells as well as those characteristics of the subtidal habitat.

Observations of biota at the principal stations which might be most affected by mill wastes were made in March 1972. The results are summarized in Tables 3.24 and 3.25. Although neither coral cover nor the analyses of the micromollusks indicate changes in the biota since the cessation of mill activity, the appearance in March of *Holocentridae* (menpachi) at Station 4 (Table 3.24) where no fish were seen in July suggest changes are occurring. Menpachi are fish normally found in rocky crevices and holes. All crevices in the area were filled with bagasse and mill trash in July but the debris has since disappeared and the crevices are now available to animals which normally inhabit them.

NATURE AND BIOTA OF REEF STATIONS. Some general observations of the nature and biota of reef stations A, B, and C made in July 1971 are summarized in Table 3.26. In general, the fringing reefs of the northern coastline of Kauai under study are wide, shallow platforms. At Anini, the reef platform extends as much as 1600 feet seaward from the shoreline. The algal ridge is about a foot below the low-tide level, and the reef flat itself is 1 to 6 feet deep at low tide, deeper at high tide and when there is heavy wave action. The reef platform is topographically heterogeneous. At the eastern end (Station D, Fig. 3.5) the platform is solid from the sand beach seaward, with an algal cover of *Padina, Colpomenia, Sargassum,* etc., and westward, towards Stations A and B, the reef flat is a complex of sand flats and chan-

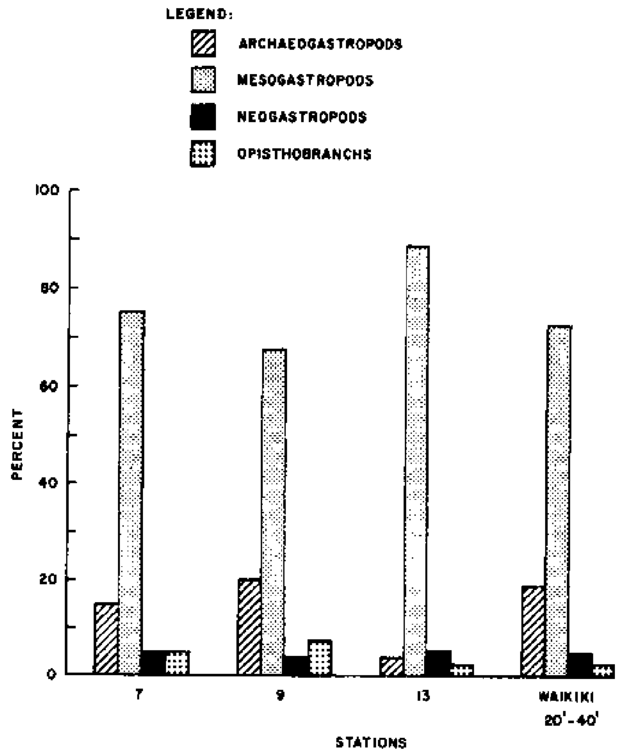


FIGURE 3.22. RELATIVE PROPORTIONS OF GASTROPODS AT STATIONS 7, 9, AND 13 AND AT STATIONS AT SIMILAR DEPTHS OFF WAIKIKI REEF.

TABLE 3.24. FISH COUNTS, MARCH 1972.

NAME	STATIONS						
	2A	3*	4	5	6	7**	8
Acantharid	2	--	4	3	0	--	20
Canthigasteridae	2	--	0	0	1	--	0
Carangidae	0	--	7	0	0	--	0
Chaetondonidae	0	--	0	0	0	--	0
Cirrhitidae	0	--	1	2	4	--	0
Holocentridae	14	--	4	0	0	--	0
Labridae	12	--	7	8	17	--	8
Lutjanidae	0	--	1	0	0	--	1
Mullidae	2	--	8	0	0	--	0
Pomacentridae	0	--	0	3	8	--	8
Priacanthidae	0	--	0	2	0	--	0
Scaridae	0	--	0	0	0	--	2
Zanclidae	0	--	2	0	0	--	0
TOTAL	32	0	34	18	30	0	39

* NO FISH SEEN
** NOT SURVEYED

TABLE 3.25. BIOLOGICAL OBSERVATIONS AT OCEAN SAMPLING SITES IN VICINITY OF NIU STREAM OUTFALL.

NAME	STATIONS						
	2A	3[1]	4	5	6	7	8
Asteroids	–[2]	--	–	–	–	–	–
Chlorophyta	–	--	–	+[3]	+	+	+
Corallina	+	--	–	+	+	+	+
Crustacea	–	--	+	–	–	+	–
Echinoids	–	--	–	–	–	–	–
Holothurians	+	--	+	–	–	–	–
Mollusca	–	--	–	–	–	–	+
Ophiuroids	–	--	–	–	–	–	–
Phaeophyta	+	--	–	+	+	+	+
Polychaetes	+	--	–	+	+	–	–
Porifera	+	--	+	–	+	+	+
Rhodophyta	+	--	–	+	+	+	+
Zooanthids	+	--	+	+	+	+	+

[1] NO MACROFAUNA SEEN
[2] – = ABSENCE
[3] + = PRESENCE

TABLE 3.26. REEF STATIONS, JULY 1971.

STATION	LOCATION	GENERAL DESCRIPTION
A	250 YARDS NORTH OF HONONO POINT (FIG. 3.5); ON ANINI REEF, 250 YARDS FROM THE BEACH.	REEFS A AND B SHOWED LITTLE OR NO CORAL COVERAGE, NUMEROUS DEAD CORAL HEADS *Pocillopora* AND *Porites*; LARGE AMOUNTS OF BAGASSE AND OTHER CANE DEBRIS STREWN ON REEF, SCUM COLLECTED IN SHALLOW STATIC POOLS, 13 OUT OF 20 QUADRATS SAMPLED SHOWED EXTENSIVE SILT LADEN ALGAL GROWTH OF *Dictyosphaeria*, *Ulva* AND *Padina*. SEA URCHINS AND OTHER INVERTEBRATES WERE SCARCE. *E. mathaei* AND *E. oblonga* WERE THE MOST ABUNDANT MACROFAUNA OBSERVED. (TABLE 3.27)
B	1/2 MILE WEST OF HONONO POINT (FIG. 3.5); ON ANINI REEF, 200 YARDS FROM THE BEACH.	
C	2 MILES EAST OF KEPUHI POINT (FIG. 3.3); 100 YARDS FROM THE BEACH.	SOME CORAL GROWTH MOSTLY *Montipora*; NUMEROUS DEAD *Pocillopora* CORAL HEADS, NO BAGASSE OR CANE DEBRIS SEEN, ABUNDANT SILT LADEN ALGAL GROWTHS OF *Dictyosphaeria*, AND *Padina* NOTED, VERY LITTLE FAUNA SEEN, SEA URCHINS *E. mathaei*, *E. oblonga*, *C. paucispinus*, AND *Tripneustes gratilla* WERE OBSERVED. (TABLE 3.27)

nels with a dense cover of *Acanthophora* shoreward and *Sargassum* toward the seaward edge. At Station A the reef extends 450 to 500 yards from shore. Visibility at the outer edge of the reef is 30 to 40 feet. There is abundant coral growth at the reef edge with *Montipora* predominating and *Porites* and *Pocillopora* also present. At Station B, there is a wide expanse of fine, silty sand bound together with a green alga in the nearshore area. Large amounts of bagasse and mill trash were noticeable the length of the reef, in crevices on the reef flat and in windrows on the shore in July. These deposits had almost entirely disappeared by March 1972.

The micromolluscan assemblages on the reef flat reflect the heterogeneous topography of the reef: at Station D where there is a variety of algal species, the dominant gastropod is *Bittium parcum*, at Station E where the sand flat is largely covered with *Acanthopora* the dominant gastropods are *Rissoina miltozona* and *Bittium zebrum*, and at Stations A1, A, and B, where there is a mixed *Acanthophora/Sargassum* environment, *Bittium zebrum* is the dominant gastropod with *Bittium parcum* occurring in lesser numbers (Fig. 3.23). The species composition in general is comparable to that of reefs at Waikiki, Oahu and Kaunakakai, Molokai.

Fishes on the reef flat at Station A are primarily acanthurids, with *Acanthurus sandvicensis* and *A. nigrofusca* predominating. The sea urchins *Echinometra mathaei* and *E. oblonga* occur in pockets on the reef flat, with *Diadema paucispinum* at the reef edge. Various holothurians were noted on the sand flats and in November, the sacoglossan opisthobranch mollusk *Plakobranchus*.

The easternmost reef station (Station C), located just east of Kepuhi Point, is a narrower (50-100 feet wide) fringing reef than the reef at Anini. The waters covering the reef flat are noticeably clear and cold. At the frontal edge of the reef, water visibility is about 60 feet. No mill trash or bagasse was noted in the area in July, but sea weeds on the reef such as *Padina* and *Distyosphaeria* were covered with brown silt. Coral growth at Station C is almost non-existent and sea urchins were not abundant (Table 3.27). *Echinometra mathaei* was the most abundant urchin noted at Station C in July. *Diademia paucispinum* with tests of 6 to 7 inches in diameter were noted in November. The predominant fish at Station C in November were acanthurids of which *Acanthurus nigrifuscus* was most common. Small schools of *Mulloidicythys samoensis* and *M. auriflamma* (weke-'ula) were also noted, as were 12 large scarids (uhu) and two eels (probably *Gymnothorax flavimarginatus* and *Echnehnassa canina*). Small, juvenile lobsters were also seen. The micromollusks in the reef flat sediments are noticeably poor in both species variety and abundance. Only 48 shells were found in 27 m^3 of sediment, representing 10 species, and most of the shells were worn. Algal growth is particularly noticeable at the shoreward edge of the reef on boulders, where two species of opihi (*Cellana* spp.) were also found.

EVALUATION OF ENVIRONMENTAL FINDINGS. The discharge from the Kilauea Sugar Company discolored the receiving waters of the Kilauea coastline, sometimes extending one mile east to the Kilauea Lighthouse and two to three miles to the west to Station 10 in July 1971. Associated with this discoloration was a definite increase in turbidity as the outfall was approached (Fig. 3.19). Deposits of bagasse and cane stalks indicated that even though the receiving waters may clear two or three miles from the outfall, debris was carried by currents as far as five miles to the west of the outfall near Station 13 (Appendix A, p. 201) and lodged at depths of at least 10 m along the front of the fringing reef.

Mill waste entered Kalihiwai Bay at certain times as evidenced by deposits of bagasse at Stations 5 and 6 in July. Part of the general murky condition of the water in Kalihiwai Bay can be attributed to suspended solids from the outfall but the outfall may not be the major contributor. Runoff from adjacent lands into Kalihiwai River brings down to the Bay terrigenous muds, silts, and clays as indicated by Moberly and Chamberlain (1964). This runoff, combined with complex inshore and offshore processes, may contribute a significant, if not a major part, in explaining the Bay's turbid nature.

In Hanalei Bay, the effect of terrigenous runoff is reflected in the low salinity of Bay waters and the nature of the bottom sediments. Station 14 in Hanalei Bay, the most westerly of all the stations surveyed located 6 miles from the sugar mill outfall, is the sink for three large streams, Hanalei

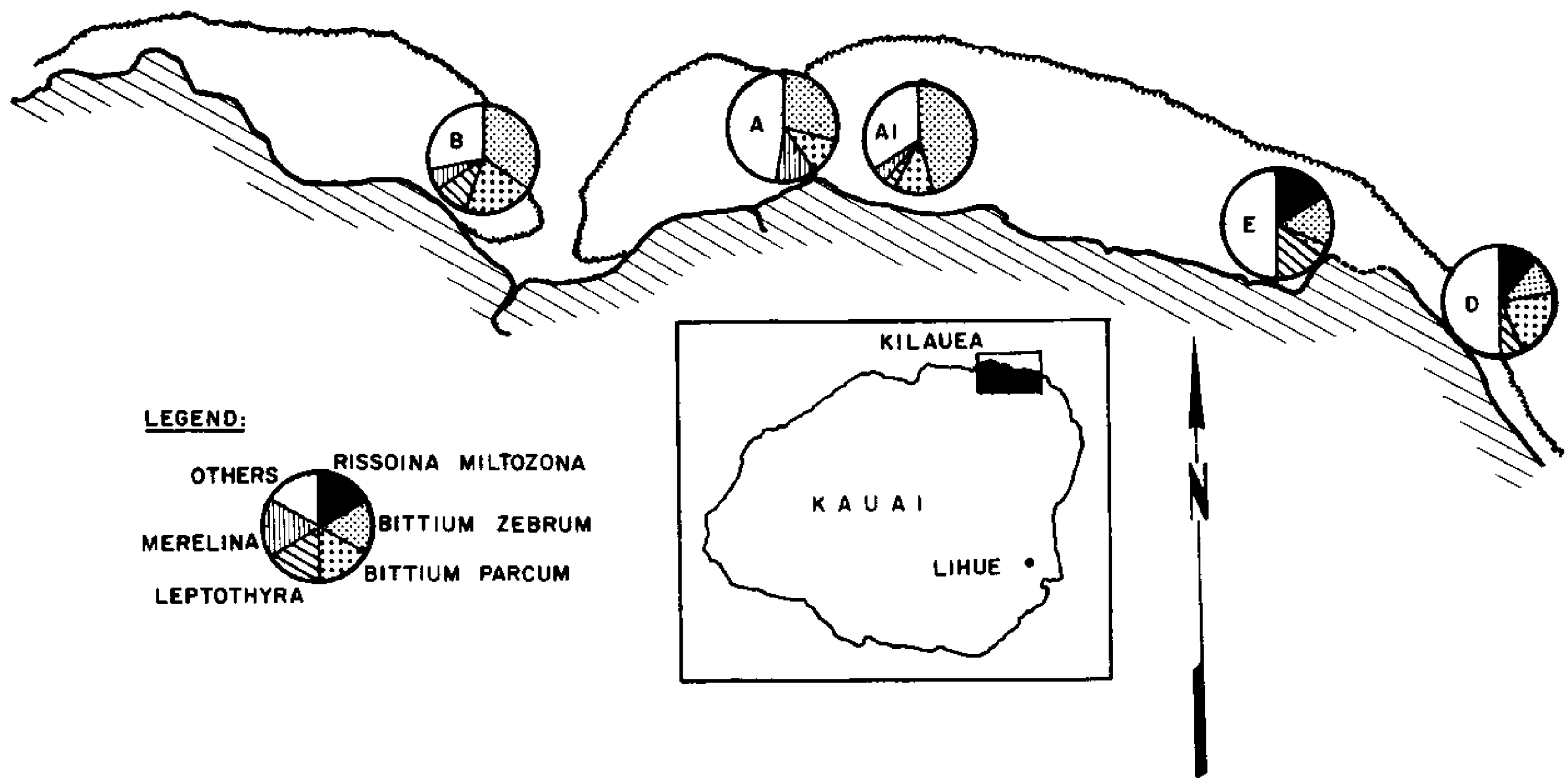


FIGURE 3.23. PERCENT COMPOSITION OF REEF GASTROPODS AT VARIOUS REEF STATIONS.

TABLE 3.27. REEF STUDY OF SEA URCHIN POPULATIONS.

SPECIES	DENSITY #/m² [1]	FREQUENCY [2]	RELATIVE DENSITY [3]
STATION A:			
Echinometra mathaei	3.0	0.77	.86
Echinometra oblonga	0.5	0.22	.14
STATION B:			
Echinometra mathaei	2.0	0.5	.82
Echinometra oblonga	0.45	0.2	.18
STATION C:			
Echinometra mathaei	18.0	1.00	.80
Echinometra oblonga	3.0	0.89	.13
Diadema paucispinum	1.5	0.56	.07

[1] DENSITY = # INDIVIDUAL / m^2

[2] $\text{FREQUENCY} = \frac{\text{NO. OF QUADRATS WITH INDIVIDUALS OF SPECIES X}}{\text{TOTAL NO. OF QUADRATS}}$

[3] $\text{REL. DENSITY} = \frac{\text{DENSITY OF SPECIES X}}{\text{TOTAL DENSITY OF ALL SPECIES}}$

River and Waipa and Waioli Streams. The Bay bottom is partly covered with a 0.5 m thick layer of fine black mud. This fact and the dissolved oxygen reading of 5.9 ppm suggest short turnover times and good mixing quality of the Bay water.

The dissolved oxygen concentrations at 9 of the 11 stations (see Table 3.21) were fairly constant, indicating that the receiving waters off the Kilauea Coast have short turnover times and these seems to be no indication of eutrophication. At Station 3 which is more than 500 yards directly seaward of the outfall the DO reading was 5.3 ppm. Waters at this station are constantly subjected to mill discharge even under the calmest conditions. Fauna at the ocean bottom was minimal and deposits of silt were observed. However, at Station 7 where the DO reading was also low and the surface waters turbid, the water was clear at the depth at which the samples were taken, the sediments were not discolored, and flora and fauna were abundant at the ocean bottom. The nearly constant salinity of the receiving waters near the outfall indicates that mixing of the offshore waters is vigorous and not severely affected by the fresh water from the outfall.

Although three biotal areas are distinguishable along the coastline, it is not clear whether or not the characteristics of these areas are or have been affected by the discharge. While it is tempting to speculate that coral and other benthic organisms may be adversely affected by the turbid waters present at Stations 2 and 4 (Fig. 3.3) when mill discharge was affecting the area, the absence of fringing reef in the area, the worn sediments, and mixed species composition of micromollusks suggest that wave abrasion and complex current patterns along the eastern slope may preclude growth of many benthic organisms. Continued monitoring of the area subsequent to the cessation of the mill discharge is crucial to testing the two hypotheses.

Coral growth and fish appear fairly abundant along the frontal edge of the fringing reef at Anini (Stations 7 and 13, Figs. 3.5 and 3.6). Although the number of species and species composition of the assemblages of micromollusks are similar to those at Waikiki, Oahu, the abundance of micromollusks is noticeably lower than those at similar depths and localities off Oahu, where the average of 17.5 shells/cm^3 was calculated for the reef front at Waikiki, Oahu, compared with 10.7/cm^3 at Anini. Nor are sea urchins, a generally ubiquitous and abundant group of marine organisms in Hawaiian waters, present in any abundance. In studies of Honaunau Bay and Kealakekua Bay, Hawaii, sea urchins were encountered at all depths to 40 feet and densities of *Echinometra oblonga* of up to 500 individuals per m^2 have been counted on Oahu (Russo, unpublished). The most abundant urchin found in this study was *Echinometra mathaei* with a density of 18 per m^2 at Reef Station C. Urchins of the genera *Echinothrix* and *Heterocentrotus* were abundant at Honaunau Bay; none were seen in this Kauai study. *Tripneustes gratilla,* second in importance to *Heterocentrotus mamillatus* for the Kona coast on Hawaii, was seen only in very small numbers at Reef Station C on Kauai.

The reef stations showed little or no coral growth (Fig. 3.21). But the presence of dead coral heads of *Porites* and *Pocillopora* observed at all three stations attests to the fact that at one time coral growth, although minimal in terms of total cover, was luxuriant. However, sparse coral growth does not necessarily mean an unhealthy reef condition. Normally, crustose coralline algae are the dominant reef building component of Hawaii reefs (Pollock, 1928 and Littler, 1971). The reef edge of Hawaiian fringing reefs tends to be characterized by both encrusting and compact branching corrallines. The mean relative density in percent of coral coverage on the Waikiki fringing is 0.7 and the mean cover is 0.2 with most of the cover being *Hydrolithon* and *Porolithon,* both encrusting coralline algae. Coelenterate corals, which cover less than one percent of the Waikiki fringing reef, are relatively unimportant in overall fringing reef habitats. On the Waikiki reef, crustose coralline cover make up 38.9 percent of the total coverage. Dead reef, rubble, and sand make up the rest. The ratio of crustose corallines to coral was 200:1 at Waikiki. This value is considered high, perhaps due to phosphates from sewage discharge (Littler, 1971). In unpolluted areas on Oahu, the coral *Porites compressa* was the major coral form between the surface and 30 m.

Both the variety and abundance of micromollusks at all Anini Reef stations (A to D) compare well with the information available for Waikiki Reef on Oahu, and the abundance and variety are higher for both these reefs than those for sediment samples from the fringing reef at Molokai where only 41 species have been recorded with an abundance of only 2 shells per cm^3 of sediment. Reef Station C, as indicated in the Results, is, however, noticeably poor in both number of species and abundance, factors which may be accounted for by the heavy wave action and complex currents in the area.

Effects of Kilauea Sugar Company Wastes on Coastal Waters

No generalized evaluation of the effects of the sugarcane industry on the quality of coastal waters can be made solely on the basis of observations of the Kilauea Sugar Company's land management and milling practices. Evidence is presented that show mill wastewater discharged without treatment to be a major contributor of sediments and bagasse to receiving coastal waters. Sediments rather than water are also shown to harbor most of the nutrients, heavy metals, and chlorinated hydrocarbons in the system. A striking improvement in the aesthetic aspects of the coastal waters off north Kauai occurred after the cessation of operations of the plantation. Some evidence of increase in fish in the area is presented although it is not certain the increase is due to the improvement of quality or improvement of habitat by the disappearance of bagasse. Continued monitoring of the area is expected to clarify this question, as well as to show whether oceanographic factors or waste discharges account for the relative absence of aquatic biota at some of the observation stations.

To evaluate[1] the findings at north Kauai (Kilauea Sugar Company) in terms of the effect of the sugarcane industry per se on coastal water quality several inputs need yet to be supplied, including:

a) The changes in land management practices and in coastal waters and sediments which follow the closing of Kilauea Sugar Company plantation.
b) The effect of changed land management and mill waste treatment on the south coast of Kauai (McBryde Sugar Company).
c) The coastal water quality effects of discharges from undeveloped land, and from land industrial and urban land development.

SOUTH COAST OF KAUAI (McBRYDE SUGAR COMPANY)

Geographical and Environmental Aspects

SELECTION OF STUDY AREA. The McBryde Sugar Company in South Kauai was selected as a situation in which a special opportunity existed to study the relationship between coastal water quality and adjacent land developed and managed for sugarcane culture. Both in situation and in urgency of timing it differed markedly from the situation at Kilauea, where the opportunity was immediate to observe the nature and water quality effects of discontinuance of free discharge of mill wastewater, both in terms of transient responses and of long term equilibria. In the McBryde situation, however, profound changes in land management to control irrigation tailwater and in treatment and reuse of mill wastewater had been instituted in recent years. Moreover, a modest amount of data on the quality of coastal water in the area had been made at about the time changes were initiated. In the interim, any immediate response of the ocean waters or biota to changed land and water management practices had long since occurred. Thus the McBryde plantation provided an excellent place to evaluate the quality of the ocean water and water environment in terms of what the industry was *not* discharging, and so by comparison with findings at Kilauea more clearly define the water quality-

[1] Such an evaluation is therefore deferred until a later chapter and, perhaps, a subsequent progress report.

sugarcane industry relationships.

On the foregoing rationale, the McBryde Sugar Company lands were selected as the study area, but because of budgetary constraints and the relatively slow rate of change to be expected on the south Kauai coast, the experimental aspects of the study were minimal until the summer of 1972. Consequently, the progress report herein presented is concerned more with relevant background information than with experimental results and the evaluations they are expected to make possible.

LOCATION OF STUDY AREA. The general location of the McBryde Sugar Company is indicated in Figure 3.24, which shows the site of the Company's mill and plantation offices. Figure 3.24, which is an index to the field plots of the plantation, shows that company lands front on the south coast of Kauai from Hanapepe Bay on the west to Poipu Road, south of Koloa, on the east, and a shoreline distance of approximately 6.5 miles. The mill site indicated in Figure 3.2 is located in the area designated 5A in Figure 3.24. The plantation covers an area of approximately 22,500 acres, of which 5930 acres are cultivated for sugarcane, some at almost 1000 feet above sea level.

SOILS OF THE PLANTATION AREA. The soils of the sugarcane lands of McBryde Sugar Company are oxisols mostly of the Lihue Series. Poorly pervious soils of the Makaweli Series, characterize the most eastern sector of the plantation.

SOURCES AND MANAGEMENT OF WATER. The McBryde plantation obtains its irrigation water from a number of sources. Surface water is stored behind some 19 dams, the largest of which is Alexander Dam near the headwaters of Wahiawa Stream, an area which receives 160 inches of rain per year. Despite such heavy rainfall there is essentially no sediment in the reservoir, indicating that erosion from land under natural cover in the area is negligible. The dam evidently intercepts most of the water of that area. There are essentially no springs in Wahiawa Valley.

The capacity of the reservoir behind Alexander Dam in 814 million gallons. Part of the water is used as a county water supply, however, enough water to irrigate 1100 acres of cane land is transferred via natural and constructed tunnels for power generation from which it is discharged into irrigation ditches or reservoirs. Several dams are located in Kawaihaka, Nomilo, and Lawai gulches. The combined storage capacity of the dams and a dozen or so smaller reservoirs is two billion gallons.

Pumped water accounts for 60 percent or more of the water used in irrigation. There are two wells in the Kukuiula Valley with a combined capacity of 6 mgd from which water is pumped into reservoirs or irrigation ditches. However, the largest pumping works extracts water from horizontal infiltration tunnels in Hanapepe Valley and delivers it to canefields in an area extending from Hanapepe Valley to Lawai Valley.

Records compiled by the McBryde Sugar Company show that the annual rainfall on the plantation area over a 48-year period, extending back to 1924, has ranged from 23.62 to 60.06 inches, with only 9 years having less than 35 inches and 23 years having more than 45 inches of rainfall. At high elevations, the rainfall is greater but only 250 of the 5930 acres cultivated by the company is unirrigated. In general, December, January, and April are the rainiest months but some irrigation is necessary every month of the year. Table 3.28 summarizes irrigation usage in mgd, and average monthly rainfall

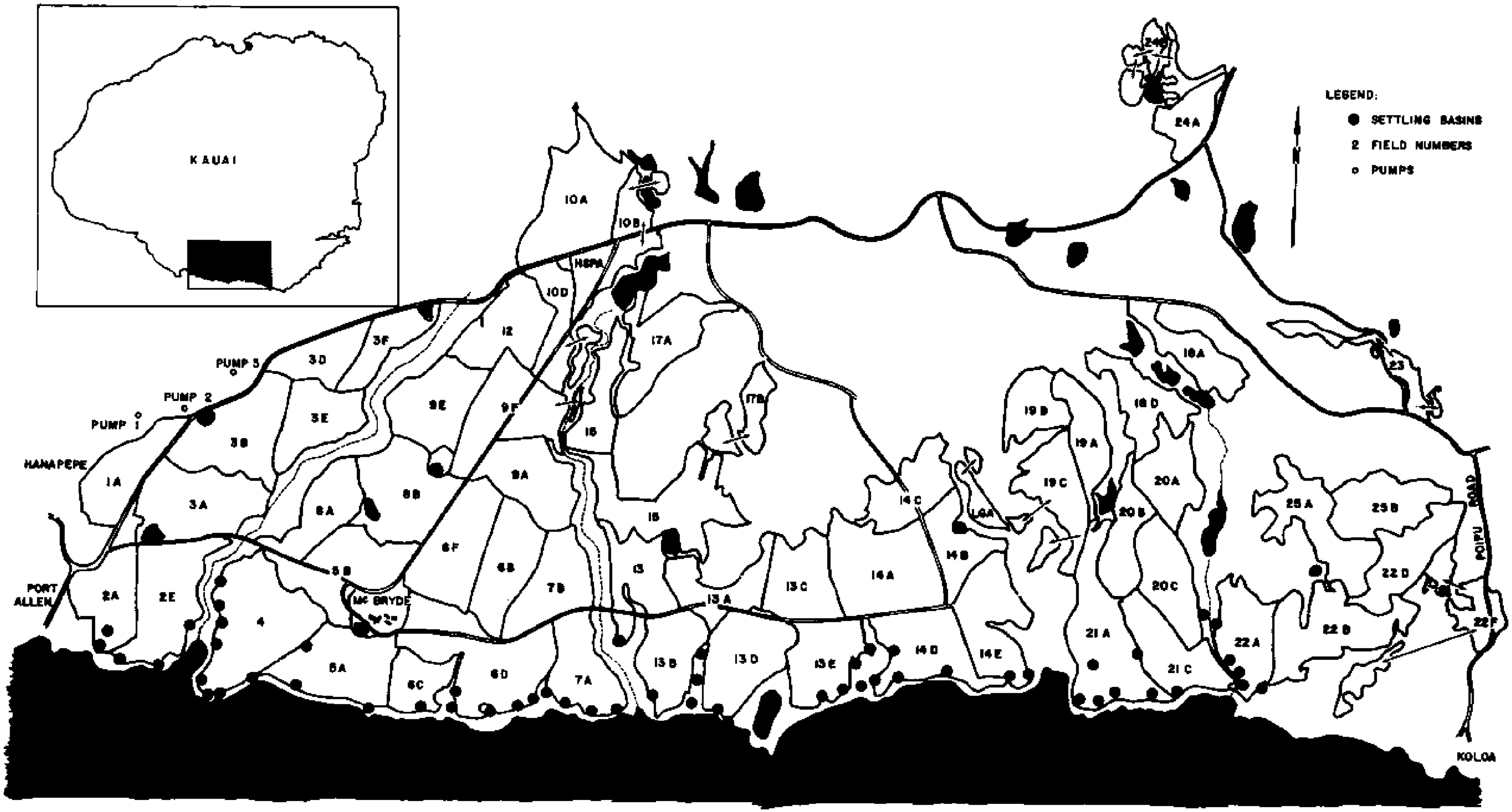


FIGURE 3.24. MAP SHOWING LOCATION OF FIELDS AND TAILWATER RETENTION PONDS, MCBRYDE SUGAR COMPANY, KAUAI.

TABLE 3.28. IRRIGATION REQUIREMENTS AND RAINFALL BY MONTHS, 1971, MCBRYDE SUGAR COMPANY.

MONTH	RAINFALL AVG. AT 5 STATIONS (INCHES)	IRRIGATION USAGE (mgd)
JANUARY	12.65	9.39
FEBRUARY	4.16	25.49
MARCH	9.69	34.41
APRIL	13.77	29.08
MAY	2.71	36.19
JUNE	2.59	44.99
JULY	2.84	47.61
AUGUST	2.73	44.89
SEPTEMBER	4.85	40.58
OCTOBER	4.15	43.42
NOVEMBER	4.84	37.37
DECEMBER	12.55	32.46
TOTAL FOR YEAR	77.55	

at five gaging stations in the plantation area.

In general, the plantation is watershort and entered the summer of 1972 on a drought irrigation schedule.

OCEANOGRAPHIC ASPECTS. Oceanographic aspects of the south coast of Kauai in the region of the McBryde Sugar Company are subject to study in greater detail as the study progresses. Superficially, the coastline is not particularly prepossessing and is apparently little used except by offshore fishermen. Precipitous cliffs characterize the ocean front, with small generally rocky beaches where deep narrow gulches reach the shore. The gross movement of the ocean current is reported to be westward, paralleling the coast, although local fishermen describe an erratically alternating current pattern. In April 1968, the EPA reported (EPA, 1971) movement of the plume from the McBryde outfall westward past Port Allen.

Preliminary observations were made by the Coastal Water Quality project biologists on June 26, 1972 during a survey for the purpose of establishing appropriate monitoring stations for ocean water, sediments, and biota. Observations were made at 8 stations between Koloa landing and Port Allen (Fig. 3.24). Off Koloa landing in 35 feet of water, the bottom was observed to be flat, with sand channels and a veneer of sand. The water was slightly turbid in about the top inch (2 cm). Inshore boulders were covered with coral growth at about 75 percent cover. Fish were numerous but few sea urchins were noted.

Off the eastern point of Kukuiula Harbor in about 30 feet of water the bottom was similar to that at Koloa landing but the water was less clear. Coral cover was less by some 40 to 50 percent and all appeared to be *Pocillopora meandrina*, including some large dead heads. Fish were fairly abundant.

At Lawai Bay observations were made in about 20 feet of water. There the bottom was flat, with very sparse cover, sand pockets, and visible evidence of sand scour. Sea urchins noted were few but included *Tripneustes gratilla* and *Diadema paucispinium*.

In about 20 feet of water off a grassy slope between Lawai and Numila, the bottom was flat. Coral was *Montipora* rather than *Pocillopora meandrina* and *Tripneustes gratilla* was present. At Numila, opposite a cinder cone at 15-foot depth, the bottom was flat with little biota other than algae.

Observations were made from the shoreline to a depth of 20 feet at the old McBryde mill outfall. Here the bottom was characterized by large boulders covered with small coral heads of various species, including many *Pocillopora meandrina*. The water was clear but a heavy cinder-gravel bottom made the area appear quite dark. The standing crop of fish observed was second in abundance only to that off Koloa landing. West of the old outfall, past a sandy beach, the bottom was flat and covered with sand and fine terrigenous silt. At a depth of 20 feet, there was very little coral and few fish or sea urchins.

In the thermal outfall at Port Allen, the water was very turbid for a depth of several feet and distinct thermocline was noted. At the 20-foot depth, the bottom was flat and small lobsters (*Panulurus marginatus*) were present.

From the field observations three sampling stations are under consideration for regular monitoring and a checklist of biota to be monitored and assayed was being prepared at the time of this reporting.

Land Use and Agricultural Practice

SUMMARY OF LAND CLASSIFICATION. Of the 22,578 acres of land under the control of the McBryde Sugar Company, 22,124 are held in fee, some 10 acres are classed as "undivided," and slightly less than 444 acres are leased from others. In turn the Company leases 181 acres of its fee lands and 53.5 acres of its leased land to others for miscellaneous purposes, mostly agricultural. A general breakdown of the acreage dedicated to various purposes is presented in Table 3.29. Values are rounded off to the nearest acre and such smaller items as airstrip, ditch, quarry, cemetary, Wainiha lots, radio facility, powerhouse, county road easement, etc. are lumped together in a single classification identified in the table as "other."

GENERAL STATISTICAL NOTES. With the exception of pineapple lands taken into cultivation during 1962 to 1963, the McBryde Sugar Company has been cultivating the same land since the early 1900's. Table 3.5 (p. 66) shows that in 1969, the productivity of the McBryde lands was about 1.5 times that of the Kilauea Sugar Company lands. Cultural practices have changed in method over the years as improved equipment has become available. Plowing depths have been about 20 inches and cane furrow spacing has ranged from 5 to 5 1/2 feet.

TABLE 3.29. LAND USE, MCBRYDE SUGAR CO., LTD., 1972.

CLASSIFICATION OF LAND	ACREAGE
SUGARCANE	5,931
FOREST	12,969
ROADS	282
RESERVOIRS	271
DITCHES	78
AGRICULTURAL (NOT CANE)	40
PASTURE	92
LEASES	1,934
MARGINAL AND WASTE	421
POWERLINE EASEMENT	74
WOODLAND	45
RESIDENTIAL AND CAMPS	86
INDUSTRIAL	18
FALLOW	253
MUD DUMP	20
OTHER (MISCELLANEOUS)	64
TOTAL	22,578

In recent years the technique has been to rip the soil to a depth of 20 inches, then disc harrow it to break up soil clumps and cane stools.

Planting and reshaping methods have been those described in "Sugarcane Culture Practices." Fertilization methods have undergone some changes since 1968. Prior to that time, applications of N, P, and K on newly planted and ratoon fields was done by hand with dry mixes. In late 1968, this practice was discontinued in favor of injection of fertilizers under the soil surface at the time of planting or ratooning. For a somewhat longer, but unspecified period subsequent applications of nitrogen and phosphorus were applied with irrigation water or by airplanes. However, since 1970, more emphasis has been placed on water application, reserving plane application to the winter months when because of rain there is no regular schedule of irrigation.

IRRIGATION PRACTICES. Like fertilization and cultural techniques, the irrigation systems to decrease man-day requirements and so make more efficient use of water by keeping more of it in the field and miniming the amount that appears as tailwater at the bottom of the field. To facilitate this, line grades have been flattened from 3 to 5 percent to 1 1/2 to 2 percent.

Although furrow irrigation continues as the principal irrigation practice (some 5600 acres being so irrigated in 1972) more effective methods of irrigation are being evaluated. One hundred and eighty acres were irrigated in 1972 by overhead sprinkler systems to evaluate their water conserving and field water retention capabilities, as well as economic aspects. Experimental results with trickling irrigation by the McBryde Sugar Company suggest that such a procedure may well change the technology of sugarcane irrigation in the future. This technique, similar to the "soaker" approach in lawn irrigation, involves small hoses laid between rows and operated at about 10 psi supply water without surface runoff and do not require relocation during the period of use nor salvage for reuse when the crop is harvested.

FERTILIZER USAGE. The methods of applying fertilizers utilized during the past few years, since the time water quality studies discussed in a subsequent section were made, have been summarized in "General Statistical Notes (p. 114). The actual tonnage applied during recent years is summarized in Table 3.30.

TABLE 3.30. LIQUID FERTILIZER USED ON MCBRYDE PLANTATION, 1966 - 1970.

YEAR	NK_1 (TONS)	NK_2 (TONS)	AQUA AMMONIA (TONS)	LK_1 (TONS)	TOTAL (TONS)
1966	--	14.6	571	--	585.6
1967	--	192.8	529	--	721.8
1968	--	936.9	220	--	1156.9
1969	964	--	--	--	964
1970	2629	--	264	--	2893
TOTAL	3593	1144.3	1584	--	6321.3

NOTE: 1 GALLON NK_1 = .87#N AND .87#K_2O
1 GALLON NK_2 = .75#N AND .98#K_2O

WEED CONTROL. The several types and amounts of herbidical chemicals used in sugarcane culture on the McBryde Sugar Company lands during the 6-year period 1965-1970 are summarized in Table 3.31.

PROCESSING CHEMICAL USAGE. Chemicals used in the milling of sugarcane by the McBryde Sugar Company and the typical amounts used each year are summarized in Table 3.32.

Wastewater Management

IRRIGATION TAILWATER. Since the study of the quality of coastal waters in the vicinity of sugar plantations in Hawaii that was reported by the EPA, management practices of the McBryde Sugar Company have greatly altered the potential of irrigation tailwater to affect coastal waters. As noted in a previous section ("Irrigation Practices, p. 115), the line grades have been reduced to maximize retention of water in the fields and experiments are in

TABLE 3.31. HERBICIDES USED ON MCBRYDE PLANTATION, 1965-1970.

HERBICIDE	GALLONS PURCHASED					
	1965	1966	1967	1968	1969	1970
DOW FORMULA 40	55	110	55	385	330	605
ESTERON-WEEDONE 245T	--	165	110	230	55	55
2, 4-D AMINE	--	50	--	--	--	--
TOTAL	55	325	165	615	385	660

HERBICIDE	POUNDS PURCHASED					
	1965	1966	1967	1968	1969	1970
DOW-DOWPON	25,000	32,000	32,000	31,550	20,000	36,500
DU PONT, KARMEX DCMU	24,000	28,000	22,000	28,000	22,000	39,600
TELVAR CMU	--	950	1,350	--	--	--
GEIGY-ATRAZINE	16,000	10,250	13,000	10,000	10,000	8,000
SODIUM TCA 94	--	1,000	--	--	--	--
GEIGY AMETRYNE	2,250	2,000	6,000	6,000	6,000	8,000
SA-88 HERBICIDES	--	--	900	1,350	--	--
CALSUD A SURFACTANTS	4,800	9,120	6,240	9,990	9,600	17,280
TOTAL	72,050	83,320	81,490	86,890	67,600	109,380

TABLE 3.32. CHEMICALS USED IN MILLING PROCESS, MCBRYDE SUGAR COMPANY.

CHEMICAL	NATURE OF CHEMICAL	USE	QUANTITY (lbs/yr)
COPPER SULFATE	$CuSO_4$	ANTIFOAM AGENT	350
KEROSENE	PETROLEUM DERIVATIVE	IN-ROCK GAP SOLUTION	1,000
CAUSTIC SODA	NaOH	CLEANING AGENT	38,000
FERMENTED MOLASSES	DILUTE FINAL MOLASSES	CLEANING AGENT	20,000
POTASSIUM DICHROMATE	$K_2Cr_2O_7$	CORROSION INHIBITOR IN CRYSTALLIZER COOLING COILS	150
NALCO 47S	(SEE FOOTNOTE[1])	SOFTENING SCALE, IN BOILER WATER	5,500
NALCO 75	(SEE FOOTNOTE[2])	CORROSION INHIBITOR, IN BOILER WATER	1,610

[1] COMBINATION OF ALKALIES, ORTHOPHOSPHATE AND COLORLESS STARCH DERIVATIVES.

[2] PRIMARILY A BLEND OF ORGANIC SALTS, THE MOTOR COMPONENT BEING AN ALKALI SOLUBLE DERIVATIVE OF LIQUIN CONTAINING CARBOXYL AND PHEUOLIC HYDROXYL AS THE PRIMARY FUNCTIONAL GROUPS.

progress to develop irrigation techniques which will likewise eliminate or reduce irrigation tailwater. Nevertheless, furrow irrigation continues to be the predominant method and it is to this method that the Sugar Company had directed its major attention in the matter of runoff control.

All tail water from irrigation along the coastline on the McBryde plantation is intercepted and retained in ponds. The location of some 50 such ponds is shown in Figure 3.24. Individual ponds are located at the lowest end of the furrow system in each area. Ponds are constructed by a bulldozer and are of random size, mostly small. They serve as settling and evaporation ponds, with such loss by infiltration to the underlying soil formations as may occur in each situation. Normally there is no overflow from the ponds but flood flows which exceed their reservoir capacity may cause overflow. On such occasions, the settling effect of the pond may be quite small and spills of sediment to the ocean may occur. However, this is not a frequent occurrence, possibly a total of 10 times per year from one pond or another.

The same floods which lead to overflow of settling ponds carry large amounts of suspended matter from non-cane lands. This is reported to be evident along the entire south Kauai coastline of the region during storms. Thus it is evident that the effect of irrigation tail water on coastal water quality, in so far as sediments are concerned, is essentially negligible. Whether or not the occasional spill is likely to carry any agricultural chemical in any significant amount is a matter to be evaluated in a later experimental phase of the study reported here.

Periodically (possibly once per year) sediment is removed from the settling ponds and returned to the fields at the nearest convenient location. One or two truckloads of sediment is reported to be a typical cleanout yield.

MILL WASTEWATER. There is no direct discharge of wastes from the McBryde milling operation to the ocean. Effluents from the plant are discharged into a hydroseparator near the mill site. There the solids are removed and the effluent decants into a mill reservoir. Additional sedimentation of solids occurs in the reservoir because its longer detention time. The reservoir water is then recycled back to the irrigation water. At the end of each milling season the year's accumulation of solids in the mill reservoir is allowed to dry. It is then picked up with a clamshell and hauled by dump truck to the mud dump noted in Table 3.29 as comprising 20 acres of land. Here a buildup of land occurs with time and the dump area is planted with seed cane or crab cane.

The hydroseparator was originally installed in 1952. When malfunctions of the facility occurred the mill washwater was bypassed down a straight ditch to the ocean. In 1967, the Company began logging the frequency of malfunctions. In 1967 and 1968 these occurrences were 82 and 85, respectively. In 1969 the number declined to 26. Thereafter, in 1970 and 1971, there were no occasions when mill wastewater went directly into the ocean. When the hydroseparator malfunctioned, the mill wastewater was discharged directly into the mill reservoir. The reservoir effluent was returned to the irrigation water and the mud was removed on weekends as necessary.

Malfunctions of the hydroseparator were reduced in 1970 through lightening the load on the equipment by diverting the mud press from the vacuum filters onto the leafy trash carrier for land disposal. In addition, the horsepower on the hydroseparator underflow pump motor was increased, thus reducing the frequency of underflow mud chokes.

Previous Studies

NATURE OF STUDIES. During November 1966 through September 1968, two studies were made of sugar mill discharges which produced some data relevant to the McBryde plantation study area. One was made by Kennedy Engineers for the Hawaiian Sugar Planters' Association; the other by the federal agency now known as the Environmental Protection Agency (EPA). The results of these two studies, although providing but limited information on the quality of the coastal water environment, do yield some information on conditions prior to the installation of irrigation tail water ponds and the elimination of hydroseparator by-pass to the ocean. Such information will be useful in interpreting the findings of the present study and in evaluating the relationship of sugarcane culture to coastal water quality control.

THE KENNEDY REPORT. As part of a study of 21 sugar mills in Hawaii, Kennedy Engineers observed some quality parameters of the receiving waters south of the McBryde Sugar Company mill during both a milling and non-milling period. Sampling stations were established along arcs of radii 1/4, 1/2, and one mile centered on a shore station at the point of mill discharge (Fig. 3.25).

Observations were first made on December 30, 1966 during a period when no harvesting or milling of sugarcane was in progress. Later observations were made on March 8, 1967 when the mill was in operation.

In December, the clarity of the coastal water was relatively good, with secchi disc readings ranging from 25 feet at Station B to 40 feet at Station C. Dissolved oxygen was in excess of saturation at all stations. Suspended solids at the surface ranged from 6.6 mg/l at Station C to 11 mg/l at Station B. BOD_5 organisms occurred at Station B (surface) with an MPN of 40. At Station F the MPN was <2/100 ml.

A period of wet weather prevailed prior to the March study but only two small streams of discolored water entered the ocean. These were observed at Stations A and G.

During the March study, Secchi disc readings ranged from 14 feet at Stations D and G to 49 feet at Stations F and I. Dissolved oxygen was equal to a greater than saturation, but suspended solids increased slightly to 14.0 mg/l at Stations A, D, and E. Coliform MPN and BOD_5 dropped to 2/100 ml and 0.2 mg/l, respectively.

On the basis of these parameters in comparison with conditions observed before and after at Kilauea Sugar Company (Section II), the Kennedy study shows little, if any, effect of mill wastes on the coastal water.

THE EPA REPORT (1971). During the 1966-67 period when EPA was engaged in studies of sugar mill discharges the McBryde mill was studied in detail because of its unique hydroseparator treatment of mill wastewater. However, significant offshore studies were not made because of the lack of an available control area. Olokele Mill was used as an offshore study site but when it was closed because of weather conditions, one survey was made at McBryde.

Results of analysis of influent and mill wastewaters and of the hydroseparator and mill reservoir system are summarized in Table 3.33.

The results reported in Table 3.33 show a solids content of mill wash-

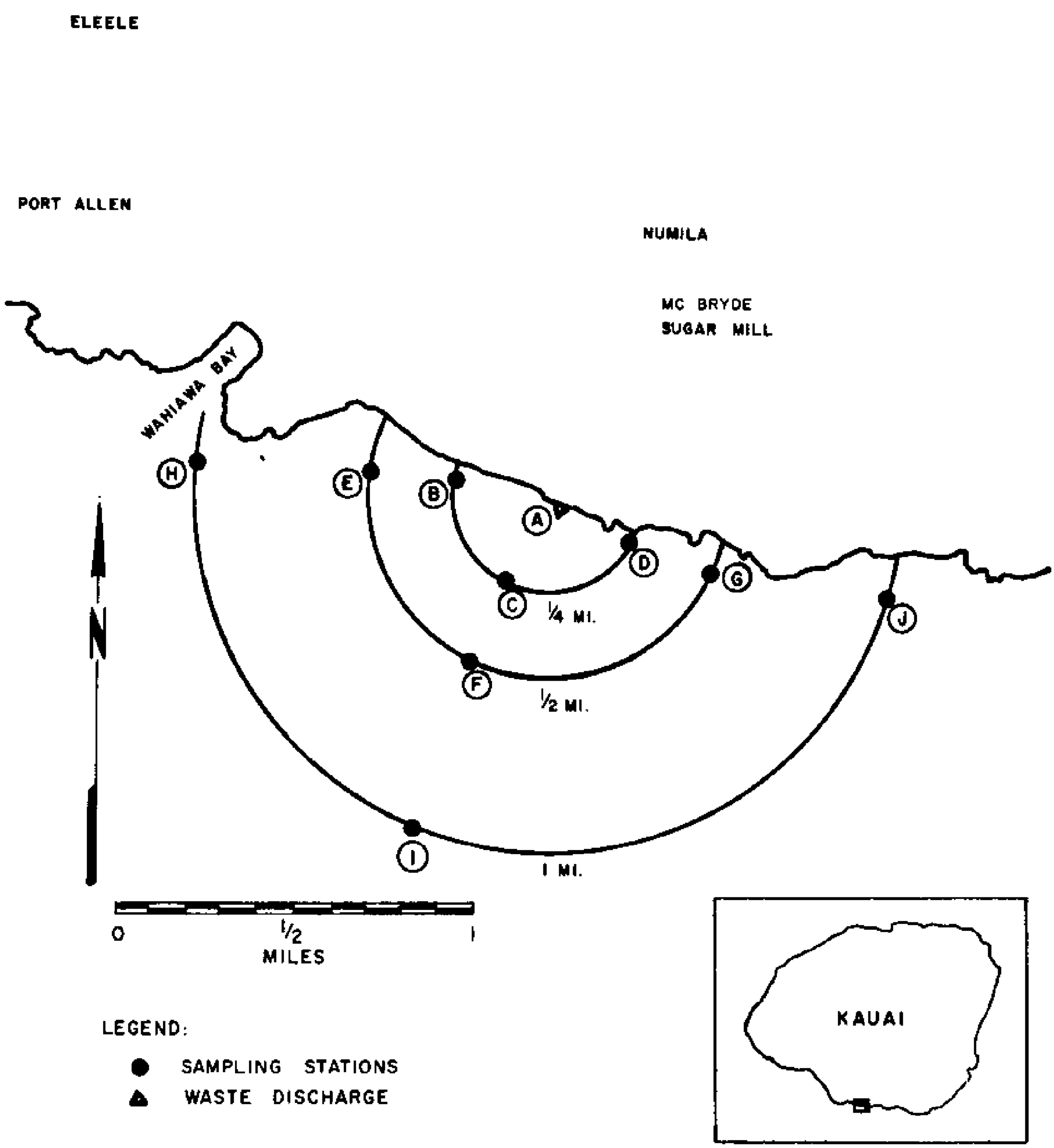


FIGURE 3.25. LOCATION OF SAMPLING STATIONS FOR KENNEDY ENGINEERING STUDY OF MCBRYDE DISCHARGE WASTE.

TABLE 3.33. QUALITY OF MILL WASTEWATER, MCBRYDE SUGAR COMPANY.

SOURCE OF SAMPLE	MPN COLIFORMS		SOLIDS (mg/l)			BOD	COD	TOC	TOTAL N	TOTAL P
	TOTAL	FECAL	TOTAL	SUS-PENDED	SETTLE-ABLE					
INFLUENT	905	116	250	13	8	8	6	4	0.4	0.03
CONDENSER	475	126	230	20	10	14	42	13	0.6	0.15
WASHWATER	$4.85x10^6$	4880	12,000	10,700	10,000	800	2300	710	44.0	13.00
HYDROSEPARA-TOR EFFLUENT	735.000	2010	2,650	2,000	1,160	655	900	330	9.1	5.80
MILL RESERV. EFFLUENT	338,000	1630	950	530	170	500	600	190	4.8	1.50

water more than 3 times that observed at the Kilauea Sugar Company mill in 1971 (Table 3.13). In fact the hydroseparator effluent compared favorably with the total mill waste at Kilauea in solids content. Nevertheless, Table 3.33 shows both the hydroseparator and the mill reservoir to be effective treatment systems.

Total solids of the influent water averaged 250 mg/l which increased to 12,000 mg/l during the cane washing. A major part of the solids was settleable (10,500 mg/l) by sedimentation to effect a 92-percent removal of total solids. The BOD_5 and COD of the incoming water was quite low, 8 and 6 mg/l, respectively, but were increased to 800 mg/l and 2300 mg/l, respectively. Treatment of the waste by sedimentation gave a BOD_5 reduction of 37.5 percent and COD reduction of 73.9 percent. The fraction of organic compounds that is readily biodegradable is contained in the soluble portion of the waste contained 89 percent of the total nitrogen and 88.5 percent of the total phosphorus. Total nitrogen and total phosphorus were low in the incoming water, 0.4 mg/l and 0.03 mg/l, respectively, but they were increased to 44 mg/l and 13 mg/l, respectively, during the milling process. The final effluent from the treatment process contained fairly high total solids, 950 mg/l of which 55 percent was suspended. The organic loading was high with a BOD_5 of 500 and COD of 600 mg/l, but the fertilizer value of nitrogen and phosphorus are low, with total nitrogen of 4.8 mg/l and total phosphorus of 1.5 mg/l.

The EPA study included tailwater analyses as well as that of the mill wastewater. Samples taken from 5 of the field areas shown in Figure 3.24 were analyzed for various components. The results are summarized in Table 3.34. Total solids are shown in the table to range from 92 to 3390 mg/l, COD from <1 to 347 mg/l, total nitrogen from 0.5 to 34 mg/l, total phosphorus from 0.17 to 25 mg/l, and coliforms from 500 to 250,000 per 100 ml. However, all of the high values noted appeared in Field 5B. Of the 5 fields examined, only 5B showed much evidence of a serious pickup of material from the field, although Field 12 was somewhat high in solids. The effect of any of the other fields on coastal water quality were insignificant in terms of

TABLE 3.34. QUALITY OF IRRIGATION TAILWATER, 1966-67 (EPA, 1971).

PARAMETERS ANALYZED	FIELD NUMBER 13A	8B	12	9A	5B
T.S. (mg/l)	574	204	900	92	3390
S.S (mg/l)	248	112	584	40	3230
SETTLEABLE S. (mg/l)	174	106	288	34	2280
COD (mg/l)	37	14	55	<1	347
TOC (mg/l)	15	5	22	5	91
NH_3-N (mg/l)	0.1	0.01	0.49	0.04	5.3
NO_2-N (mg/l)	0.065	0.01	0.016	0.005	0.002
NO_3-N (mg/l)	0.165	0.438	0.29	0.006	0.29
KJELDAHL N (mg/l)	0.5	0.7	13.9	1.0	34
T-P (mg/l)	--	0.37	1.7	0.17	251
ORTHO-P (mg/l)	0.05	0.092	0.01	0.008	0.043
As (mg/l)	--	<10	<10	<10	<30
pH	7.3	7.2	6.9	6.9	6.6
TOTAL COLIFORM/100 ml	--	13,000	500	500	250,000
FECAL COLIFORM/100 ml	--	1,300	70	70	7,000
DATE PLANTED	05/66	07/67	11/67	08/67	03/66
DATE OF SAMPLE	11/01/67	03/27/68	03/27/68	03/27/68	03/28/68

the parameters reported.

EPA data on offshore water quality from the McBryde site are limited to turbidity studies. These were made by a transmissometer measuring light transmittance at various depths. According to the EPA report (1971) a mill discharge entering the sea was observed on April 27, 1968. The "discharge was not true washwater, but cooling water which contained significant amounts of material that had been scoured from the (mill) reservoir." The discharge formed a reddish-brown streak with a clarity of 0 to 8 feet and was visible for about 2 1/2 miles from the actual discharge point.

No coliform density studies at the McBryde site were reported by EPA. Total coliform densities reported from other mills, however, ranged from 5000 to 10,000/100 ml in the discharge plume, in contrast with <100/100 ml in control areas. These results differed significantly from those obtained in the Kennedy study of 1967 which reported average maximum coliform densities of 6 plants as 126/100 ml.

From a consideration of these two past studies, it is clearly evident that the parameters of water quality used in 1967-68 are inadequate for 1972. Both the intensity of concern for aesthetic values and the range of quality factors of concern have increased markedly in the interval. Nevertheless, data from past studies are important background information for evaluating current field and laboratory observations being made as part of the study reported.

Field and Laboratory Observations

The preceding sections review most of the data obtained by field observations in published reports and information furnished by the McBryde Sugar Company. A field sampling and laboratory analysis program has, however, been initiated. The mill reservoir pond located in Field 5A (Fig. 3.24) is used as a sampling point for treated mill wastes. The settling pond in Field 14D is used to collect irrigation tail water samples. Three offshore stations have been adopted for initial observation of marine sediments and biota and others will be added. Preliminary data have been obtained from samples at these stations but as of this writing (June 1972) they are insufficient in scope to permit any meaningful evaluations and hence are not reported at this time.

OTHER SITUATIONS REPORTED

EPA Studies

SCOPE OF STUDIES. The EPA report, discussed in relation to the McBryde Sugar Company in "The EPA Report" (p. 119), also included offshore surveys of three of the 26 active sugar mills in Hawaii. These included the Honokaa Mill on the northeast (Hamakua) coast of the island of Hawaii; the Pioneer Mill on the west-southwest coast of Maui; and the Olokele Mill west of the McBryde plantation on the south coast of Kauai. Mill surveys were made at the Honokaa and Pioneer Mills, as well as at the McBryde Mill.

In addition, the EPA report included a comparative study of the quality of runoff from a sugarcane field and an undeveloped area in the Wahiawa area of Oahu.

OFFSHORE STUDIES. The findings of the offshore studies are discussed in detail in the EPA report. In general, visible plumes were produced by mill discharges which involved a loss in clarity of the water in a pattern related to the oceangraphic characteristics of the discharge site. In cases where waste foliage and bagasse were discharged, floating trash typically formed into windrows near the outer edge of the turbid water zones and extended long distances along the coast.

Bacterial densities were directly related to the proximity to the mill outfall and location within the plume, decreasing precipitously beyond the outer edge of the plume. At the Honokaa Mill, for example, the average coliform density exceeded 10,000/100 ml over 90 acres of surface adjacent to the mill outfall. This diminished to 200/100 ml in a northeasterly direction and extend a maximum distance of one mile from the outfall. At the Pioneer Mill densities as high as 5000/100 ml were observed at a distance of approximately 2 miles from the outfall, and some 250 acres exceeded the 1000/100 ml often suggested as limiting for water contact sports.

The effects of phosphorus and nitrogen described in the report indicated that nutrient discharge was of little consequence. Temperature effects were minimal, and only minor depressions in salinity occurred. Dissolved oxygen was not seriously impaired.

Bottom conditions reported included extensive sludge banks and retarded coral growth extending 3/4 of a mile on both sides of the outfall of Honokaa Mill. Similar findings were reported at the Pioneer and Olokele Mill outfalls. All three sites showed increases in sponges and benthic algae.

MILL WASTE SURVEYS. Mill waste surveys showed increased values in solids concentration, BOD, COD, TOC, N and P, and coliform organisms. These increases accounted for the turbid discharge plume, and coliform increases observed in offshore surveys. They also contributed the floating trash and sludge deposits interpreted as deleterious to coral growth and, perhaps, enhanced the environmental conditions suited to sponge and algal replacement of coral.

COMPARATIVE RUNOFF STUDIES. To evaluate the effect of the sugarcane industry on coastal water quality factors discharged to the ocean from undeveloped land under uncontrolled natural conditions, the EPA runoff study was designed to obtain comparative data on a relatively small scale. Because of the importance of such comparative data to the objectives of the Coastal Water Quality study, the EPA study is outlined here in some detail.

Figure 3.26, taken directly from the EPA report, shows the location of the study areas. The sugarcane cultured area includes 0.55 square miles of canefield of the Waialua Agricultural Company, plus 0.24 square miles in service roads, gulches, and irrigation flumes. The undeveloped land comprises 0.97 square miles.

Automatic sampling and monitoring equipment were installed in November 1, 1967 and operated through 1968. A single storm was monitored in February 1969 to observe relative amounts of solids picked up from the two areas. Tables 3.35 and 3.36, condensed from the EPA report summarize the results of those two study periods.

Findings reported by the EPA led to the observation that:

a) The undeveloped land could retain 90 percent of a 4-inch/24 hour rain if there was no antecedent rainfall, whereas more than 80 percent appeared as runoff if rainfall had previously occurred.

b) The canefield could retain over 80 percent of a 3.5-inch/12-hour rain.

c) Maximum and minimum values of concentrations of nitrogen and phosphorus were found to be similar to those from mill wastes.

From Table 3.35 it is evident that much of the solids discharged from undeveloped lands is dead vegetation as the suspended solids vastly exceeded the settleable solids. By subtraction, a much narrower range of dissolved solids (46 to 190 mg/l) appears to have occurred.

When significant runoff ccurred, as summarized in Table 3.36 the sugarcane land at peak discharges was between 4 and 5 times that from undeveloped land. The ratio of settleable to suspended solids is variable, although at peak flow from the sugarcane land (1400 hours), the percentage of sediment was exceptionally high.

In all canefield samples, the suspended solids were more than 50 percent settleable material, whereas 3 of the 5 samples from undeveloped land had settleable fractions less than 50 percent of the suspended solids value. A most significant finding reported by EPA is that although the discharge from the undeveloped land was some 8 times as great as from the sugarcane land, the discharge of suspended solids was only 1.5 times as great on a unit acre basis.

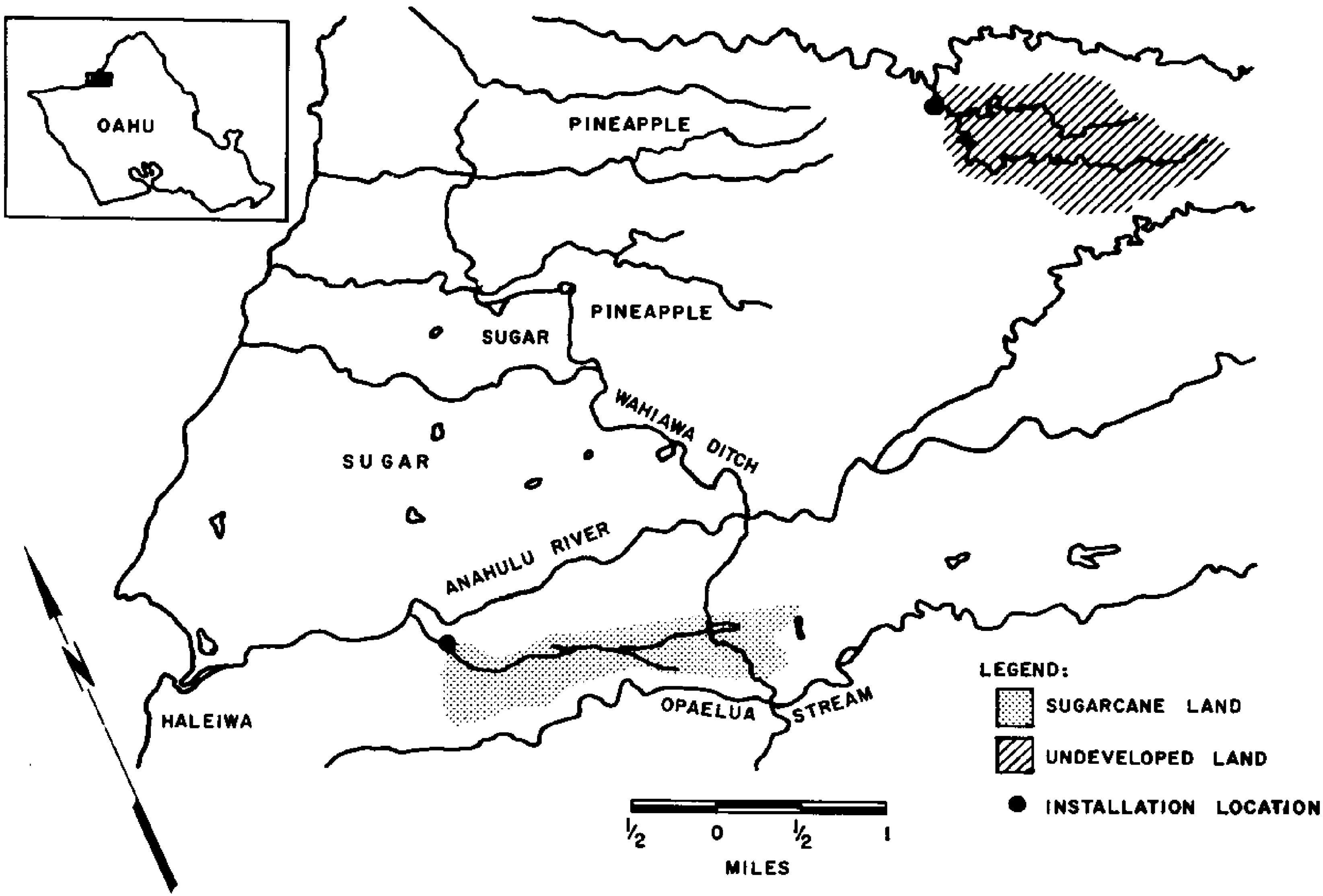


FIGURE 3.26. MAP OF UNDEVELOPED LAND AND SUGARCANE LAND USED IN COMPARATIVE RUNOFF STUDY (FROM EPA, 1971).

TABLE 3.35. ANALYTICAL RESULTS OF THE EPA RUNOFF STUDY (EPA, 1971).

QUALITY FACTOR (mg/l)*	UNDEVELOPED LAND (RANGE OF VALUES)	SUGARCANE LAND (RANGE OF VALUES)
TOTAL SOLIDS	56 - 570	--
SUSPENDED SOLIDS	10 - 240	--
SETTLEABLE SOLIDS	<1 - 140	--
COD	20 - 153	160 - 253
TOC	5 - 71	64 - 116
AMMONIA	<1 - 0.4	<0.1
KJELDAHL-N	0.3 - 4.1	1.2 - 2.6
NO_2-N	<0.05 - 0.08	0.02 - 0.16
NO_3-N	0.04 - 0.92	0.16 - 0.33
PO_4-P	0.003 - 0.08	0.025 - 0.07
TOTAL-P	0.02 - 1.68	1.9 - 3.5
ARSENIC (g/l)	<10	<10
pH (UNITS)	5.6 - 7.1	6.7 - 8.1

* UNLESS OTHERWISE NOTED.

TABLE 3.36. SOLIDS IN RUNOFF IN THE EPA STUDY (EPA, 1971).

TIME OF OBSERVATION (HOURS)	DISCHARGE (cfs)	SUSPENDED SOLIDS (mg/l)	SETTLEABLE SOLIDS (mg/l)
UNDEVELOPED LAND			
1310	185	234	81
1410	380	575	469
1510	870	552	328
1610	490	121	48
1710	185	55	24
SUGARCANE LAND			
1200	10	1580	1024
1230	10	1730	1022
1300	11	1800	1196
1330	22	1140	604
1400	140	2640	2025
1430	80	2470	1350
1500	90	2560	1540
1530	60	2300	1196
1600	40	2640	1412
1630	20	--	--

NOTE: TOTAL DISCHARGE UNDEVELOPED LAND: 9.7×10^6 cu. ft.
TOTAL DISCHARGE CANEFIELD LAND: 0.87×10^6 cu. ft.

In terms of the study of coastal water quality changes resulting from sugarcane culture, the relationships observed in the EPA runoff study will be useful in evaluating the potential contributions of irrigation tailwater and field flood runoff (Wastes A and B, Fig. 3.1) and in comparing these with runoff from undeveloped land such as is under study at Kahana Bay (Chapter 2, p. 13) when the volume of accumulated data is adequate to support valid comparisons.

Study of Hamakua Coast (Grigg, 1972)

NATURE OF STUDY. With the support of C. Brewer and Company, Ltd, and Theo H. Davies and Co., Ltd., a study was made by Richard W. Grigg and reported in 1972. In this study stations were selected offshore from four sugar mills on the Hamakua Coast, Hawaii for the purpose of evaluating the ecological effects of sugar mill waste discharges. The study area included stations at varying distances from the Pepeekeo, Hakalau, Ookala, and Honokaa Mills. A station off Kolekole Stream was monitored to assess the effects of sediments from natural runoff in comparison with those from active mill operations. Surveys off Papaaloa Mill, which closed down in 1966, were included to identify, if possible, any recovery of environmental quality.

FINDINGS REPORTED. From what appears to have been a well organized and objective survey which the author describes in detail in his report, the following conclusions were presented:

a) "No significant changes in temperature, salinity, or oxygen concentration were detected in the receiving waters off the sugar mills. There is no evidence that eutrophication has occurred in the receiving waters off the Hamakua Coast.

b) "Significant deposits of sediments and bagasse exist in the immediate vicinity off the sugar mills at Pepeekeo, Hakalau, Ookala, and Honokaa. These deposits are quite localized; limited for the most part to 1/4 mile on either side of the mills. At depths greater than 50 feet, sediments deposits off Kolekole Stream, due to natural runoff, appear to be greater than deposits off the mills. At the 1,100-foot depth off Pepeekeo mill, fragments of trash are present on the bottom but no significant deposits were observed. Strong bottom currents appear to transport and disperse the cane wastes.

c) "Where sediments have accumulated, intertidal organisms, coral, and other benthic invertebrates have been covered. In the immediate vicinity of the mills, on rock outcrops, coral cover and diversity are reduced considerably. Normal reefs are present within one mile of all mills.

d) "Observations off Papaaloa Mill indicate that recovery of coral and associated organisms in shallow water (<40 feet) appears to begin soon after the mills cease discharging sediments. Observations in deeper water suggest that effects there are not irreversible but that recovery requires more time. *P. meandrina* appears to be particularly sensitive to sedimentation. The pattern of distribution and abundance of this species may be a good indicator of the degree to which an area is polluted by sugar mill wastes.

e) "Changes in both species and abundance of nearshore fishes have been observed off sugar mills. Fish catches off the sugar mills were about one-third those off control stations. Although some species have increased in the immediate vicinity off the mills (Omilu, ulua, papio, Akule, O'io, Awaawa and snappers), others have declined (Kole, Kupipi, Menpachi, Kumu and Aholehole). Analysis of stomach contents of fishes collected at all stations revealed that several appear to be partially utilizing bagasse as a food source in the vicinity of the mills. Interviews with local fishermen suggest that long-term changes have occurred. Offshore fishing for pelagic species primarily aku, has steadily declined since World War II. The decline in aku landings may well be due to a combination of mill wastes and overfishing, however, all fishermen agree that the major changes occurred shortly after mechanical harvesting began. Floating mats of trash and bagasse interfere with fishing operations along the entire Hamakua Coast (30 miles) extending seaward for several miles."

As the monitoring program of the Coastal Water Quality project reported here obtains more data from the north and south coasts of Kauai and from Kahana Bay and other undeveloped areas, the findings of the Hamakua Coast Study (Grigg, 1972) will be increasingly useful in the overall evaluation of the relation of the sugarcane industry to coastal water quality.

SUMMARY OF PROGRESS: SUGARCANE CULTURE VS WATER QUALITY

Significant progress was made during 1971-72 toward evaluating the effects of sugarcane culture and milling on the quality of coastal waters and coastal water environments. Some of these are summarized in "Effects of Kilauea Sugar Company Wastes on Coastal Waters" (p. 110) in relation to the findings at Kilauea Sugar Company. Others are suggested in "South Coast of Kauai" (p. 110), which identifies the potential of the McBryde Sugar Company's operations to generate water quality factors of the type detailed in Table 3.1 (p. 43), and the ability of the Company's land and wastewater management procedures to prevent these factors from reaching and affecting coastal waters. Findings of the EPA and others lead to conclusions partially summarized in "Previous Studies" (p. 119) and "Other Situations Reported" (p. 123). Aspects of the study needed to permit a well-documented evaluation of the relation of land development for sugarcane culture and the quality of coastal water, sediments, and biota are highlighted throughout the discussions.

To recapitulate the most significant of these findings and the data yet needed for meaningful evaluations, Table 3.37 is presented.

TABLE 3.37. SUMMARY OF PROGRESS: SUGARCANE STUDIES.

PRINCIPAL PRELIMINARY FINDINGS	
1.	UNTREATED MILL WASTE IS THE MAJOR CONTRIBUTOR OF WASTES FROM THE SUGARCANE INDUSTRY, CARRYING COLIFORMS, SEDIMENTS, LEAFTRASH, AND BAGASSE TO COASTAL WATERS.
2.	MILL WASTES ARE THE PRINCIPAL SOURCE OF VISIBLE PLUMES AND DEBRIS.
3.	SEDIMENTS RATHER THAN WATER HARBOR MOST OF THE NUTRIENTS, HEAVY METALS, AND CHLORINATED HYDROCARBONS IN THE WASTE AND IN THE OCEAN.
4.	DDT WAS PRESENT AT EXTREMELY LOW LEVELS IN MILL WASTE SOLIDS AND IN OCEAN SEDIMENTS EVEN THOUGH IT IS NOT USED IN THE SUGARCANE CULTURE.
5.	THE MOST COMMON HERBICIDES USED IN SUGARCANE CULTURE--ATRAZINE AND AMETRYNE--DO NOT APPEAR, FROM PRELIMINARY SAMPLES, TO BE A FACTOR IN WATER QUALITY.
6.	IRRIGATION TAILWATER MAY CARRY SUSPENDED SOLIDS IN CONCENTRATIONS 5 TIMES THAT OF RUNOFF FROM UNDEVELOPED LAND.
7.	WITH TAILWATER PONDING AND GOOD IRRIGATION PRACTICE, TAILWATER DISCHARGE TO THE OCEAN IS ONLY AN OCCASIONAL FLOOD WATER OVERFLOW PHENOMENON.
8.	SETTLEABLE SOLIDS IN FLOOD RUNOFF FROM EPA EXPERIMENTAL PLOTS UNDER SUGARCANE CULTURE EXCEEDED THAT FROM NATURAL COVER BY A FACTOR OF ONLY 1.5 ALTHOUGH THE DISCHARGE FROM UNDEVELOPED LAND WAS 8 TIMES AS GREAT.
9.	IN EPA STUDIES CONCENTRATION OF NUTRIENTS FROM SUGARCANE LAND WAS ABOUT THE SAME AS THAT FROM MILL WASTES.
10.	A STRIKING IMPROVEMENT IN THE AESTHETIC ASPECTS OF THE COASTAL WATERS OFF NORTH KAUAI OCCURRED AFTER THE CESSATION OF MILL WASTE DISCHARGES.
11.	AESTHETICS, COLIFORM ORGANISMS, AND SEDIMENTS ARE EVIDENTLY THE MAJOR PROBLEMS OF MILL WASTE DISCHARGE.
12.	FACTORS CITED IN ITEM 11 CAN BE AVOIDED BY TREATMENT AND MANAGEMENT TECHNIQUES SUCH AS USED BY THE MCBRYDE SUGAR COMPANY.
DATA TO BE COLLECTED	
1.	CHANGE IN QUALITY OF DISCHARGES FROM KILAUEA SUGAR COMPANY LANDS, AS SORGHUM CULTURE TAKES OVER.
2.	FIELD LIFE OF HERBICIDES USED.
3.	CHANGE IN RUNOFF CHARACTERISTICS OF SOIL UNDER OVERHEAD OR DRIP IRRIGATION AS THEY REPLACE FURROW IRRIGATION.
4.	EXTENT TO WHICH HEAVY METALS, ESPECIALLY LEAD AND CADMIUM, MAY BE UBIQUITOUS IN HAWAIIAN SOILS AND SEDIMENTS.
5.	QUALITY OF IRRIGATION TAILWATER AS IT ENTERS INTERCEPTING PONDS ON MCBRYDE PLANTATION.
6.	CHANGES IN BIOTA WITH TIME AT NORTH KAUAI SAMPLING STATIONS.
7.	NATURE OF BIOTA IN COASTAL WATER AND SEDIMENTS AT SOUTH KAUAI.
8.	CHANGES IN COLIFORM DENSITY, TURBIDITY, AND BOTTOM CONDITIONS OFF MCBRYDE DISCHARGE SINCE THE EPA STUDY IN 1967-68.
9.	THE EXTENT TO WHICH DISCHARGES FROM NATURAL UNDEVELOPED LAND AFFECTS BIOTA NEAR THE OUTFALL POINT.

chapter 4

Coastal Water Quality and Urban Land Development

INTRODUCTION

Concepts and Rationale

THE URBAN SITUATION. Of the several situations cited in Chapter 1, land development for urban use is by far the most critical in terms of both consequences to water quality and degree of public concern. In fact, the history of water pollution control is the history of man's attempts to overcome one of the most obvious public health, aesthetic, and environmental effects of his crowding together with his fellows in concentrations which exceed the biological limit of the soil. The story of urbanization as a social and cultural phenomenon is in itself a fascinating one. It is, however, beyond the scope of this report. Suffice it to say here that at one point in history, the survival of cities hung in the balance because of the health problem associated with water pollution. Effective solutions to that problem made possible the higher density and vastly expanded urban centers of today and so permitted the development of another crisis which many now believe again threatens the continued existence of urban man.

In terms of coastal water quality and coastal water environments, the current crisis involves but little by way immediate direct threat by any specific waterborne disease. Its most prominent features are an impoverishment of the quality of urban life: a loss of shoreline and of coastal waters as recreational facilities, albeit sometimes for reasons of hazard to health, the creation of aesthetic nuisance and causes of economic loss, and, most serious of all, the possibility, if not indeed the prospect, of a disaster to man himself.

The scale of the urban situation in general is suggested by the statistics cited in Chapter 1 which reports that more than half of all Americans live within 50 miles of the ocean and more than 80 percent live in urban centers. In Hawaii, both geography and occupational opportunity destine people to live along the coastline; and more than 83 percent of them dwell in the state's urban centers.

Several factors characterize the urban situation in terms of the relationship between land development and the quality of coastal waters. Most obvious of these is the concentration of large amounts of wastewater and their discharge into the ocean in but a few locations. Moreover, such discharges most commonly are directed into bays and estuaries because it is in such locales that cities logically develop. The offensive nature of decomposing sewage and the obvious effects of depleted oxygen resources on aquatic biota have caused this human waste aspect of urban land development to receive the greatest public attention. Less obvious and less clearly understood are the factors associated with the origin of urban communities and the daily occupancy of land by human beings. In preparing land and in protecting structures, marshes are drained, natural channels are straightened and lined with concrete, hillside slopes are steepened by cuts relatively large areas are stripped of vegetation, ship channels are dredged, revetments extended into the ocean, and water circulation is interrupted by marines and shoreline facilities. Occupancy of land involves constructing roofs and walls, paving roads and parking areas, and compacting soil surfaces. These activities decrease the fraction of rainfall infiltrating the earth's surface and increase the amount and rate of runoff. Fertilization of lawns and gardens, pest control by househoulders or commercial operators, wear of automobile tires on pavements, and general refuse add quality factors of uncertain nature and in undetermined amounts to surface waters reaching the ocean.

Finally, industry and commerce which sustain an urban community contribute in myriad ways to the amount and variety of quality factors moving from land to the ocean, both by discharge of wastes and by surface wash. Except where industries are large and discharge wastes via routes other than the city sewers, industry is but one aspect of the urban situation. Otherwise, it becomes in itself a situation of land development worthy of especial attention.

SCOPE OF PUBLIC CONCERN. Public concern for the effects of urban communities on coastal water quality was for many years primarily associated with sewage disposal expressed in terms of a vaguely defined concept of "water pollution." In scope, this concern has been widely shared by citizens for a number of reasons. First, because a large percentage of people live in urban developments, they are physically close to where the problem exists, hence it becomes a real rather than a distant and impersonal problem. Next, the very nature of a modern city limits the opportunity for recreational activity out of doors, and by exceeding the capacity of local natural resources, the sense of awareness of any shortage of recreational facilities is heightened. Finally, urban man is reached daily by the various media of communications and is therefore impressed by constant attention to a subject, be it by a propagandist or by an objective reporter.

In recent years, public concern for water quality has grown far beyond the basic problem of sewerage. The events of history have contributed to a growing understanding of the interrelationships of living things and to an uneasiness lest the "closed sphere" referred to in Chapter 1 turn out to be more fragile than man has customarily believed to be the case. Without attempting to evaluate how much of the public mood may be derived from fact and how much from fancy, there is no question but that the public is deeply concerned over the environmental impact of land development for urban use and is emotionally, if not economically, prepared to look for ways to improve the situation.

Investigative Approach

COOPERATION WITH OTHER AGENCIES. Explicit in the Sea Grant Program and in the Coastal Water Quality Project is the concept that the study should involve cooperation and coordination with other agencies and investigators concerned with studies having similar or related objectives. Consequently, the first approach of the study was to establish any added lines of communication needed, to determine the appropriate sphere of activity for the Coastal Water Quality Project and to decide upon such matters as scale, priorities, and timing of the project's input.

The sugarcane industry described in Chapter 3 called for an immediate and full-scale effort. In the case of coastal water quality versus urban land development, however, extensive action programs had already been initiated by public agencies at the time the Coastal Water Quality Project was initiated. These programs were primarily concerned with wastewater disposal in the most critical situations in the Honolulu, Pearl Harbor, and Kaneohe areas. It was at once evident that the current project could best contribute by establishing the relationship between coastal water quality and urban land development and management through a cooperative program with other agencies and by conducting experimental studies in specific instances as opportunity and needs arose.

The City and County of Honolulu and its consultants, the State Health Department, the U.S. Navy, and numerous institutes and projects of the University of Hawaii were among the many with which the project cooperated in the studies herein reported.

SCOPE OF COASTAL WATER QUALITY PROJECT STUDIES. Studies concerned with the effect of urban activites on coastal water quality in Hawaii in which the Coastal Water Quality Project was involved during the report period fall into three classes:

a) Major wastewater disposal projects under City and County and federal agencies in Hawaii.

b) Specific instances of especial public concern where coastal water quality is influenced primarily by urban land management.

c) Potential of developed urban land to generate water quality factors.

In the first of these three categories are Sand Island, Kaneohe Bay, Mokapu Point, and Pearl Harbor. Studies of the second type are in progress in the Waikiki Beach area, Maunalua Bay and vicinity, and Sandy Beach. Less comprehensive, but nevertheless significant studies in the third category include Manoa Stream, and two studies on the type of water quality degrading materials generated on paved streets and transported by storm runoff.

Although Sand Island and Pearl Harbor are but two aspects of a greater geographical area of coastal water (Mamala Bay) which is of major concern to Hawaii, they are herein considered as separate studies because of the magnitude of each situation and the difference in the nature of the pollution involved and in the proposals for its alleviation.

FIELD AND LABORATORY STUDIES

Sand Island

NATURE OF SITUATION. Of the three major sewerage systems comprising the principal sources of pollution of coastal waters attributable to urban land development in Hawaii (Sand Island, Pearl Harbor, and Kaneohe Bay), Sand Island is by far the largest, although it is debatable whether it exceeds either of the other two in long-term potential to damage the coastal water environment of Hawaii. Fortunately, this question does not require an answer because, as summarized in this chapter, the City and County of Honolulu has already initiated measures to manage the quality of the wastewater in all three areas in a manner which should render the question academic. Other effects of urban land development on coastal water quality, however, remain to be evaluated by studies such as the Coastal Water Quality Project with which the current report is concerned.

As noted in the preceding section the Sand Island system and the Pearl Harbor (Honouliuli) system discharge wastewater into Mamala Bay but management of the two calls for different approaches and corrective measures unique to each situation.

As indicated in Figure 4.1, the Sand Island system handles domestic sewage from two tributary areas. Area I includes the portion from Niu Valley to Nuuanu Stream. Area 2 includes the portion from Nuuanu Stream to

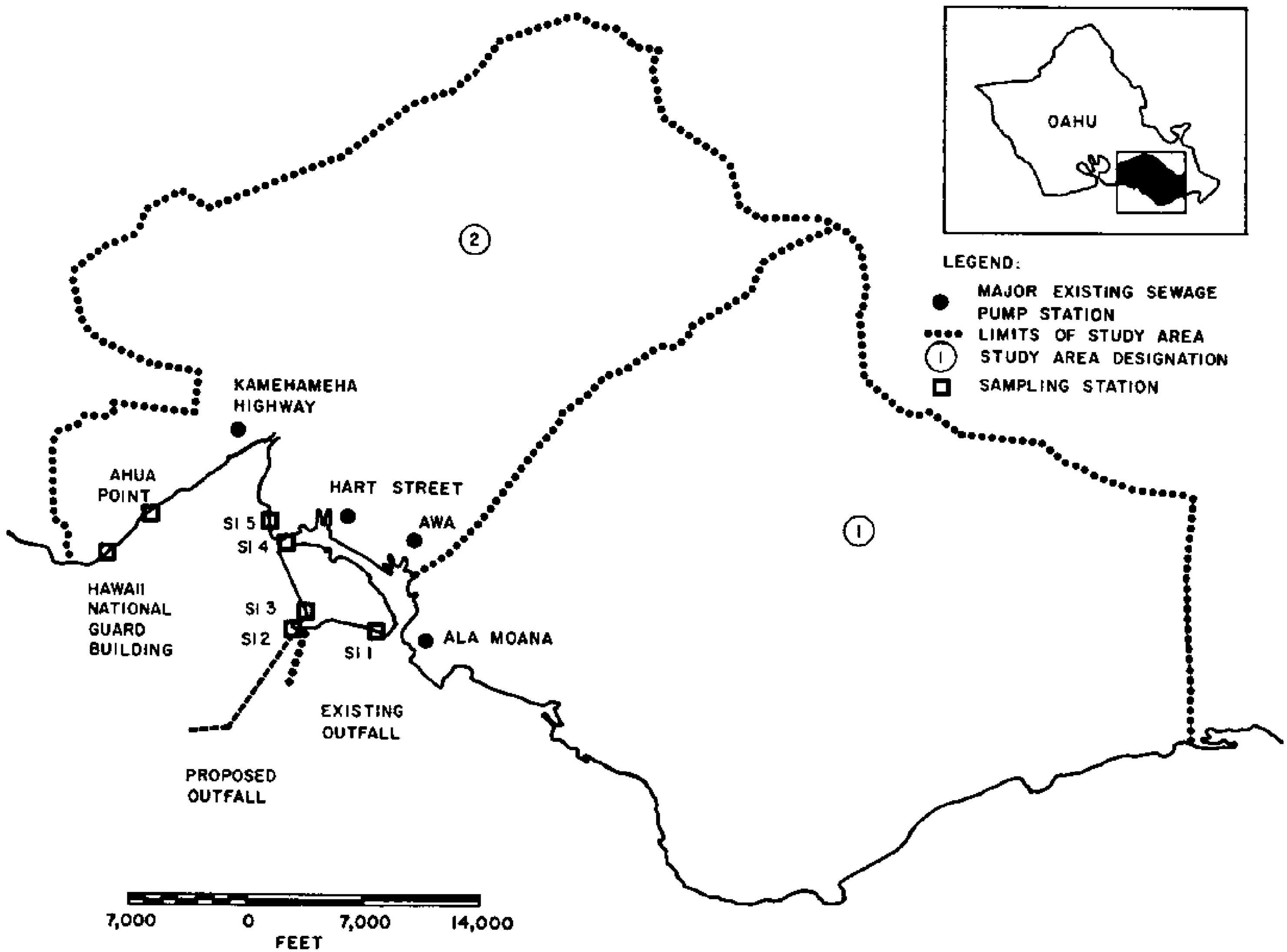


FIGURE 4.1. MAP OF SAND ISLAND SEWAGE SYSTEM, 1970.

Moanalua, thus it picks up a significant amount of industrial wastes from two pineapple canneries and some other light industries. Each area is served by a raw sewage pumping station -- Ala Moana pumping station for Area 1 and Hart Street pumping station for Area 2. These discharge through a common ocean outfall in 40 feet of water 3600 feet offshore of Sand Island. Sewage from Army facilities at Fort Shafter and Tripler Hospital is not connected to the Sand Island system but is pumped separately through an outfall which terminates 1200 feet offshore of Sand Island in 18 feet of water. The design average flow of the Sand Island system in 1970 was 62.8 mgd, 39.2 of which originated in Area 1. The Army discharge amounts to about 1.4 mgd.

It has been estimated (City and County of Honolulu, 1972) that 49 percent of the domestic sewage generated on Oahu, exclusive of infiltration, is discharged through the Sand Island outfall. Infiltration, however, is extensive in the Honolulu sewer system. Consequently, 44 percent of the actual discharge at Sand Island is infiltration.

The discharge at Sand Island surfaces in a plume which is readily visible from nearby high rise buildings in downtown Honolulu, from aircraft, or from boats. The significance of this plume is variously interpreted by citizens, environmentalists, and public officials but all agree that it is environmentally unsatisfactory and must therefore be eliminated, along with whatever real or fancied damage to the water environment may be associated with it. Consequently, it is the focus of various action programs.

ACTIONS AND FINDINGS OF PUBLIC AGENCIES. To bring together in a single document all of the official actions by public agencies, and the unofficial and official turbulence, that has centered around the Sand Island sewage discharge question is beyond the scope and purpose of this report.

The State Department of Health (1968) has classified the waters off Sand Island as Class A waters. This means that the uses to be protected are recreational and include fishing, swimming, bathing, and other water-contact sports and aesthetic enjoyment. The intent of this classification is that recreational use and aesthetic enjoyment shall not be limited in any way. Consequently, the water must be kept clean of trash, solid materials, or oils and shall not receive sewage effluent that has not received the best practicable treatment or control compatible with standards established for Class A waters. Table 4.1 summarizes the standards which apply.

For routine monitoring purposes the State Department of Health maintains five monitoring stations in the Sand Island area (Fig. 4.1). At all five, weekly bacteriological samples are collected and analyzed. Chemical samples are taken monthly at Point 2 (State Health Sta. No. 0166). However, even without monitoring of any sort, it was obvious that more than 50 mgd of raw sewage discharged in 40 feet of water could not approach the standards for Class A water. Consequently, as soon as the state standards were established in 1967, the City and County of Honolulu was immediately under pressure from the state to improve its wastewater management procedures.

To meet the need for improved treatment of sewage at Sand Island, the City and County of Honolulu began the water quality program for Oahu with special emphasis on waste disposal in 1970 under which a Board of Advisors

TABLE 4.1. STANDARDS FOR CLASS A WATERS.

QUALITY FACTOR	REQUIREMENT
COLIFORM, MPN	NOT MORE THAN 1000/100 ml MAX. OF 10% OF SAMPLES MAY EXCEED 2400/100 ml
FECAL, COLIFORM, MPN	AVERAGE NOT EXCEED 200/100 ml, ANY 30-DAY PERIOD MAX. OF 10% OF SAMPLES EXCEED 400/100 ml, ANY 30-DAY PERIOD
pH (UNITS)	NOT MORE THAN 1/2 UNIT FROM NATURAL CONDITIONS MIN. 7.0; MAX. 8.5 FROM OTHER THAN NATURAL CAUSES
NUTRIENTS	MAX. 0.025 mg/l, TOTAL P MAX. 0.15 mg/l, TOTAL N
D.O.	NOT LESS THAN 5.0
TEMPERATURE	NOT CHANGE MORE THAN 1.5°F FROM NATURAL COND.
TURBIDITY	SECCHI DISC (OR EQUIV.), MAX 10% FROM NATURAL CONDITIONS
RADIONUCLIDES	NOT EXCEED 1/30 OF MPC VALUES FOR CONTINUOUS EXPOSURE BSH NO. 69^{W}

assisted the city and state in guiding a consortium of consulting engineering firms, in a study of its sewerage problems.

At about this same time (1970) the Federal Environmental Protection Agency established its own ocean water quality objectives and concerned itself with the Sand Island situation, eventually expressing its impatience with the rate of progress toward a solution by calling an enforcement conference in the matter.

The WQPO in a series of reports recommended in 1971 that:

a) A primary treatment plant be constructed at Sand Island with an initial capacity of 85 mgd and provision for future expansion to 106 mgd.

b) An extension of the existing ocean outfall with 2900 feet of 90-inch diameter pipe and two 60-inch diameter diffuser legs 1000 feet long. (The diffuser section if 440 feet long.)

c) A new effluent pumping station be constructed and provisions be made for sludge handling and incineration at the plant.

During the design phase of the plant in 1972 these recommended values were changed to include a new 84-inch outfall sewer 9000 feet long extending in a southwesterly direction from Sand Island and terminating in a 3350-foot diffuser section located at depths of from 220 to 240 feet (Fig. 4.2). (City and County of Honolulu, 1972).

To meet the bacteriological and nutrient standards for Class A water a "zone of mixing," beginning at the ocean floor and extending upward to the water surface was considered necessary. Such a zone of mixing 3400 feet long and 3000 feet wide and directly over the diffuser section was requested

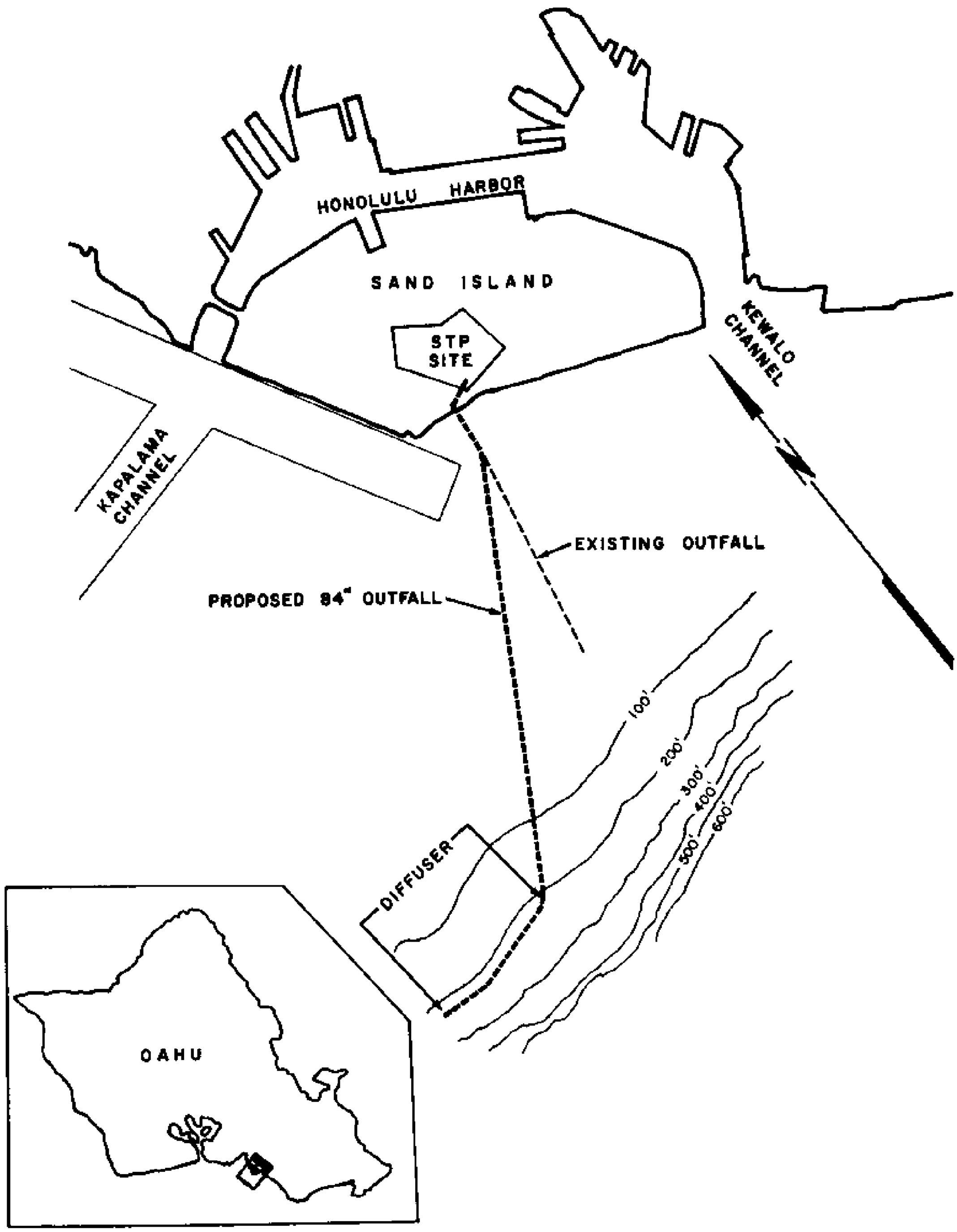


FIGURE 4.2. SAND ISLAND STP AND OUTFALL, MARCH 1972.

by the City and County of Honolulu and approved by the state in mid-1972. With chlorination of the effluent, if necessary, and a zone of mixing 6000 feet from the shore, the designers expect no problem with contamination of nearshore waters.

The WQPO studies reported high total and fecal coliform concentration over the existing Sand Island outfall. However, the time for 90 percent of the coliform to die away (T-90 value) varied from 9 minutes in summer to 15 minutes in winter, with one observation showing a T-90 value of 33 minutes.

Analyses of heavy metals and pesticides in sediments in the vicinity of the existing Sand Island outfall made by the WQPO (1971) are summarized in Table 4.2.

TABLE 4.2. HEAVY METALS AND PESTICIDES IN THE SEDIMENT AT SAND ISLAND OUTFALL.

LOCATION*	Hg ppm, dry wt.	As_2O_3 ppm, dry wt.	Cu ppm, dry wt.	Zn ppm, dry wt.	Pb ppm, dry wt.	CHLORINATED HYDROCARBONS ppm, dry wt.
500 yds NE OF OUTFALL	0.01	5.2	3.1	7.1	70	0.0+
AT OUTFALL	0.01	9.5	7.8	25	90	4.4
500 yds SW OF OUTFALL	0.00	2.8	0.9	5.7	--	0.06

* WIND FROM NE

The data indicate a substantial dispersion occurring especially in the downward direction from the outfall.

Water samples collected over a 7-month period from Mamala Bay were analyzed (WQPO, 1971) for nutrients and presented in Table 4.3. The

TABLE 4.3. NUTRIENTS IN WATER, MAMALA BAY.

LOCATION	TOTAL PHOSPHORUS (mg/1)		TOTAL NITROGEN (mg/1)	
	MEAN	RANGE	MEAN	RANGE
SAND ISLAND	0.013	0.001 - 0.026	0.145	0.037 - 0.315
EWA BEACH	0.035	0.008 - 0.229	0.225	0.010 - 0.612
DIAMOND HEAD	0.035	0.003 - 0.152	0.184	0.032 - 0.562

Diamond Head station is representative of a pristine area. The results, shown in the table, indicates that Class A standards of .025 mg/1 Total phosphorus and 0.15 mg/1 Total nitrogen are commonly exceeded in ocean water.

An area 800 to 1000 yards around the Sand Island outfall showed effects from the sewage in lowered diversity and density of the benthic biological community. However, biomass concentrations (dry weight) in the surface of the ocean near the outfall were very high, approximately 14 times that observed in Kilauea Bay, Kauai and off Sandy Beach, Oahu where treated sewage effluents are also discharged.

The WQPO report comprises of 10 volumes plus a final summary report and is concerned with the entire island of Oahu rather than only the Sand Island problem. Consequently, many observations of the quality of sewage discharged and the environment of the outfall appear in comparative tabulations which deal with other aspects of sewerage on Oahu. Nevertheless, the data present a good evaluation of what is being discharged at Sand Island and the oceanographic conditions that justify offshore discharge at a deeper depth following modified primary treatment. For the purpose of this report it is neither necessary nor feasible to recapitulate the entire engineering study at Sand Island. In terms of the quality of coastal waters what is now being discharged is well established, and the State Health Department has had to restrict the use of the water in the areas influenced by the Sand Island discharge.

COASTAL WATER QUALITY PROJECT PARTICIPATION. At the time the Coastal Water Quality Project of the University's Sea Grant Program was approved and funded, the City and County of Honolulu had already organized and funded the WQPO. Consequently, the appropriate function of the Coastal Water Quality was that of cooperation and assistance. To this end, representatives of the Project Control Group of the Coastal Water Quality Project met with the City's Board of Advisors and the consultants comprising WQPO, at their invitation during their regular meetings and participated in the deliberations. In turn, three WQPO technical staff members responsible for the oceanographic, biological, and wastewater treatment and reclamation aspects of the WQPO study were assigned to meet regularly with the Coastal Water Quality Project Control Group. In this manner the Group was kept informed of technical findings such as needed for evaluation of the "before" phase of a study of the effects of urban wastewater on the coastal waters at Sand Island as well as in other situations. In turn, various specialists of the University Group (see Chapter 1) were able to assist the WQPO through advice and counsel on the various parameters of quality needed and in the evaluation of findings.

Because of the intensive nature of the study launched by the WQPO, the cooperative arrangements described above, and the limitations of the Sea Grant budget, investment of funds by the Coastal Water Quality in field and laboratory studies at Sand Island offered little prospect of adding significantly to the data to be made available by the City and County of Honolulu through its WQPO and by the State Department of Health. Consequently, the activity of the Coastal Water Quality Project in the Sand Island situation during the period herein reported was limited to three activities:

a) Cooperation with the WQPO in the manner described above,

b) Assembling and studying the data available on the Sand Island sewerage problem, with especial concern for the quality of coastal waters resulting from existing discharges, and

c) Reviewing and evaluating the Sand Island project's environmental impact statement for the City and County of Honolulu.

Plans for the future, however, call for active field and laboratory studies of the changes in water quality, sediments, and biota of the area now influenced by the Sand Island outfall following the installation of the new system and cooperating with state agencies in monitoring changes, if any, in the region of the new outfall.

STATUS OF SITUATION. At the time of reporting (June 1972) the WQPO study has been completed for the Sand Island area, design activities are being completed, a Zone of Mixing permit has been granted by the state of Hawaii, and an environmental impact statement has been prepared as a part of the procedure for project approval by the state of Hawaii and the EPA and for a construction grant from the EPA. The Coastal Water Quality Project continues to assemble and to evaluate data and assess the over-all situation in terms of what it may find relevant to the economic, institutional, and related aspects of urban land development and management in the interests of coastal water quality. The non-technical aspects of the Sand Island situation are discussed in Chapter 5.

Pearl Harbor

NATURE OF SITUATION. The situation herein discussed in the context of Pearl Harbor is more properly designated as the Honouliuli sewerage system. However, the principal destination of runoff from urban development in the area is Pearl Harbor and past sewage treatment objectives have largely been the protection of Pearl Harbor as a coastal water. Moreover, the nature of Pearl Harbor is such that the long-range dream that all or a portion of the harbor will some day become a recreational area is irresistible.

Natural runoff into Pearl Harbor comes from land under a variety of uses, hence the situation is not a particularly good one in which to identify the over-all effects of urban land development on coastal water quality. The WQPO (1971) estimated that the average storm runoff into the Harbor is 45 mgd carrying 69,400 tons of sediment per year. Both the magnitude of this load and the map of the area draining into Pearl Harbor attest to the fact that this is not strictly an urban discharge. Nevertheless, if the quality of water and sediments and the types and diversity of biota are established both before and after proposed changes in wastewater treatment are effected, the change can be identified directly with the sewage fraction of urban discharge to Pearl Harbor. The remainder should then represent a combination of discharges from natural land cover, urban developments, and agricultural lands, plus activities within the harbor itself. To some degree, these sources may be assigned their appropriate share of responsibility on the basis of studies of other situations in which one of these sources predominates. A survey of the waste-generating potential of government activities within the Harbor is already being made by the U.S. Navy.

As noted in the preceding section (see p. 135), the WQPO study sponsored by the City and County of Honolulu included the Honouliuli system and Pearl Harbor in its study of the sewerage problems of Oahu. This study noted that the Honouliuli system serves the Pearl Harbor tributaries extending from Halawa to Barbers Point. The only significant industrial waste discharged in this area is from the Primo Beer Brewery. The general layout and the features herein discussed are shown in Figure 4.3.

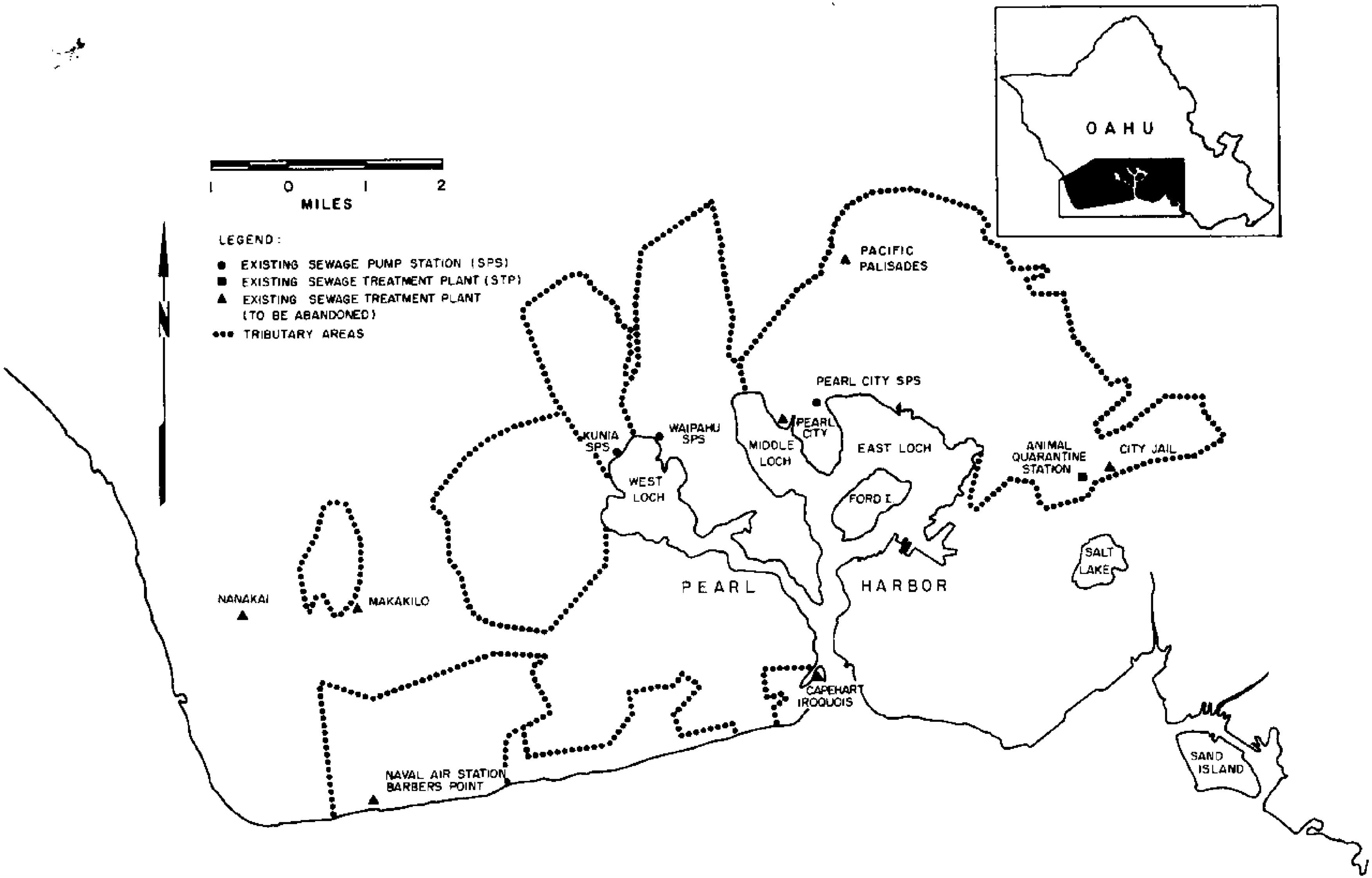


FIGURE 4.3. HONOULIULI WASTEWATER SYSTEM.

There are eight sewage treatment plants located in the Honouliuli area, of these only one (Pearl City) discharges effluent directly into the harbor. The Pearl City outfall extends 2300 feet into Middle Loch in Pearl Harbor and terminates in 35 feet of water which is classified as Class A by the State Department of Health. The location and nature of the eight treatment plants, together with the recommended future utilization of each as recommended by the WQPO, are summarized in Table 4.4.

TABLE 4.4. SUMMARY OF SEWAGE TREATMENT PLANTS IN HONOULIULI SYSTEM.

LOCATION	TYPE OF TREATMENT	RECOMMENDED ACTION
PEARL CITY	PRIMARY	ABANDON
CITY AND COUNTY JAIL	TRICKLING FILTER	ABANDON
PACIFIC PALISADES	TRICKLING FILTER	ABANDON
MAKAKILO	ACTIVATED SLUDGE	WATER RECLAMATION IF SURROUNDING AREA REMAINS AGRICULTURAL
NANAKAI	EXTENDED AERATION	SAME AS ABOVE
ANIMAL QUARANTINE STATION	EXTENDED AERATION	WATER RECLAMATION FOR TURF IRRIGATION IF FEASIBLE OR ABANDON
(NAVY) CAPEHART -- IROQUOIS POINT	PRIMARY	ABANDON
(NAVY) BARBERS POINT NAS	PRIMARY	ABANDON

ACTION AND FINDINGS OF PUBLIC AGENCIES. Among the public agencies which have given particular attention to the water quality of Pearl Harbor are the State Health Department, the City and County of Honolulu, the Federal Water Pollution Control Administration and its successor, the Environmental Protection Agency, and the U.S. Navy. No single water quality characteristic can describe Pearl Harbor in its entirety because the 9 square mile area of the harbor is divided into three lochs (East, Middle, and West Loch, Fig. 4.3) and 5 streams drain into the harbor. In 1969, the FWQA (1969) estimated the mean flow of these streams at 56 mgd; and further reported that springs near each stream contribute another 87 mgd to the harbor.

The nature of the discharge as summarized by FWQA is presented in Table 4.5.

Five major sources of sewage discharge were investigated by the FWPCA:

a) Navy South Avenue outfall, discharging 3.5 mgd raw sewage into the main Pearl Harbor Channel.

b) Halawa sewage treatment plant, discharging 0.5 mgd primary effluent

TABLE 4.5. NATURE OF DISCHARGES INTO PEARL HARBOR, 1971 (WQPO, 1971).

STREAM	DISCHARGE (mgd)	DISCHARGE AREA	TYPE OF DISCHARGE
HALAWA	6.2	EAST LOCH	RUNOFF FROM UNDEVELOPED LAND AND URBAN AREA, 0.08 MGD SECONDARY SEWAGE FROM ANIMAL QUARANTINE STATION.
KALAUAO	1.7	EAST LOCH	RUNOFF, UNDEVELOPED LAND
WAIMALU	4.7	EAST LOCH	RUNOFF, UNDEVELOPED LAND
WAIAWA	18.0	MIDDLE LOCH	AGRICULTURAL RUNOFF, 0.5 MGD SECONDARY EFFLUENT
WAIKELE	26.8	WEST LOCH	RUNOFF FROM HIGH MOUNTAIN AREAS, AGRICULTURAL AND URBAN LAND SEWAGE EFFLUENT 3.8 MGD
AIEA	1.5	EAST LOCH	RUNOFF, UNDEVELOPED LAND, THERMAL DISCHARGE C & H SUGAR CO.
PEARL CITY	2.2	EAST LOCH	RUNOFF, UNDEVELOPED AND URBAN LAND
HONOULIULI	3.0	WEST LOCH	RUNOFF, UNDEVELOPED AND AGRICULTURAL LAND

into East Loch.

c) Aiea outfall, discharging 0.5 mgd raw sewage into East Loch.

d) Pearl City sewage treatment plant, discharging 2.6 mgd primary effluent into Middle Loch.

e) Waipahu Ditch, discharging 2 mgd raw sewage into a stabilization pond in Wapio peninsula and 2 mgd sugar mill wastes into West Loch.

From these daily waste concentrations and waste loads were tabulated for nutrients, solids, and coliform organisms. Although the data are too extensive for reproduction here it may be noted that phosphorus ranged from 5.8 to 11.2 mg/l and nitrogen from 10.2 to 20.1 mg/l. Numbers of coliforms from the raw sewage discharges were, of course, in the millions.

An extensive bacteriological sampling program (FWPCA, 1969) was undertaken by the FWPCA in 1969 and its successor EPA in 1971 of all the surface waters in the three lochs comprising Pearl Harbor. In all of the 13 stations sampled by EPA in 1971 in West Loch (Class AA water), the standards for bacteria were exceeded. High bacterial counts in the area adjacent to Waipahu dump and Waipahu ditch indicated that these were sources of pollution. East Loch samples showed low fecal coliform densities and fell within the limits for Class A waters.

In the case of nutrients, several studies showed that phosphorus values in West Loch exceeded standards. The FWPCA survey found phosphorus to average 0.098 mg/l in the designated Class AA waters of upper West Loch, 0.051 mg/l in the Class A waters of Lower West Loch, and 0.051 mg/l in Middle Loch. Nitrogen values (FWPCA, 1969) were inconclusive, with average values of 0.44 mg/l in West Loch and 0.18 mg/l in the East Loch channel.

In 1970-71, the City and County of Honolulu directed its attention to Pearl Harbor as one aspect of its WQPO study. By that time, the nutrient concentrations had increased beyond those observed by FWPCA in 1969. Annual averages of 0.164 mg/l in West Loch and 0.211 mg/l in Middle Loch were reported for phosphorus. Nitrogen values reported by the WQPO were the same as that previously reported: 0.335 mg/l for West Loch, 0.28 mg/l for Middle Loch, 0.338 mg/l for upper East Loch, and 0.208 mg/l for the East Loch channel.

Four surveys have been made of coliform organisms in oysters (*Crassotrea virginica*) in Pearl Harbor since 1962. The data show a decline in coliforms over the years but all but one bed examined in 1971 (FWPCA, 1971) exceeded the allowable fecal coliform limit of 230/100 gm.

Observations of phytoplankton and zooplankton in Pearl Harbor were made by Au (1965) in 1965. Of the phytoplankton present, diatoms of the species *Chaetoceros* and *Skeletonema* occurred in greatest numbers. Chlorophyll A concentration averaged 6 mg/m^3 and ranged from 2 to 8 mg/m^3 in the channel. Zooplankton were mainly chaetognaths, ctenophores, and calanoid copepods. In the channels and main harbor entrance, however, these organisms were replaced by crustacean larvae. The standing crop of zooplankton ranged from 1 cc/m^3 to 22 cc/m^3.

During the period May 13 to June 18, 1971 the U.S. Navy conducted a short term, high intensity proximate biological survey of Pearl Harbor (U.S. Navy, 1972) with particular reference to the presence of heavy metals in the biota of the area. Nevertheless, a wide range of biological observations of intertidal and subsurface communities on piling and other structures were made and reported. The Navy investigators noted that the horizontal and vertical differences in community structure suggest "that many complex, and probably interacting, factors are important in shaping the marine environment of Pearl Harbor." Silt appeared to be the dominant factor in Middle and West Lochs, and oil was evidently important in all the lochs. Body burdens of heavy metals (Cd, Cu, Hg, and Pb) seemed highest near known sources of industrial waste discharges but in the organisms tested, the burdens did not appear to be dangerously high.

The WQPO of the City and County of Honolulu found relatively high concentrations of heavy metals in the sediments in Pearl Harbor. Some of the WQPO findings and nutrients in the water at some of the same sampling points, are summarized in Table 4.6.

TABLE 4.6. METALS AND NUTRIENTS IN SEDIMENTS AND WATER, PEARL HARBOR.

LOCATION	METALS IN SEDIMENTS (mg/l)				NUTRIENTS IN WATER (mg/l)	
	Hg	As_2O_3	Cu	Zn	NO_3-N	PO_4-P
MIDDLE WEST LOCH	0.29	8.8	61	120	--	--
MOUTH WAIKELE STREAM (WEST LOCH)	0.25	14.8	57	80	1.2	2.58
SOUTHEAST LOCH (SHIP WAYS)	0.12	25	42	69	--	--
MOUTH KALAUAO STREAM	0.08	12	37	57	--	--
MOUTH WAIMALU STREAM	0.15	5.3	47	87	0.144	0.013
MOUTH PEARL CITY STR.	0.35	22	29	133	0.144	0.013
MOUTH WAIAWA STREAM	0.12	9.8	42	61	0.56	0.25

The WQPO made a number of physical, chemical, and biological assays of the quality of water discharged from Pearl Harbor as a part of a larger survey of Mamala Bay waters from Diamond Head to Ewa. The study also included analyses of the Pearl City sewage and other influents discharged into Middle Loch. The results are reported and analyzed in the several volumes which comprise the WQPO report. They are too extensive in nature to evaluate within the context of any single area such as Pearl Harbor but are sufficient to support the recommendations of the WQPO study. One especially interesting finding, however, was that the biomass in the surface waters at the entrance to Pearl Harbor was but 11 percent of the concentration observed at the Sand Island outfall.

From the findings of its own investigative work, together with that of others which served as sources of information and data, the WQPO made specific recommendations for managing the sewage in the Honouliuli system so as to protect the quality of the waters of Pearl Harbor. Some of these recommendations were included in Table 4.4 for convenient reference. However, the principal recommendation is that a secondary treatment plant be constructed at Honouliuli to make possible the abandoning of individual plants as noted in Table 4.4. It was recommended that the new plant feature water reclamation for cane irrigation in the Ewa area and the excess effluent be discharged into the ocean via an outfall east of Barbers Point (see Fig. 4.3). To implement such a system, a number of pumping stations would need to be added or existing ones modified as indicated in Table 4.7.

TABLE 4.7. PROPOSED PUMPING STATIONS.

GENERAL LOCATION	AREA SERVED	ACTION REQUIRED
PEARL CITY	AIEA, WAIMALU, WAIAU, PEARL CITY	MODIFY EXISTING (40 MGD) AND ADD NEW STATION (19 MGD)
KUNIA	WAIPAHU - KUNIA	MODIFY EXISTING STATION (9 MGD) AND ADD NEW STATION (7 MGD)
WAIPAHU	WAIPAHU - WAIAWA AND KUNIA PUMPING STATION	MODIFY EXISTING STATION (20 MGD) AND ADD NEW STATION (13 MGD)
EWA	EWA BEACH, NAVY CAPEHART HOUSING AT IROQUOIS POINT	NEW STATION (9 MGD)
HONOULIULI	PROPOSED NEW TOWN	NEW STATION (17 MGD)

COASTAL WATER QUALITY PROJECT PARTICIPATION. Because the Pearl Harbor situation was a part of the broader area of study of the WQPO of the City and County of Honolulu, the Coastal Water Quality Project and its individual participants contributed to the WQPO study of Pearl Harbor through the cooperative arrangements previously described in relation to Sand Island (see p. 141). However, in the Pearl Harbor situation active investigative work as well as data coordination and scientific consultation resulted from cooperation with the Navy in an ongoing extensive study of Pearl Harbor.

The Navy's investigative study of the Pearl Harbor waters was initiated in 1971-1972 as an integral part of a 2-year Environmental Protection Data Base Program to gather information to show the extent to which the environment is affected by naval ships, aircraft, and shore installations. The program consists of two parts: (1) data collection--a pilot test program which includes Pearl Harbor as one of the three initial Navy test complexes and (2) centrally developed data processing, storage, retrieval, and display components of an information management system.

The Navy's Pearl Harbor study is an intensive fact-finding activity of water quality parameters of the Harbor water and pollution sources from streams, ditches, storm, and sanitary sewers and leachates from landfills. The study includes biweekly observations and sampling of a network of stations (about 100 harbor stations and about 50 source stations). Clarity, dissolved oxygen, pH, salinity, and temperature are measured at the sites. Laboratory capabilities developed will enable the analysis of BOD, turbidity, various forms of solids, chloride, phosphorus, nitrogen, carbon, phenols, pesticides, heavy metals, and total and fecal coliform to be made. Later phases may include sediment. A biological survey of fish and benthic and encrusting biota in the Harbor is being separately performed by the Naval Underseas Center.

In view of the comprehensive scope of the Navy's EPDB program for Pearl Harbor and the availability of its findings to the Coastal Water Quality Project, the role of the Coastal Water Quality Project is to encourage and assist in doing whatever needs to be done and to supplement, to the extent possible, what is not being done but is judged desirable by the Coastal Water Quality group. The Coastal Water Quality Project has established close communication with the Navy and, responding to the Navy's request, has assisted in reviewing its proposed water data collection program, advising on pesticide laboratory instrumentation and procedures, conducting the micromollusk study of the harbor sediment, and making site visitations to the sampling net and laboratory facilities. A Coastal Water Quality sediment study for the West Loch of Pearl Harbor is coordinated with the Navy regarding the stream sediment load and the herbicide content in the harbor and stream sediments.

STATUS OF SITUATION. Pearl Harbor is presently a center of activities of many agencies having the common goal of transforming it into an environmental model. Governor Burns in 1971 formed a Pearl Harbor Task Force which consolidated into a single body all federal, state, and local government agencies responsible for pollution abatement. The Task Force offers a forum for mediating conflicting situations, identifying problems, and seeking alternative systems solutions. Assessment of the present environmental quality of the Pearl Harbor waters and contributory watercourses is underway by the Navy's two-year Environmental Protection Data Base Program, assisted by the Coastal Water Quality Project participation. The State Health Department has maintained a number of shoreline stations, routinely monitoring the chemical and bacterial quality of water. It is expected that the need for further studies of the Harbor water quality may be realistically determined upon the completion and evaluation of the Navy's investigative effort.

As previously noted, the major wastewater reclamation facility for the Pearl Harbor area is the Honouliuli sewage treatment plant as recommended by the Oahu Water Quality Program. Work on the design of the treatment facilities and additional oceanographic study was begun in August 1972 under the direction of the City and County.

Kaneohe Bay and Mokapu Point

NATURE OF SITUATION. Kaneohe Bay is located on the northeast coast of Oahu. It is the largest embayment in the Hawaiian islands, covering 18 square miles (46 sq. kilometers). Although it is by no means confined by headlands as is Pearl Harbor, it is protected by a barrier reef. In fact, the Bay is a combination of a coastal-plain estuary and a lagoon some 45 feet in depth. It lies within several coalescent drowned valleys that were eroded into the northeast flank of the Koolau Range and carved in the lava bedrock of the island. The barrier reef, however, is cut by only two old stream channels to depths of 20 and 7 feet, respectively. Dredging, however, has increased the depth of the deeper channel to 40 feet. Figure 4.4 prepared by Bathen (1968) in 1968 presents a good picture of the bathymetry of the Bay.

Some 10 surface streams, mostly perennial, enter Kaneohe Bay. Their combined average flow is 79 mgd and approaches 48 mgd 90 percent of the time. About half of the streamflow is diverted and exported from the area for agricultural uses. Lands around the Bay, once agricultural, are rapidly becoming suburbs of Honolulu as improved highways have broken through the precipitous headlands of the valley.

Mokapu Point which defines the eastern boundary of the Bay is a military base, the Kaneohe Marine Corps Air Station. A sewerage system serving this base discharges 1 mgd of secondary effluent and the town of Kaneohe discharges some 2.5 mgd of effluent from a secondary treatment plant into Kaneohe Bay (Fig. 4.5). Observations reported in 1968 (Cox, *et al.*, 1969) indicate that the Kaneohe plant is capable of producing a good secondary effluent. For example, during one period of observation the effluent had values of: 21 mg/l of BOD, 66 mg/l of Suspended sediments, 7 mg/l of phosphorus, and 17 mg/l of nitrogen. A smaller discharge (0.003 mgd) of settled sewage is discharged from installations on Coconut Island.

Figure 4.5 shows the general aspect of Kaneohe Bay, including the sewer outfalls and other features. A large portion of Kaneohe Bay is designated as Class AA and only a boat harbor is classified as Class B. Consequently, control of pollution of the Bay continues as a subject of great public and official interest. Pollution is ascribed to a combination of accelerated sediment discharge owing to land development, and nutrients and bacterial contamination from stream and sewer discharges. The resource values threatened are esthetics, recreation, fishery, and research uses of the Bay. A major field laboratory, the Hawaii Institute of Marine Biology of the University of Hawaii, is located on Coconut Island in the Bay (Fig. 4.5). This gives added importance to the research value of the bay waters.

Although four public parks are located on the shores of Kaneohe Bay, not much water-based recreation stems from them. Nevertheless the Bay is used for all types of water recreation. Sailing, boating, fishing, yacht racing, and water skiing are extensive activities throught the Bay. Clamming is confined to beach areas.

Commercially the Bay is the source of baitfish for skipjack tuna (aku) fishing. Forty or 50 fishing boats are based at Kaneohe Bay piers.

As a situation in which the effect of man's activities on coastal

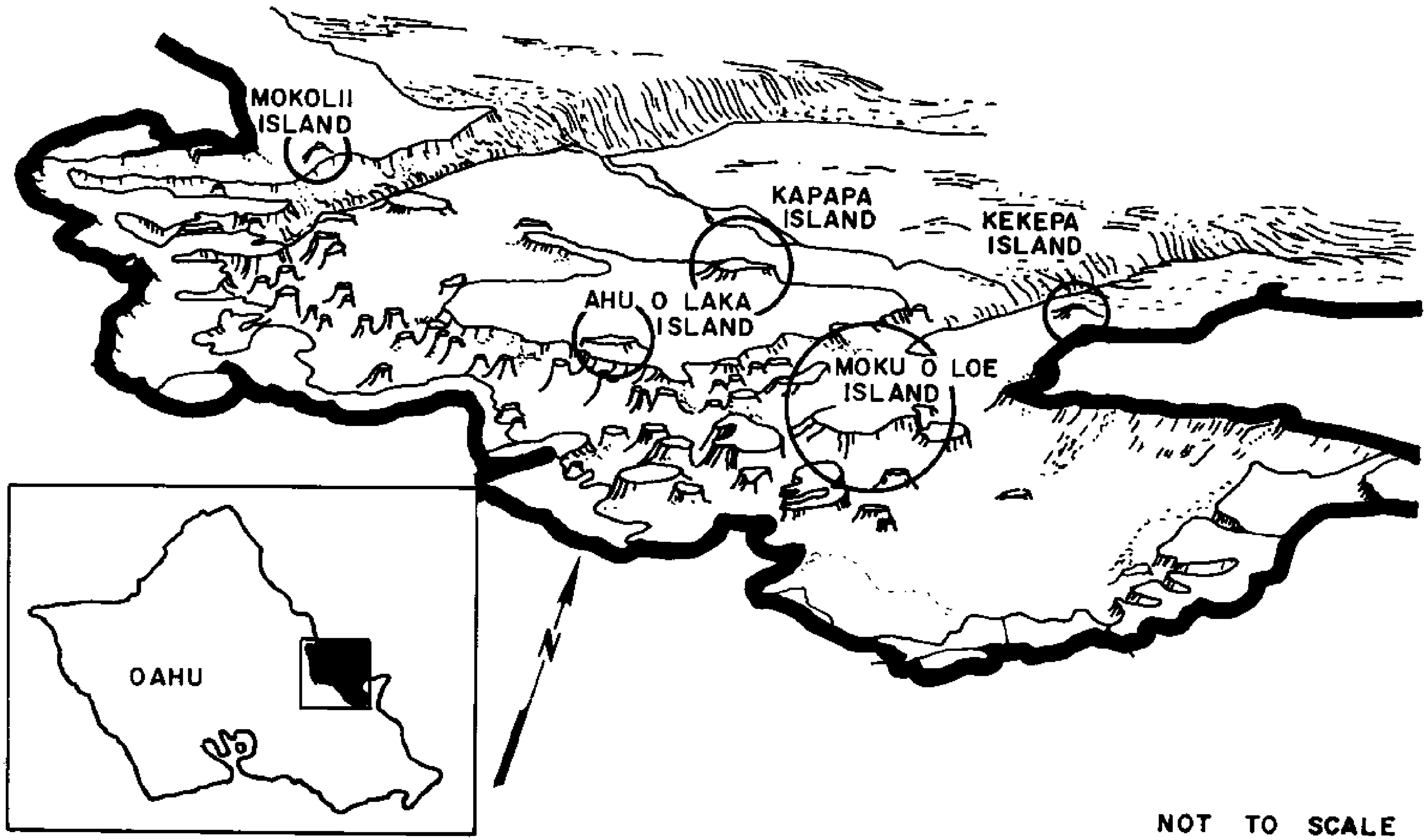


FIGURE 4.4. PERSPECTIVE VIEW OF KANEOHE BAY (FROM BATHEN, 1968).

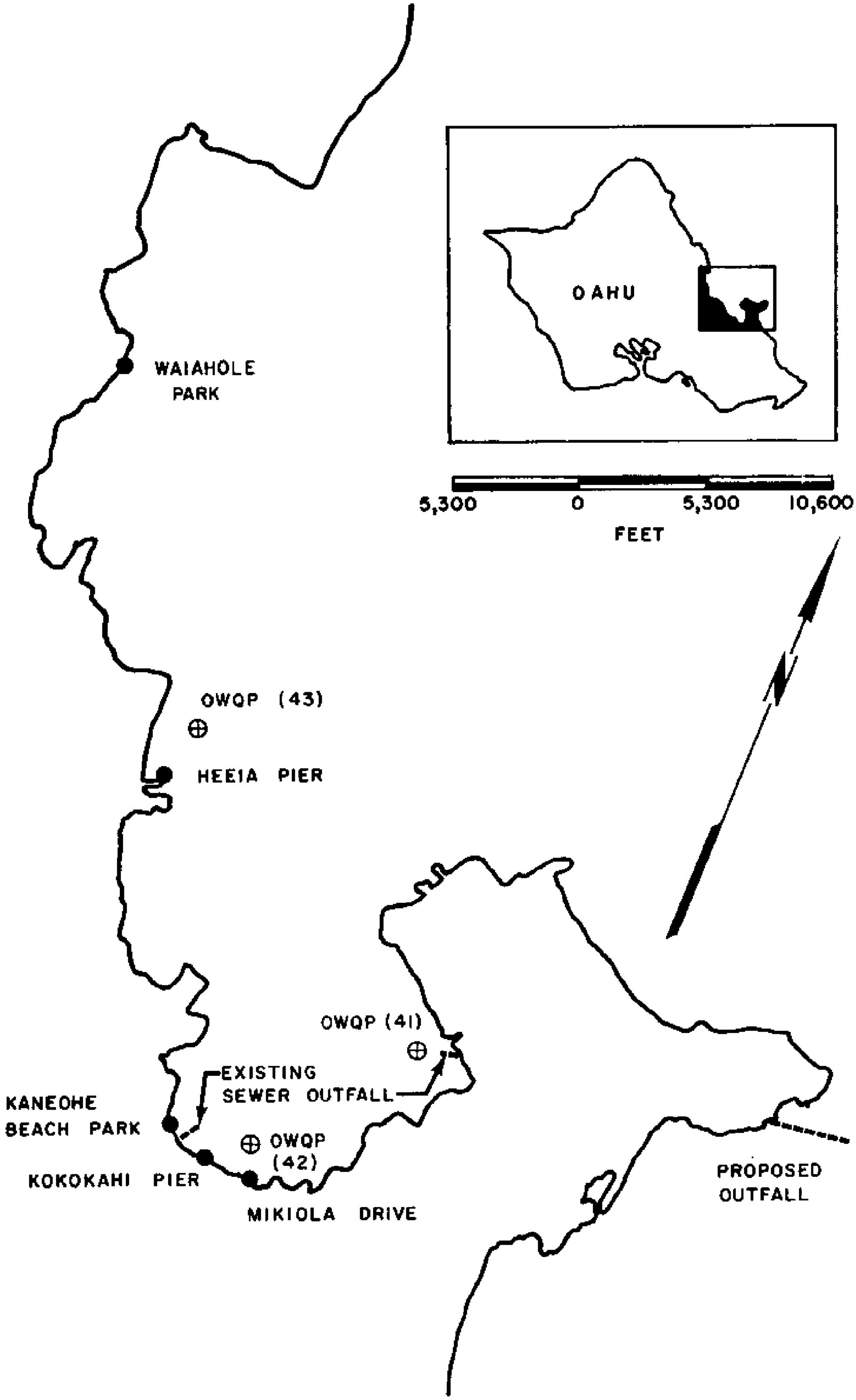


FIGURE 4.5. LOCATION OF SAMPLING STATIONS FOR THE OWQP STUDY AND THE EXISTING AND PROPOSED OUTFALLS IN THE VICINITY OF KANOEHE BAY, OAHU.

water quality is overwhelmingly associated with urban use of land with a minimum of other influences, Kaneohe Bay is without parallel in the state. This does not mean, however, that isolating and evaluating the individual effects of wastewater surface runoff, and land development practices will be an easy task. Nevertheless it is not a hopeless one for a number of reasons. First, the water environment and biota of Kaneohe Bay have been studied more extensively and in greater detail, if in a fragmentary manner, than those of any other body of water in Hawaii by a variety of top level scientists, many of whom are participating in the Coastal Water Quality Project. Thus, although there may be bases for divergent opinions as to the cause of any observed phenomenon or biological stress, there is a wealth of background data against which to weigh similar future data when dishcarges into the Bay are changed. Next, as discussed in a subsequent section, the WQPO study has recommended (and engineering plans are being formulated) that sewage effluents now going into Kaneohe Bay be discharged through an ocean outfall at Mokapu Point (Fig. 4.5). Thus, by continued monitoring of changes in the Kaneohe Bay water environment, some assessment of the role of domestic sewage in determining its quality should be possible.

Later, a comparison of the equilibria that follow removal of sewage discharge from Kaneohe Bay with the findings at Kahana Bay (Chapter 2) over a period of time, may yield more accurate estimates than are presently available of the effects of water quality factors other than sewage generated by an urban community. Obviously, as noted from time to time in this report, the subtleties of nature which determine the variation in the structure of aquatic communities from situation to situation will affect the accuracy of any such estimates. Nevertheless, they should be invaluable to public agencies in refining standards and regulations so that the proper cause may be attacked in an effective and realistic manner to achieve any desired result.

RESULTS OF OTHER STUDIES. The situation at Kaneohe Bay, together with the results of a very thorough study and analysis of the situation, was made by the University of Hawaii in 1967-1968. The results reported by Cox, *et al.*, (1969) evaluated what was known from previous studies, conducted new studies of water quality, assessed the cause and effects of Bay pollution, and summarized alternative methods of wastewater treatment to meet the then existing water quality standards for the Bay. Subjects discussed and analyzed in the report, together with the principal investigators and authors involved are summarized in Table 4.8.

A thoroughgoing analysis of the findings reported by the University of Hawaii scientists is beyond the scope of this report and is untimely until the results which follow changed sewage discharge systems for the area are available for comparison. Nevertheless, in summary, it was noted (Cox, *et al.*, 1969) that the Bay encompasses a variety of environmental conditions, hence varied ecological relationships exist. To reduce the situation to manageable proportions Kaneohe Bay was divided into three sectors--north, middle, and south. Helfrich (Cox, *et al.*, 1969) noted that no single comprehensive biological study of the Bay has been made despite an impressive number of studies on various biotic elements and ecological relationships. He cites more than 200 references which deal directly with, or are pertinent to, the ecology of Kaneohe Bay.

Plankton studies in 3 sectors conducted by Clutter revealed significant

TABLE 4.8. PRINCIPAL SUBJECTS AND INVESTIGATORS, KANEOHE BAY STUDY. UNIVERSITY OF HAWAII (1967-68) (COX, *et al.*, 1969).

SUBJECT	INVESTIGATORS
INTRODUCTION	DOAK C. COX
BACKGROUND AND SCOPE OF STUDY	DOAK C. COX
THE KANEOHE AREA	DOAK C. COX AND POW FOONG FAN
GEOLOGY	DOAK C. COX
PHYSICAL OCEANOGRAPHY	BRIAN L. GRAY AND L. STEPHEN LAU
ECOLOGY AND BIOTA	PHILIP HELFRICH
WATER QUALITY STANDARDS	BRIAN L. GRAY AND L. STEPHEN LAU
SELECTED BENEFICIAL USES	HIROSHI YAMAUCHI, HANI A. AFIFI, AND FRANCOISE RUTHERFORD
PLANKTON ECOLOGY	ROBERT I. CLUTTER
SEDIMENTATION	POW FOONG FAN
WATER QUALITY	REGINALD H.F. YOUNG, KENNETH L. MORPHEW, AND NATHAN C. BURBANK,JR.
MICROBIOLOGY	KAARE R. GUNDERSEN
ALTERNATIVE METHODS FOR SEWAGE DISPOSAL	BRIAN L. GRAY AND L. STEPHEN LAU

changes in microplankton in the south sector of the Bay, where circulation is poorest. In that sector, however, productivity was highest as a result of longer residence time, deeper water, less transport, and the presence of nutrient sources. Clutter cautioned that discharges which increase turbidity by changing the level of productivity not only reduce aesthetic quality, but also may change the structure of the ecosystem rendering it less diverse and stable.

Gundersen (Cox, *et al.*, 1969) found conditions good for nitrification to occur in Bay waters. Fecal coliforms were found at the surface of the water near the sewage outfall plume in concentrations above that for Class B water standards from August until February of the study year, which then declined beginning in February to near zero in April.

Water quality studies were made by Young, *et al.*, Cox, *et al.*, 1969) at 12 stations in Kaneohe Bay. One station was directly over the sewer outfall. Nutrient concentrations were highest in the winter months, indicating that wash from fertilized land, overflow from cesspools, and other activities on the land were contributing to the phosphate load. The concentration from this source, however, was one order of magnitude less than that in the treatment plant effluent. The maximum values for phosphorus ranged from 0.008 to 0.70 mg/l at stations other than over sewer outfalls. Over outfalls, however, concentrations of 0.140 and 0.170 mg/l were observed. Reactive phosphorus was generally one order of magnitude lower than the standards except for the outfall plume where Class A (0.025 mg/l) and Class B (0.03 mg/l) standards for phosphorus were exceeded.

All forms of nitrogen were also highest in the rainy season. Total nitrogen at all depths exceeded Class AA (0.1 mg/l) standards. Over the outfalls, however, some samples from the surface exceeded Class B (0.2 mg/l) standards.

COD values were run for all 12 stations from north to south in the Bay. Values over the outfall were similar to those in the open sea, indicating good dilution. Dissolved oxygen was below the minimum standard of 6.0 at all stations, being lowest at 2.3 mg/l over the outfall and as high as 5.5 mg/l at other stations.

A similar intensive sampling and analysis program was conducted by Young, *et al.*, (Cox, *et al.*, 1969) on streams entering Kaneohe Bay. Enough data were compiled to establish an excellent background against which to evaluate future data. An appreciable bacterial load was observed on streams, but the data indicated that urbanization did not materially affect this load.

Gray and Lau (Cox, *et al.*, 1969) evaluated the technological potential and the economic feasibility of upgrading the quality of sewage entering Kaneohe Bay to meet various standards, such as Class A or Class AA, designated by the State Department of Health. It was not their purpose, however, to recommend a system for the City and County of Honolulu.

ACTION AND FINDINGS OF PUBLIC AGENCIES. The State Department of Health takes bimonthly samples from shore stations at Kaneohe Bay with special concern for the bacteriological quality of its water. Stations are located at Kaneohe Beach Park, Kokokahi Pier, Mikiola Drive, Waihole Beach, and off Heeia pier in Kaneohe Bay. Samples for chemical analysis are also taken at Kokokahi pier. Bacteriological results from these stations, together with observations made for the State Health Department by Gunderson and Stroup show that during 1968 and 1969 both total and fecal coliform concentrations exceeded Class A tolerance limits. Near the sewer outfalls and stream discharge points even Class B requirements were exceeded most of the time. The numerous small streams which empty into the middle sector of the Bay were found to have high coliform and fecal streptococci levels. The studies, however, did not reveal the nature of urban or other activities responsible for the high bacterial content of surface runoff.

The WQPO of the City and County of Honolulu considered Kaneohe Bay as a part of its study for waste disposal on Oahu. However, because of the extensive information already available, little field work of a water quality nature was necessary in reaching a decision concerning the appropriate method of managing the sewage problem of the Kaneohe Bay area.

COASTAL WATER QUALITY PROJECT PARTICIPATION. The Coastal Water Quality Project participated in the WQPO studies in the cooperative manner described in relation to Sand Island (see p. 141). In addition, it furnished the WQPO with most of the documents on which the Coastal Water Quality Project findings at Kaneohe were based because many of them were based on the work of participants in the Coastal Water Quality Project prior to or concurrent with the beginning of Sea Grant support of the Coastal Water Quality studies.

Actual participation of the Coastal Water Quality Project in the

Mokapu Point area was encouraged by the City and County and subsequently made possible through the assistance of the Mokapu Outfall Baseline Study, funded by the National Science Foundation in its Student Oriented Study program. The students' project was conducted during summer 1972 by a group of fifteen UH undergraduate students in zoology, oceanography, and other disciplines and under the counsel of a faculty advisor, L. Stephen Lau, who is also the principal investigator of the Coastal Water Quality Project. E.A. Kay and S.A. Reed of the Coastal Water Quality Project also assisted in providing technical guidance to the students' study.

The investigative study will provide a baseline description of the area in terms of the community structure and composition of the biota and to delineate selected physical and chemical properties of the ocean water prior to the addition of effluent through the proposed diffusers. Physical properties including temperature, salinity, and precipitable particulate matter are to be measured *in situ* and phosphorus and nitrogen to be analyzed in laboratories. Biological investigations will be accomplished through surveys and transects of algae, fish, and invertebrates. Besides the primary study area which is within 500 feet radius of the diffuser section, the biological survey will be extended to the intertidal zones near the shore on both sides of the outfall and to the area around the existing Kailua outfall.

Additional Coastal Water Quality Project efforts at this site includes the examination of water and sediment samples for pesticides, heavy metals, and the whole range of chemical quality parameters and the examination of biota specimens for pesticides and mercury.

STATUS OF SITUATION. Field and laboratory observations of Kaneohe Bay of the type previously reported by scientists of the University of Hawaii (Cox, *et al.*, 1969) should be repeated following the removal of sewage discharges from the Bay via the Mokapu Point outfall. In the meantime, information necessary to evaluate the non-sewage waste load attributable to urbanization will continue to be collected.

Design and associated ocean engineering field studies for the Mokapu outfall are currently (June 1972) in progress. Provision is being made to handle 17 cfs in 1973 and 33 cfs by the year 1993. The general location of the outfall is shown in Figure 4.5.

In the proposed design, the outfall extends about 5000 feet from shore with the last 960 feet serving as a diffuser section which is in a depth of water ranging from 90 to 105 feet. The effluent is expected to surface owing to a lack of density stratification in the natural ocean waters in the general outfall area but after leaving the diffuser orifices the effluent is expected to be diluted by the ocean water at least 100 times under all environmental conditions 200 times and under normal conditions. The outfall design criterion is that no aesthetically objectionable condition be produced, including visible suspended solids, floatables, or obvious discoloration.

The outfall alignment follows a generally gradual drop until the end of the diffuser where the ocean bottom drops steeply. Most of the ocean bottom material is coral formation with many small pockets of generally very coarse sand. Extensive live coral is reported to a water depth of about 35 to 40 feet, but below this depth range, the bottom is composed of many dead coral.

The ocean water in the general area of the outfall has been described as relatively pristine, which is probably and to a large measure due to the strong ocean currents at that depth. Quality parameters of the ocean water are being monitored for a one-year period beginning September 1971 by consultants of the City and County of Honolulu at 14 stations at several depths up to 50 feet for pH, clarity, temperature, salinity, phosphorus, and nitrogen.

Waikiki Beach Area

NATURE OF SITUATION. Waikiki Beach and the inshore waters which it fronts is perhaps a unique situation in Hawaii although in years to come there may well be other situations similar in nature. Overall, Waikiki represents an urban metropolitan situation in which intensive high rise development provides a vertical reservoir of great capacity to hold masses of people bent on a recreational objective which requires a spreadout of humanity over a horizontal plane. Inasmuch as the carrying capacity of this plane, or beach, was not a determinant in sizing the reservoir, a number of problems are generated by the system. In terms of water quality, however, two are of major importance:

a) The effect of intensive use of limited beach area and of inshore water by people on the quality of the water and, hence, upon the continued suitability of the water environment for human recreation.
b) The possibility that pollution of other sectors of the coast may be carried by ocean currents into the Waikiki Beach area and so make its waters unsuited to human use.

If either of these possibilities should prove critical, an economic disaster to the area would occur even though tourists might seek beaches elsewhere in the islands of Hawaii. The situation at Waikiki beach therefore affords the opportunity to study the effects of intensive recreational use on coastal water quality, provided that such effects can be isolated from the effects of natural phenomena and that any other quality factors which may migrate into the area from elsewhere.

Originally, Waikiki Beach was a barrier beach between the Ala Wai-Moiliili duckponds and swamps and the ocean. Interception of surface runoff from Manoa and Palolo streams and adjacent areas by the Ala Wai Canal and drainage of the swamps by that canal, changed the character of the area significantly. Thus, in recent years, Waikiki Beach has become an artificial beach, nourished by imported sand. Typical artificial sections are Kuhio Beach, near the center of Waikiki, and a new extension of this beach toward the east.

South of Kuhio Beach the width of Waikiki Beach appears to depend on the presence or absence of groins. The central reef area off Kuhio Beach and the adjacent hotels has been largely cleared of coral heads for the convenience of swimmers. Sand lies in large patches that according to evidence cited by Moberly (1963) are relatively fixed in position. The reef offshore of the Royal Hawaiian Hotel has few sandy areas, but a moderately large channel filled with sand to a depth greater than 20 feet does cross the reef offshore from the Halekulani Hotel.

Figure 4.6 shows the general aspect of Waikiki Beach along with sampling stations used by the State Department of Health and the Corps of Engineers in studies of the area. Of particular note is that the beach area is bounded on the east by the relatively pristine waters off Diamond

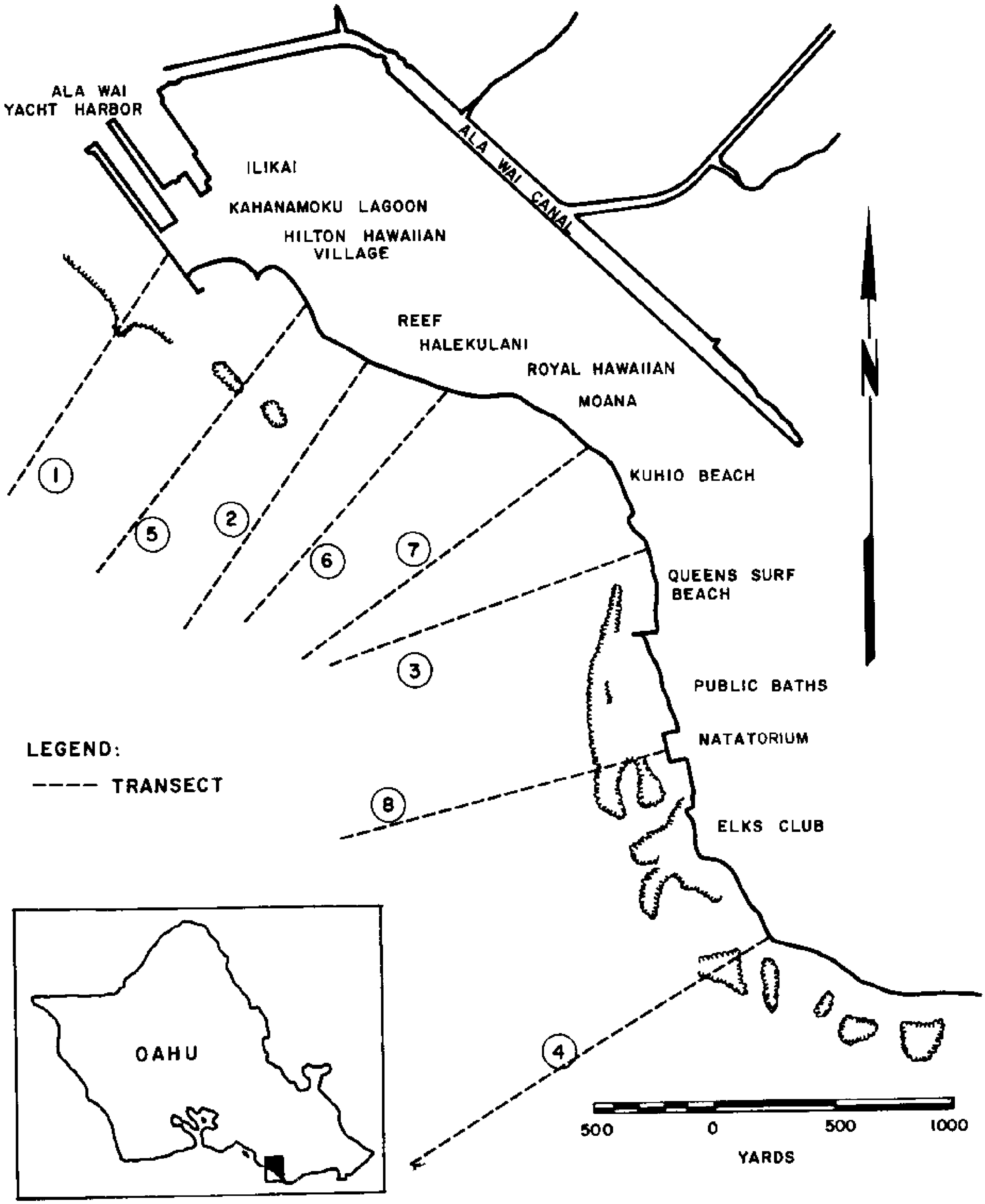


FIGURE 4.6. TRANSECTS FOR SAMPLING STATION LOCATION AT WAIKIKI BEACH.

Head. On the west however, is the Ala Wai Boat Harbor and the mouth of the Ala Wai Canal which intercepts and concentrates at one point the urban run-off from a large urban land area in Honolulu. Thus, it might be expected that any major contamination of Waikiki Beach by discharged surface runoff would come from the west and not from the east. Should such transport not occur, then monitoring the coastal waters off the beach should reflect any effects that loading of the area with people per se might produce.

STUDIES OF WAIKIKI BEACH. The State Department of Health has designated the coastal water at Waikiki Beach as Class A. To monitor its quality, bacteriological analyses are made every two weeks of samples taken at eight stations between the Elks Club on the east and Kahanamoku Beach (Fig. 4.6). Results of these analyses, summarized in Table 4.9 show that

TABLE 4.9. ANALYSIS OF COLIFORM DATA, WAIKIKI BEACH.

STATION LOCATION	TOTAL NUMBER OF SAMPLES TAKEN 1969, 1970, 1971	NUMBER OF SAMPLES $\geq$1100 MPN/100 ml
KAHANAMOKU BEACH	163	4
FORT DERUSSY BEACH	162	7
GRAY'S BEACH	183	17
TAVERN BEACH	166	4
KUHIO BEACH	172	12
PUBLIC BATH BEACH	183	10
ELK'S CLUB BEACH	164	2
WAIKIKI NATATORIUM	92	2

about 4.5 percent of 1285 samples taken at eight stations during the 3-year period between 1969 to 1971 exceeded the maximum coliform concentrations of 1000/100 ml standard for Class A waters.

An extensive study to determine the movement of water, circulation of sands, and wave front patterns off Waikiki Beach under various weather, wave, and tide conditions is being conducted by Keith E. Chave of the University of Hawaii, Department of Oceanography, for the U.S. Army Corps of Engineers. Although the basic objectives of the Chave project is concern physical aspects of the environment, cooperation between the project and the Coastal Water Quality group was arranged to obtain analytical data on the quality of ocean water and sediments. Tables 4.10 and 4.11 present the results of analysis of samples taken along the transects (TR-1 to TR-8) of Figure 4.6. Although data are taken at more frequent depths along these transects, they are sufficiently similar so that only the values at 6, 25, and 50 feet depth need be summarized here.

From Table 4.10, it is evident that at all stations total coliform densities were negligible when compared with a standard permitting a maximum of 1000/100 ml. Moreover, the water at all depths along all transects

TABLE 4.10. ANALYSES OF WATER SAMPLES AT WAIKIKI.

	pH						D.O., mg/l						TURBIDITY, ALPHA UNITS						TOTAL COLIFORM/1000.1					
DATE	01/13/72			03/29/71			01/13/72			03/29/72			01/13/72			03/29/72			01/13/72			03/29/72		
DEPTH	6	25	50	6	25	50	6	25	50	6	25	50	6	25	50	6	25	50	6	25	50	6	25	50
TR-1	8.30	8.30	8.35	8.25	8.25	8.23	—	—	—	7.85	7.20	7.05	4.1	2.3	0.9	0.34	0.36	1.05	—	—	—	0	0	0
TR-2	8.40	8.35	8.40	8.19	8.20	8.19	—	—	—	7.30	7.20	7.35	1.3	2.4	1.0	0.75	0.49	0.86	—	—	—	2	2	24
TR-3	8.20	8.35	8.35	8.19	8.22	8.20	—	—	—	7.35	7.20	7.30	3.0	3.8	1.0	1.00	0.36	0.22	—	—	—	38	5	11
TR-4	8.35	8.30	8.35	8.24	8.20	8.20	—	—	—	8.19	7.62	7.82	3.0	2.8	4.0	1.05	0.95	0.46	—	—	—	9	15	0
TR-5	8.40	8.30	8.35	8.20	8.21	8.22	—	—	—	8.05	7.40	7.10	1.7	2.4	0.5	0.63	0.34	0.45	—	—	—	0	1	0
TR-6	8.40	8.40	8.40	8.19	8.21	8.21	—	—	—	8.20	7.10	7.25	2.8	3.0	1.0	0.46	0.49	0.63	—	—	—	14	1	0
TR-7	8.25	8.45	8.35	8.21	8.18	8.21	—	—	—	8.20	6.90	7.10	2.7	2.4	0.8	0.80	0.36	0.69	—	—	—	5	1	0
TR-8	8.30	8.30	8.30	8.21	8.19	8.21	—	—	—	7.78	7.65	7.40	3.2	1.25	0.5	0.83	0.40	0.40	—	—	—	0	17	0

	SALINITY, °/..						TOTAL NITROGEN, mg/l						TOTAL PHOSPHORUS, mg/l					
DATE	01/13/72			03/29/72			01/13/72			03/29/72			01/13/72			03/29/72		
DEPTH	6	25	50	6	25	50	6	25	50	6	25	50	6	25	50	6	25	50
TR-1	32.8	—	26.0	33.4	33.4	33.0	0.254	—	0.091	—	—	0.085	0.026	—	0.039	—	—	0.038
TR-2	36.6	31.2	—	32.8	33.0	32.8	0.174	0.793	0.061	—	—	0.044	0.032	0.031	0.042	—	—	0.025
TR-3	35.0	33.0	—	32.2	33.0	33.0	0.267	0.181	0.115	—	—	0.057	0.113	0.017	0.025	—	—	0.030
TR-4	32.0	32.8	—	32.4	32.0	31.9	0.255	0.266	0.063	—	—	0.081	0.032	0.041	0.028	—	—	0.032
TR-5	32.4	31.2	—	32.5	32.4	33.0	0.594	0.546	0.041	—	—	0.048	0.024	0.054	0.021	—	—	0.045
TR-6	33.2	31.2	—	32.4	33.0	33.2	0.308	0.812	0.043	—	—	0.078	0.014	0.026	0.017	—	—	0.029
TR-7	32.2	33.0	—	32.2	32.8	32.8	0.078	0.704	0.045	—	—	0.084	0.011	0.035	0.025	—	—	0.023
TR-8	—	33.0	—	33.0	32.8	33.0	0.220	—	0.075	—	—	0.037	0.029	0.048	0.018	—	—	0.030

TABLE 4.11. NUTRIENTS AND METALS IN SEDIMENTS AT WAIKIKI.

NUTRIENTS AND HEAVY METALS	STATION NUMBER																					
	1A	1B	1C	1D	1G	2A	2B	2D	3A	3B	3D	3E	3F	3G	4A	5H	6A	6B	6D	8A	8B	8C
TOTAL-N, mg/l	210	334	358	328	320	338	306	254	368	306	299	237	260	394	386	310	368	383	345	405	292	320
TOTAL-P, mg/l	532	400	419	454	550	552	327	500	427	548	627	585	810	475	511	478	574	518	534	512	573	544
TOTAL-K, mg/l	207	305	291	256	231	214	352	321	300	299	361	270	240	294	350	294	300	260	344	288	444	238
Pb, ppm	28.1	37.8	31.0	37.2	34.7	35.7	44.8	44.6	34.3	33.4	31.7	52.6	39.5	33.8	37.4	34.6	31.7	37.1	28.8	48.1	42.2	33.8
Cu, ppm	4.1	3.4	4.8	4.5	3.2	1.8	4.2	2.1	3.3	4.2	5.4	2.0	10.2	2.1	5.2	5.2	2.0	2.8	1.9	2.9	4.1	11.8
Zn, ppm	6.0	8.8	4.1	6.5	5.9	3.6	4.1	8.6	5.1	5.1	4.9	21.1	6.9	3.2	10.8	10.3	2.2	6.9	4.8	3.7	9.2	6.4
Cd, ppm	0.6	0.8	0.8	0.5	0.6	0.7	1.1	0.3	0.5	1.4	1.3	0.8	0.6	0.6	0.8	1.0	0.3	0.3	0.6	0.5	0.6	0.8
Hg. ppm	0.09	0.02	0.08	0.11	0.05	ND	0.08	1.16	0.09	0.03	0.09	ND	0.06	0.12	0.09	0.11	0.08	0.07	0.18	0.11	0.09	0.08
Ni, ppm	27.5	42.7	33.3	32.0	42.5	27.4	41.9	35.7	51.1	48.2	40.4	41.5	32.9	ND	31.5	40.8	30.7	31.2	44.7	47.1	54.4	31.8
Cr, ppm	16.3	9.4	15.8	17.9	15.0	7.5	15.8	14.3	20.0	20.0	19.8	18.9	19.5	15.9	23.1	11.1	14.7	14.9	15.0	15.4	17.8	17.2

ND = NOT DETECTABLE

was clear, high in dissolved oxygen content, and of normal pH and salinity. Values of total phosphorus and total nitrogen of 0.025 mg/l and 0.15 mg/l, respectively are not generally met. Nitrogen is particularly high at the shallower depths. At the present writing, there is mounting evidence throughout the Coastal Water Quality studies (Chapters 2, 3, and 4) that the limits specified for Class AA and generally Class A are too restrictive and are exceeded normally by unpolluted open ocean waters.

Analyses of sediments show that in nitrogen, phosphorus, and potassium the sediments at Waikiki are comparable to those observed in north Kauai (Table 3.17, Chapter 3). Of the heavy metals, lead content in the Waikiki samples is similar to that found in coastal sediments at north Kauai but about 1.5 to 2 times those reported for the one observation at the Kahana Bay assumed pristine area. On the other hand, the cadium content in the Kahana Bay sample was one order of magnitude greater than that for Waikiki. Essentially the same is true for the zinc content which was low for Waikiki compared to that for north Kauai and Kahana Bay. Mercury levels compare favorably with that observed at other stations. No comparable data are presently available for nickel and chronium.

SUMMARY OF SITUATION. Waikiki continues to offer an opportunity for observing the quality of water and sediments under intense recreational use of coastal water in an urban metropolitan area. Through cooperation with the Corps of Engineers' sponsored study, data on the quality of water and sediments at Waikiki can be obtained essentially for the cost of laboratory analysis. Such data are already proving useful in judging levels of nutrients and heavy metals which may characterize Hawaiian waters and sediments without particular regard to land use. It is this kind of data which will ultimately provide the background information necessary for the evaluation of land use-water quality relationships. In the meantime, the Waikiki data do not identify any specific water quality effect attributable solely to the presence of large numbers of people in a relatively small area of coastal water.

Maunalua Bay

NATURE OF SITUATION. One aspect of urbanization of land, which may have unique effects on coastal water quality not identifiable by an overall analysis of surface runoff or of wastewater discharges, is the construction of housing units around marinas made by dredging and draining low-lying swampland. This has the effect of releasing at one single point in time the accumulated organic matter of perhaps centuries. Such an effect is, however, transient and hence not as serious as two other factors--the confining of water under circumstances of poor circulation and the continuous presence of people and their urban activities on the shoreline. The first of these two often provides an incubator for organisms under eutrophic conditions and serve as settling basins for solids which may be flushed out from time to time. The second may provide the nutrients from lawn fertilization and general debris needed to encourage eutrophication and introduce pesticides from garden maintenance or protection of structures. In a developing area, therefore, the marina itself may be esthetically objectionable between flushouts and may discharge periodically an appreciable volume of unsatisfactory water into adjacent coastal environments. An opportune area to isolate and study this facet of urbanization exists at Maunalua Bay.

The Maunalua Bay study area is located on the island of Oahu approximately 10 miles from the heart of Honolulu. The area selected for study includes four small watershed areas; the Kaalakei Valley, Hahaione Valley, Kamilonui Valley, and Kamiloiki Valley to Kalanianiole Highway as shown in Figure 4.7. The projected land drainage area is slightly greater than 4000 acres and is characterized by steep ridges and mildly sloping valleys. The study area extends from an elevation of over 2000 feet on the Koolau Mountain Range at the northern boundary of the watershed areas to sea level at the 258 acre Hawaii Kai Marina which constitute the southern boundary.

Each of the four valleys are separated by steep ridges that are generally perpendicular to the Koolau Range. The ridges are eroded remanents of accumulations of lava flows. There is an abundance of haole koa bushes and "California grass." The slopes of the Koolau Range and the abutting ridge portions adjacent to the Koolau Range, particularly near the base, support a large variety of grasses, bushes, and trees. Soil slippage and land slides are common where the gradient is steep and near the mountain crests.

According to the Hawaii Water Authority isohyetal map (1959), the study area receives 30 to 40 inches of rainfall annually. Each of the four valleys have at least one well-defined intermittent stream which carries water from its respective watershed to the Hawaii Kai Marina.

Construction of the Hawaii Kai Marina and portions of the adjacent land were started in the early 1960's by the Kaiser Aetna Corporation by dredging the approximately 2500-acre Kuapa pond, an old Hawaiian pond into a series of channels separated by fingers of land and islands. The completed 258 acre marina is reported to have 12 miles of shoreline and an average depth of 6 feet (Kaiser Aetna Corporation, undated). The marina has two openings into Maunalua Bay beneath bridges on Kalanianiole Highway that travere the narrow strip of land between the marina and the Bay. The opening into the main body of the marina is large enough to permit boats with superstructures up to 13 feet above the waterline to pass through at high tide.

The Hawaii Kai area, currently in a fairly rapid state of development, has a population presently, estimated at 17,000, to 18,000, including the area representing 20 to 25 percent of the land southeast of the Kalanianiole Highway at the base of Koko Head, outside the defined study area. At the ultimate state of development the population is anticipated to range between 45,000 and 50,000. (The WQPO gives 67,000 as the anticipated total population.)

The portion of the marina that has been completed for the longest period of time, since the early 1960's, is the area near the mouth of Hahaione Valley. The major quantity of excess surface water from the Valley is conducted through the concrete lined Hahaione canal that drains the upper portion of Hahaione Valley and discharges into the eastern finger of the marina between Hawaii Kai Drive and Kumukahi Place road. The drainage canal has recently (1972) been extended a distance of approximately three-quarters of a mile to accommodate surface drainage from some 400 new dwellings in the initial stages of construction in mid-1972. This "older" portion of the marina, thus, should represent the most stable portion of the entire 258-acre marina development.

The marina opens into Maunalua Bay through two outlets, as previously noted. The Bay itself, within the boundaries selected for study, is one of

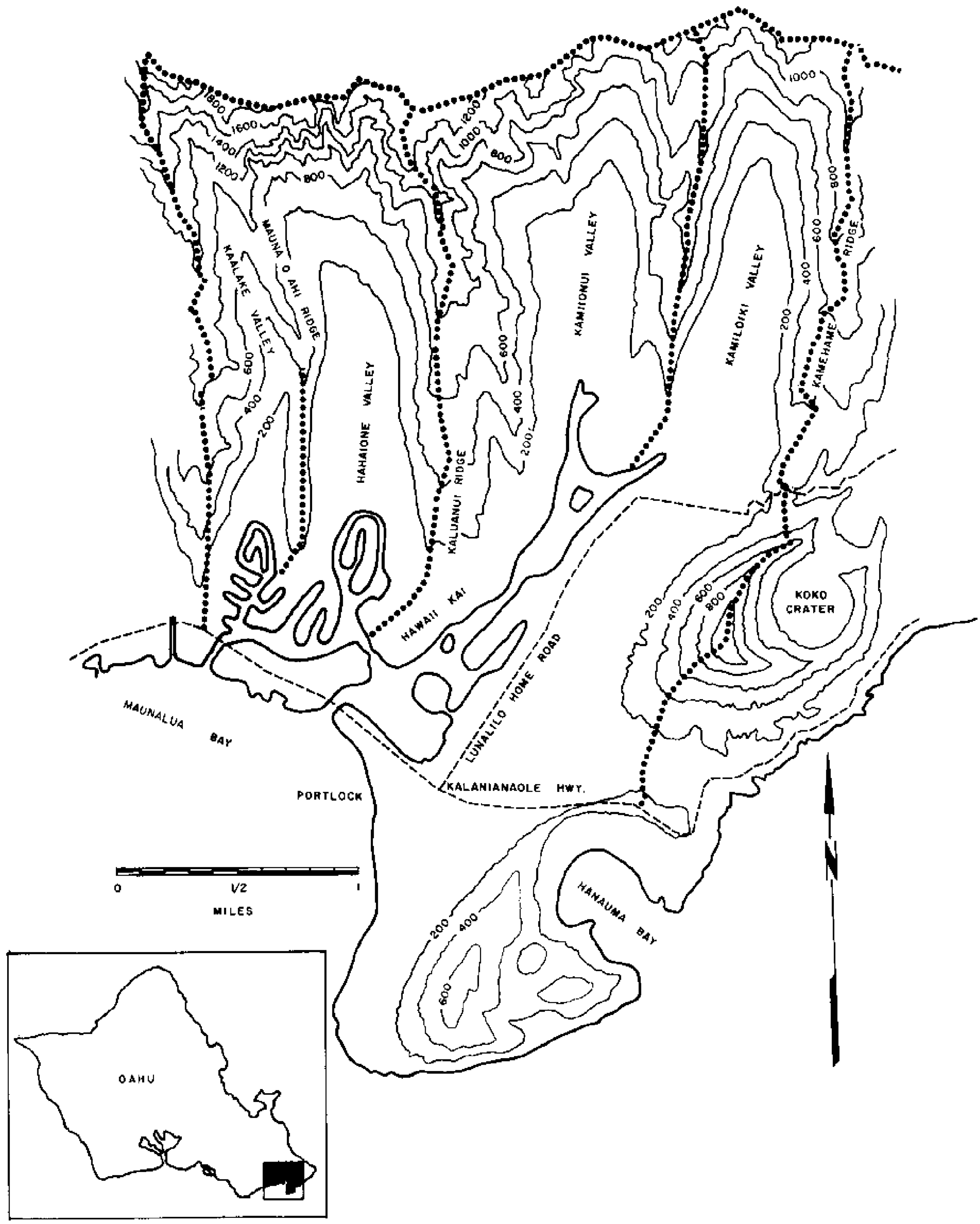


FIGURE 4.7. MAUNALUA BAY AREA.

Hawaii's shallowest reefs. In the area extending from Koko Head to the easternmost of the two outlets of the Hawaii Kai Marina, the bottom is fairly flat and covered with sand. West of the outlet, mud deposits are evident along the small boat channel which extends parallel to shore from the boat launching ramp and the westernmost outlet toward the east channel. Seaward of this channel, the reef flat consists of coral rock covered by benthic algae interspersed with large pockets of sand. West of the westernmost outlet, mud deposits are evident on the inner reef flat all the way to the Paiko Peninsula. Suspended solids carried out of the marina during storm flushout periods are evident, especially when construction activities have stripped vegetation from the highly colored soils of the valley walls. Some sediments are deposited in the marina and Maunalua Bay. Extensive reef is readily visible through the shallow water and is exposed at low tide. In times of storm, the sediment may become resuspended, discoloring the marina and the Bay. The rapid accumulation of sediments within about three years in parts of the marina has prompted recent redredging.

FINDINGS OF OTHERS. The State Department of Health has been collecting water samples for bacteriological analysis since 1970. Currently they collect and analyze samples from the six stations within the marina, shown on Figure 4.8 on a twice per month schedule. Results of coliform analyses shown that the maximum concentration of coliform organisms occur at the Koko Isle sampling site with a monthly average concentration of 851 total coliforms/100 ml and 185 fecal coliforms/100 ml over a twelve-month period.

Similarly, a station located at the Hawaii Kai Drive bridge had an average of 730 total coliforms/100 ml and 114 fecal coliforms/100 ml over a fourteen-month period. The other four stations sampled have relatively low coliform concentrations and all stations are within the State Health Department microbiological requirements for Class A waters.

COASTAL WATER QUALITY PROJECT STUDIES. In order to evaluate the various parameters of the older portion of the marina, four stations were established within the marina, one in Maunalua Bay proper, and one in the nearshore waters below Koko Head (Fig. 4.8). Station 1 will not only evaluate the effects of urbanization, but will serve also as a baseline for possible effects of active construction leading ultimately to approximately doubling the present housing units in its drainage area. This portion of the marina is small enough that rapid environmental changes to the input of the marina will be reflected in the water samples and not be dampened out as might be the case in larger portions of the marina. Station 2 is intended to reflect possible effects of the interconnecting channel and Stations 3 and 4 are intended to measure the effects of the interchange of marina and Bay waters. The degree of influence that the marina has on Station 5 and to some degree on Station 6 can at best only be speculative at this time.

The water quality analyses for the six stations are tabulated in Table 4.12. Of particular note are the large differences in total solids and chloride values on January 27, 1972 between the wet and dry weather flows. The difference in the chloride values of 100 mg/l for wet weather flow to 12,250 mg/l for dry weather flow indicates the large quantity of dilution that must have taken place even considering that it is possible that fresh water may have been somewhat stratified over the salt water and the wet weather, sample was collected in the fresh water stratum. A gradual

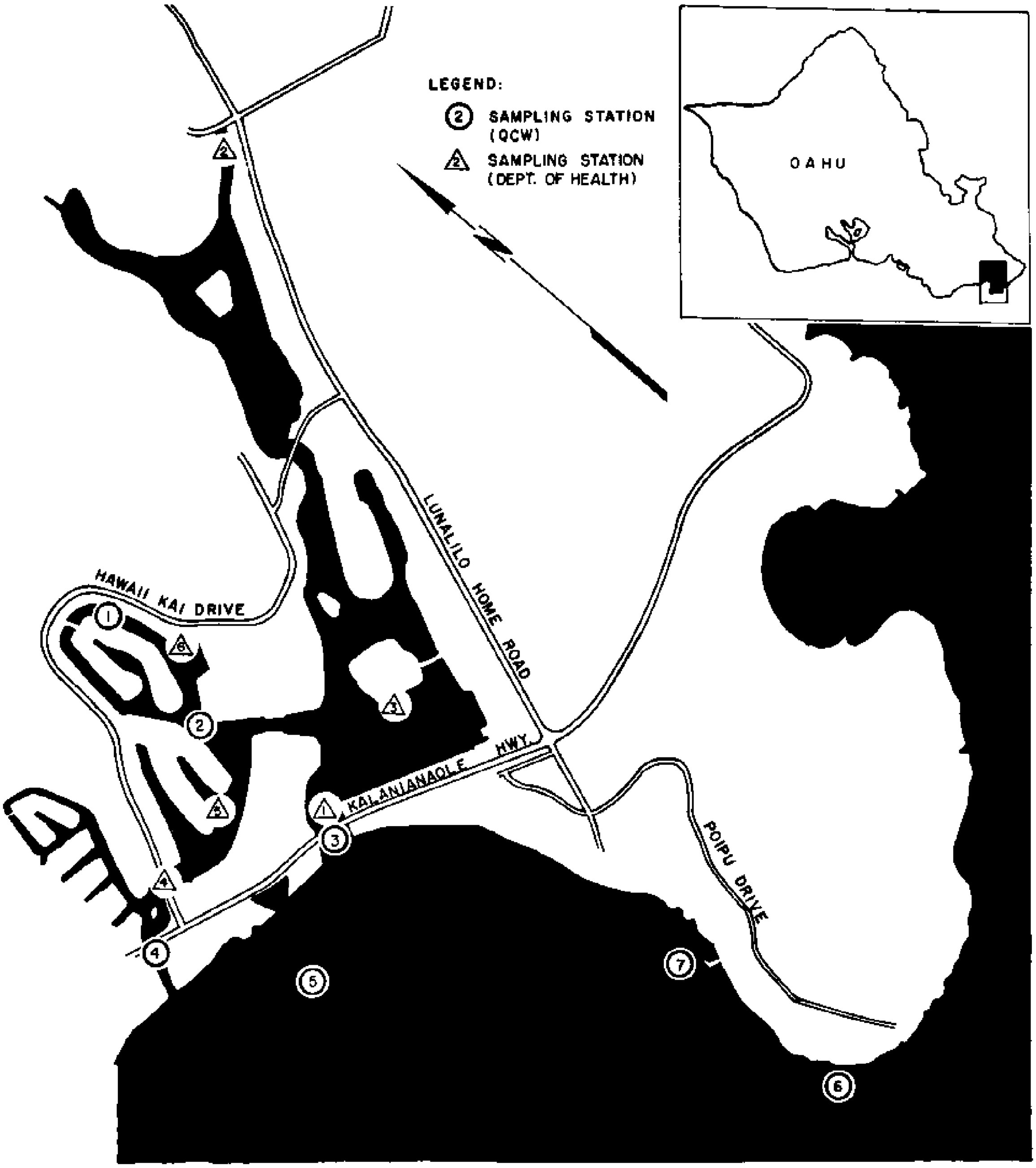


FIGURE 4.8. HAWAII KAI MARINA SAMPLING STATIONS USED IN THE COASTAL WATER QUALITY STUDY.

TABLE 4.12. WATER QUALITY ANALYSES, MAUNALUA BAY AREA.

DATE	STATION	pH	TOT. SOLIDS mg/l	TOTAL-N mg/l	TOTAL-P mg/l	K mg/l	Cl mg/l	TURBIDITY α units
03-27-72	1[2]	7.2	1,052	0.616	0.015	--	100	136
	1[3]	7.6	23,695	0.840	0.021	--	12,250	13
04-29-72	1[4]	7.6	39,244	0.055	0.084	463	18,798	--
	3[4]	7.8	38,612	0.127	0.043	475	19,421	--
	4[4]	7.8	32,998	0.184	0.058	450	19,076	--
05-06-72	5[4]	8.0	38,934	0.142	0.035	535	19,421	--
	6[5]	8.1	43,812	0.058	0.023	512	19,421	--
06-10-72	1	--	--	0.279	0.047	--	18,894	20.0[6]
	2[4]	--	43,090	0.224	0.040	--	19,094	14.0
	3	--	38,418	0.204	0.030	--	19.094	12.0
	4	--	38,865	0.155	0.041	--	18,994	17.0
	5	--	38,040	0.203	0.031	--	18,994	5.5
	6	--	38,663	0.077	0.023	--	19,094	4.0

		CARBON			HEAVY METALS[1]					PESTICIDES			
DATE	STATION	ORG. mg/l	INORG. mg/l	TOT. mg/l	Pb µg/l	Cu µg/l	Zn µg/l	Cd µg/l	Hg µg/l	LINDANE ng/l	DIELDRIN ng/l	DDT ng/l	PCP ng/l
03-27-72	1[2]	--	--	--	--	--	--	--	--	--	--	--	--
	1[3]	--	--	--	--	--	--	--	--	--	--	--	--
04-29-72	1[4]	12	18	30[5]	ND	ND	ND	ND	ND	0.4	1	0.5	ND
	3[4]	9	17	26	ND	ND	ND	ND	ND	0.4	1	2	ND
	4[4]	10	18	28	ND	ND	ND	ND	ND	0.7	2	2	ND
05-06-72	5[4]	9	17	26	ND	ND	ND	ND	ND	<1	<1	4	62
	6[5]	9	15	24	ND	ND	ND	ND	ND	<1	<1	4	27
06-10-72	1	8.5	--	--	ND	ND	ND	ND	ND	--	--	--	--
	2[4]	6.8	--	--	ND	ND	ND	ND	ND	--	--	--	--
	3	8.1	--	--	ND	ND	ND	ND	ND	--	--	--	--
	4	8.5	--	--	ND	ND	ND	ND	ND	--	--	--	--
	5	4.0	--	--	ND	ND	ND	ND	ND	--	--	--	--
	6	5.8	--	--	ND	ND	ND	ND	ND	--	--	--	--

[1] LIMITS OF DETECTABILITY: Pb--5.0 µg/l; Cu--1.0 µg/l; Zn--1.0 µg/l; Cd--1.0 µg/l; AND Hg-- µg/l.
[2] WET WEATHER FLOW
[3] DRY WEATHER FLOW
[4] REFER TO FIGURE
[5] NON DETECTABLE
[6] TURBIDITY IN FTU (HACH)
[7] ng/l = NANOGRAM/LITER

increase of nitrogen and phosphorus in the water from the most inland station to the ocean station in Maunalua Bay is clearly identifiable. While heavy metals (lead, copper, zinc, cadmium, and mercury) are absent in the samples, DDT and several other pesticides are ubiquitous despite their minute content. Further discussions must await additional data not only for water but also sediment and biota.

Sandy Beach

NATURE OF SITUATION. Sandy Beach is a popular recreational beach area at the mouth of Kalama Valley on the Windward Coast of southeastern Oahu. The Kalama Valley watershed itself encompasses about 1560 acres and its coastal extent spans Kaloko Point to the north to Halona Point or the "Blowhole" to the south. The area is warm and dry with Kalama Stream flowing intermittently, principally during the heavy rainfall occurring during the winter season of cyclonic storms. There are two defined beach areas: Wawamalu or Queen's Beach, northward toward Kaloko Point, and Sandy Beach. The former being rocky is little used: the latter, true to its descriptive name, is a well-frequented area for body surfing and sunbathing.

The selection of Sandy Beach as a study area for this project resulted from its use as a recreational area coupled with the fact that treated domestic sewage from the Hawaii Kai sewage treatment plant is discharged through an ocean outfall offshore from the beach area into water designated Class A by the State Department of Health. The general beach area, treatment plant site, and outfall location are presented as Figure 4.9 and the beach shoreline and profile as Figure 4.10. The watershed area mauka of the brach in Kalama Valley has been relatively undeveloped prior to 1972. The area has historically been agricultural in nature with farm plots for truck crops, pig, and chicken farms held on leasehold from the Bishop Estate. Since control of the area has passed to the Hawaii Kai Development Corporation all the lessees have been removed from the Valley preparatory to its development of the area for residential or resort or both.

The sewage flow to the Hawaii Kai treatment plant presently comes from residential areas as far west as Kuliouou Valley and includes the presently developed Hawaii Kai units in the Kuapa Pond marinas and Hahaione, and Kamiloiki Valleys. The treatment plant went on line in 1966 as a primary facility with chlorination, discharging through a 1400 foot outfall at a depth of 46 feet, using only four of the ten 8-inch diffuser ports installed. The plant was converted to the activated sludge process in early 1972 at a design flow 3.1 mgd. The estimated sewage discharge for Sandy Beach by the year 2020 is 8.6 mgd.

FINDINGS OF OTHERS. A preliminary search for information pertaining to the quality of the coastal water and the nature of wastewater treatment and disposal in the Sandy Beach area was made in early January 1972. Available data were found to be principally those collected by the State Department of Health in its routine monitoring program and by the City and County of Honolulu through its consultants, Oahu Water Quality Program.

The state has analyzed shoreline water samples from two locations at Sandy Beach for total coliform bacteria since 1963, beginning with a once per month sampling in 1963 which was increased to a twice per month schedule in July 1970. In August 1970, monthly data collection was extended to such other water quality parameters as fecal coliform, total nitrogen,

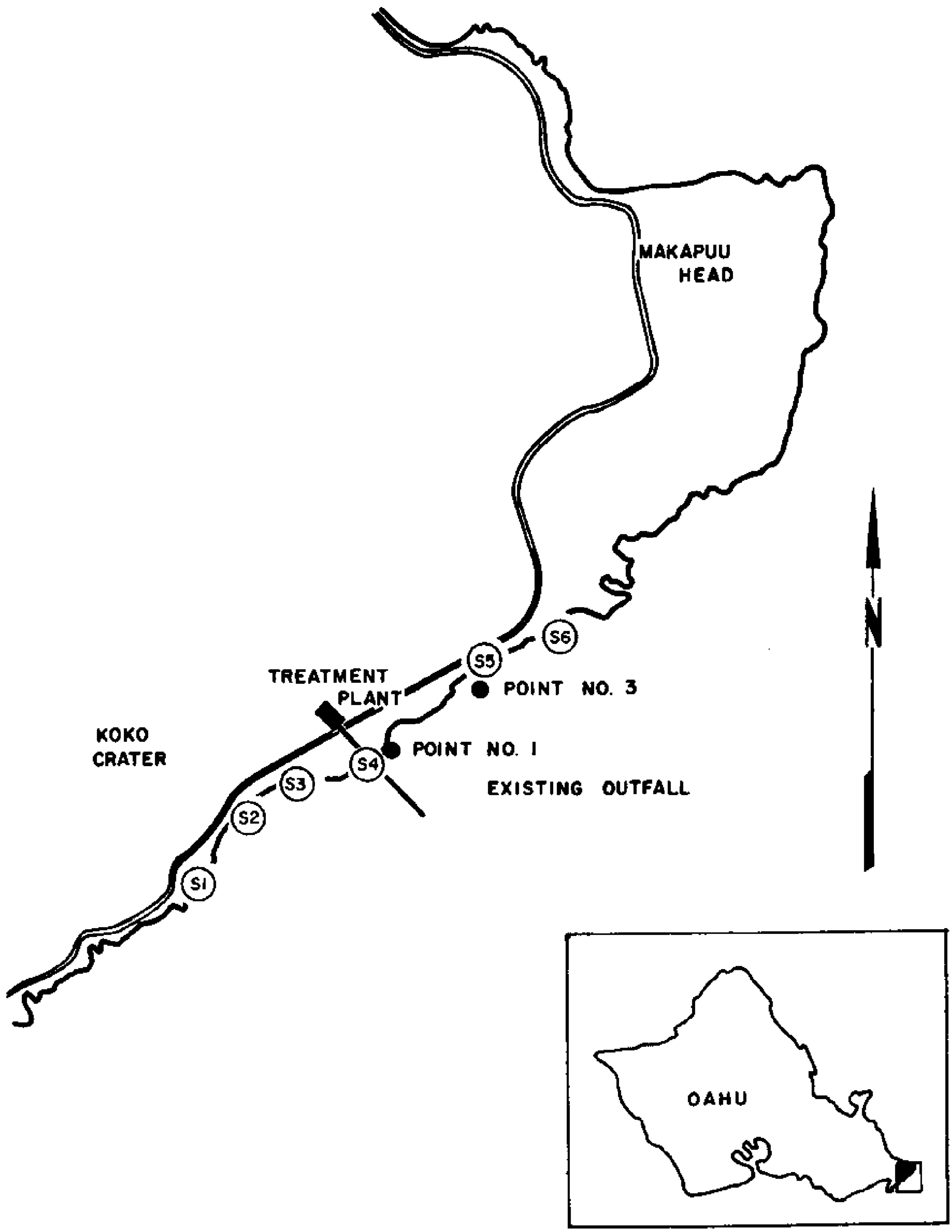


FIGURE 4.9. LOCATION OF OUTFALL SEWER AND WATER SAMPLING STATIONS, SANDY BEACH.

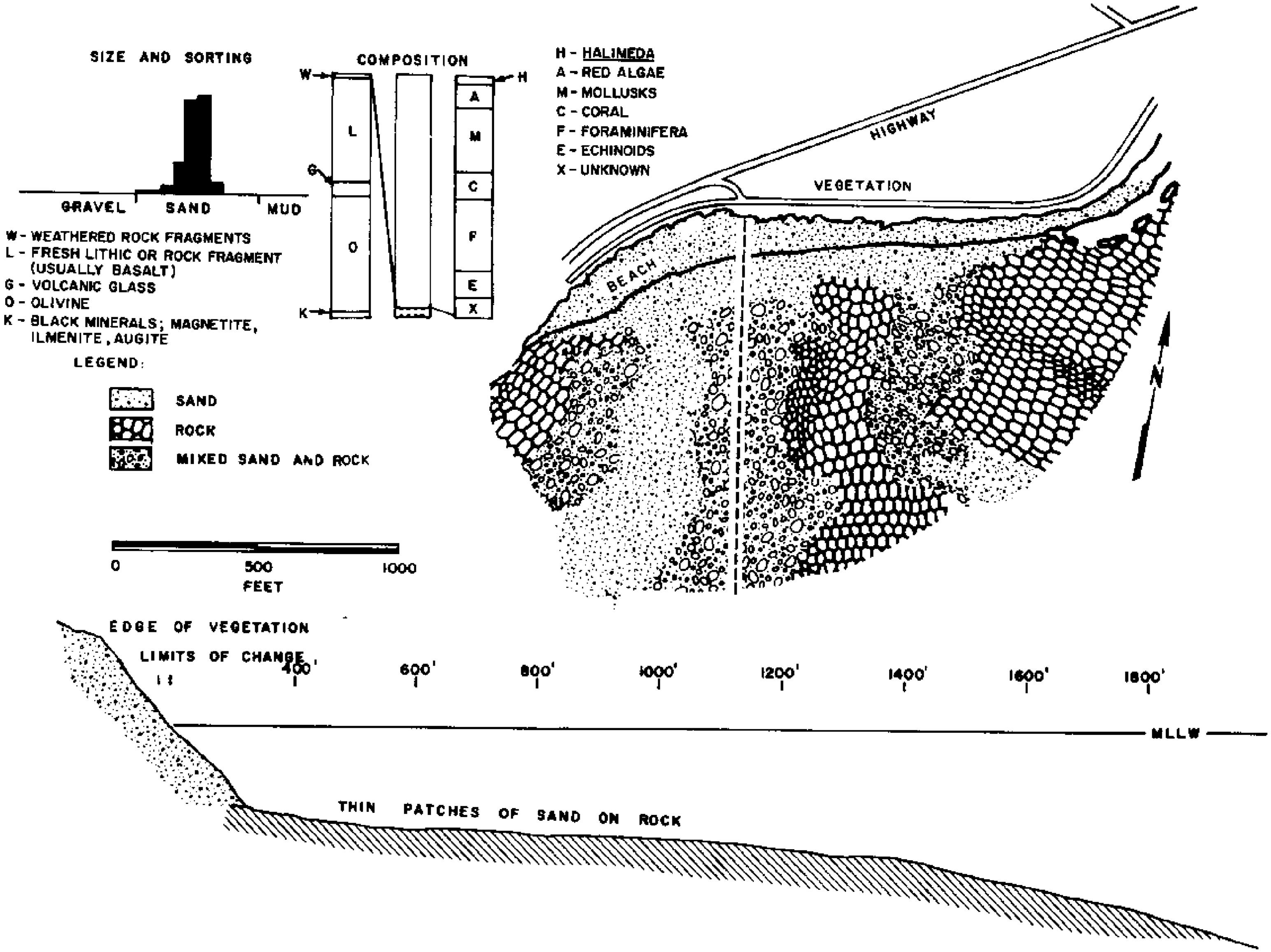


FIGURE 4.10. SHORELINE AND PROFILE, SANDY BEACH (FROM MOBERLY, 1963).

total phosphorus, pH, and total solids. From July 1970 to January 1971, WQPO conducted monthly analysis of surface water samples from one shoreline station and one ocean station over the discharge end of the existing outfall sewer. Water quality parameters observed included such physical factors as temperature, salinity, dissolved oxygen, clarity, and wind velocity and direction; the chemical factors of pH, BOD, various forms of nitrogen, chlorophyll, and reactive and total phosphorus; and coliform organisms. The presently available data from these sources are summarized as follows:

a) Reported total coliform and fecal coliform concentrations are at a level far below the permissible maximum established by the state for Class A waters. However, the frequency of detection of total coliform in shoreline water samples definitely increased between 1963 and 1971. For example, of the 6 samples reported in 1963 none were positive, whereas in 1971 the frequency of positives in 24 samples was 60 to 80 percent. Reported fecal coliform concentrations were at levels below that for total coliform.

b) In 5 of the 16 monthly samples taken in 1970-71, measured total nitrogen content in the shoreline samples exceeded state standards. Three samples were equal to state standards (Fig. 4.11). Measured phosphorus in these same samples exceeded the standards only once (Fig. 4.12).

c) pH was below the state standard of 7.0 in three of the 16 monthly samplings (Fig. 4.13).

d) During the month of November 1970 when the surface current measurements were reported to be generally offshore and to result in a net transport in the southeast direction (Fig. 4.14), none of the shoreline water quality parameters exceeded state standards. No similar current measurements for other months are available, but generalized probable current patterns are predominantly offshore.

The consulting firm of Sunn, Low, Tom, & Hara, Inc. initiated a yearlong study in January 1972 for the Hawaii Kai Development Corporation to evaluate existing conditions at the outfall discharge site and the area between Kaloko to Halona Points and also to provide information for future water quality management decisions as deemed necessary. The study is focused on three major work areas: quality of the water column, dilution and dispersion of the waste discharge, and biological effects, particularly on the benthos. The results of this study are not publicly available, however, a tentative arrangement has been made between the consulting firm and the Coastal Water Quality Project for information and data exchange.

COASTAL WATER QUALITY PROJECT STUDIES. With the availability of past WQPO and Health Department data together with the on-going consultant study offshore from Sandy Beach, the Coastal Water Quality Project control group made a decision to focus on collecting data from shoreline studies to complement the existing and projected work. The field data collection system design was twofold: a biological survey based on photographic observations at the shoreline at three sites and a water quality survey using six shoreline sites, including the three used in the photographic survey and the two Health Department stations. The Coastal Water Quality Project stations are shown in Figure 4.9 and designated as station numbers S1 to S6. The stations were selected to include the areas directly onshore from the outfall and also in both the northerly and southerly directions from the outfall. The photographic observations, begun in January 1972, are made on a monthly basis while the water quality observations are made

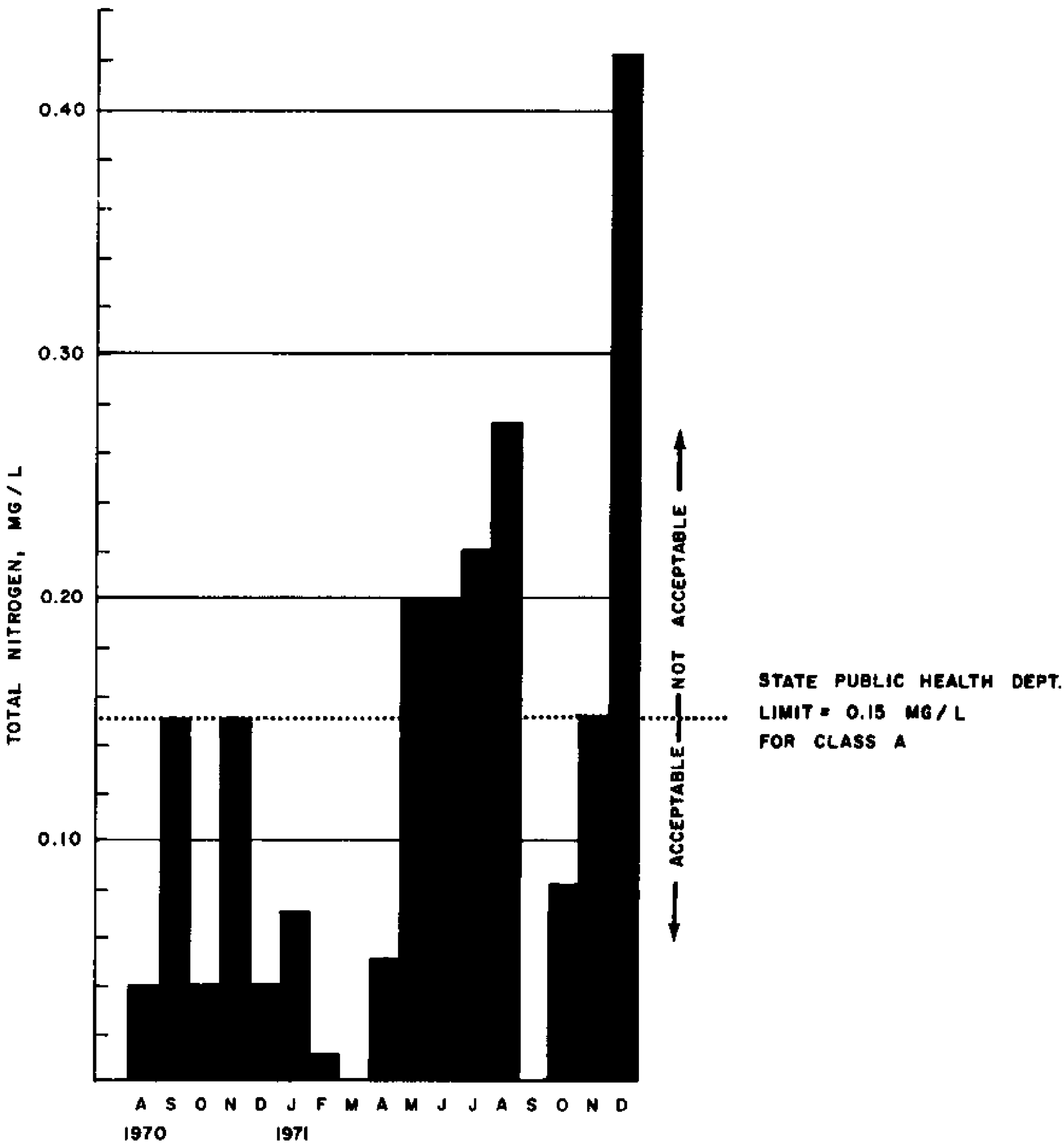


FIGURE 4.11. TOTAL NITROGEN AT SAMPLING STATION 3, SANDY BEACH, 1970-71.

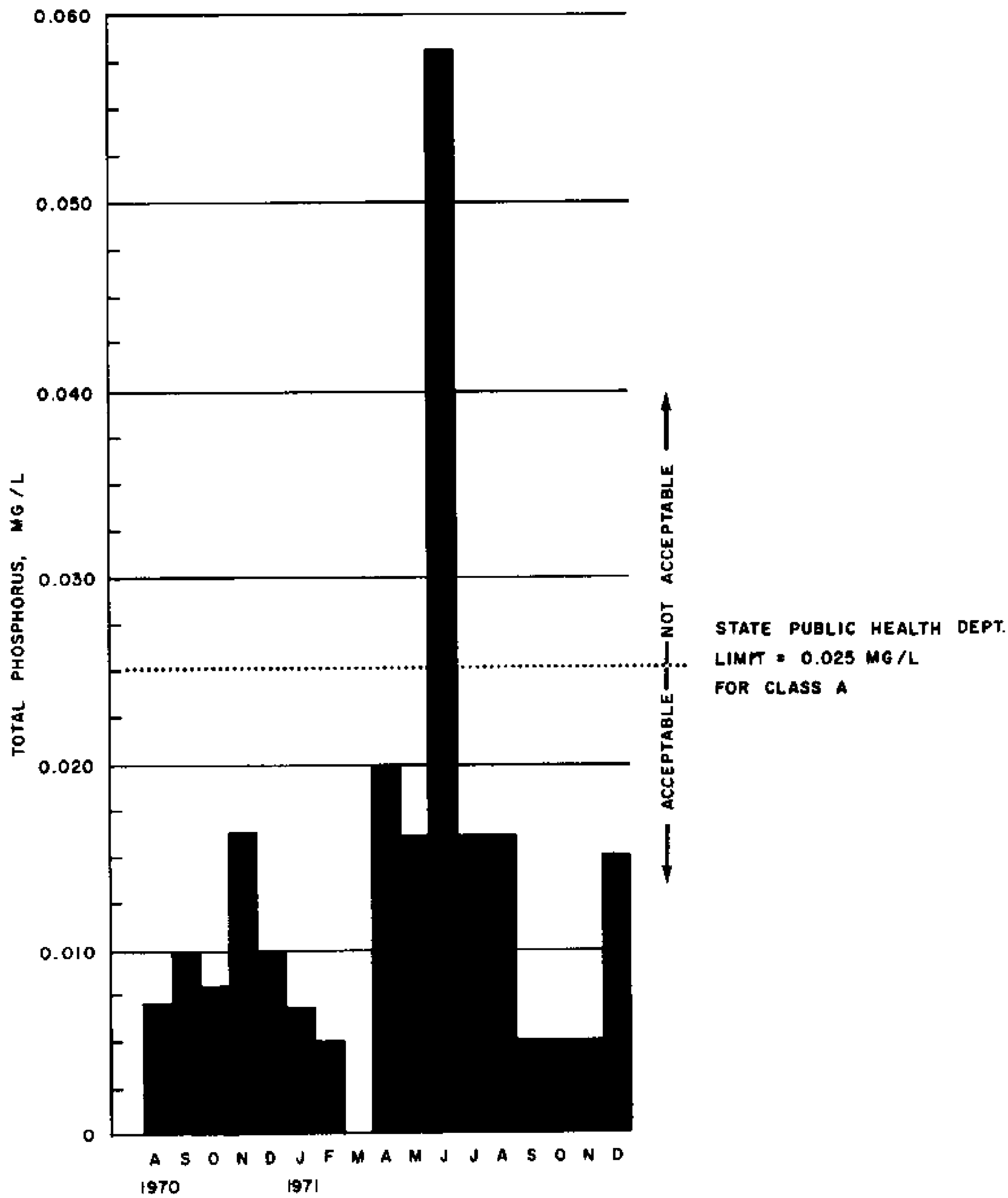


FIGURE 4.12. TOTAL PHOSPHORUS AT SAMPLING STATION 3, SANDY BEACH, 1970-71.

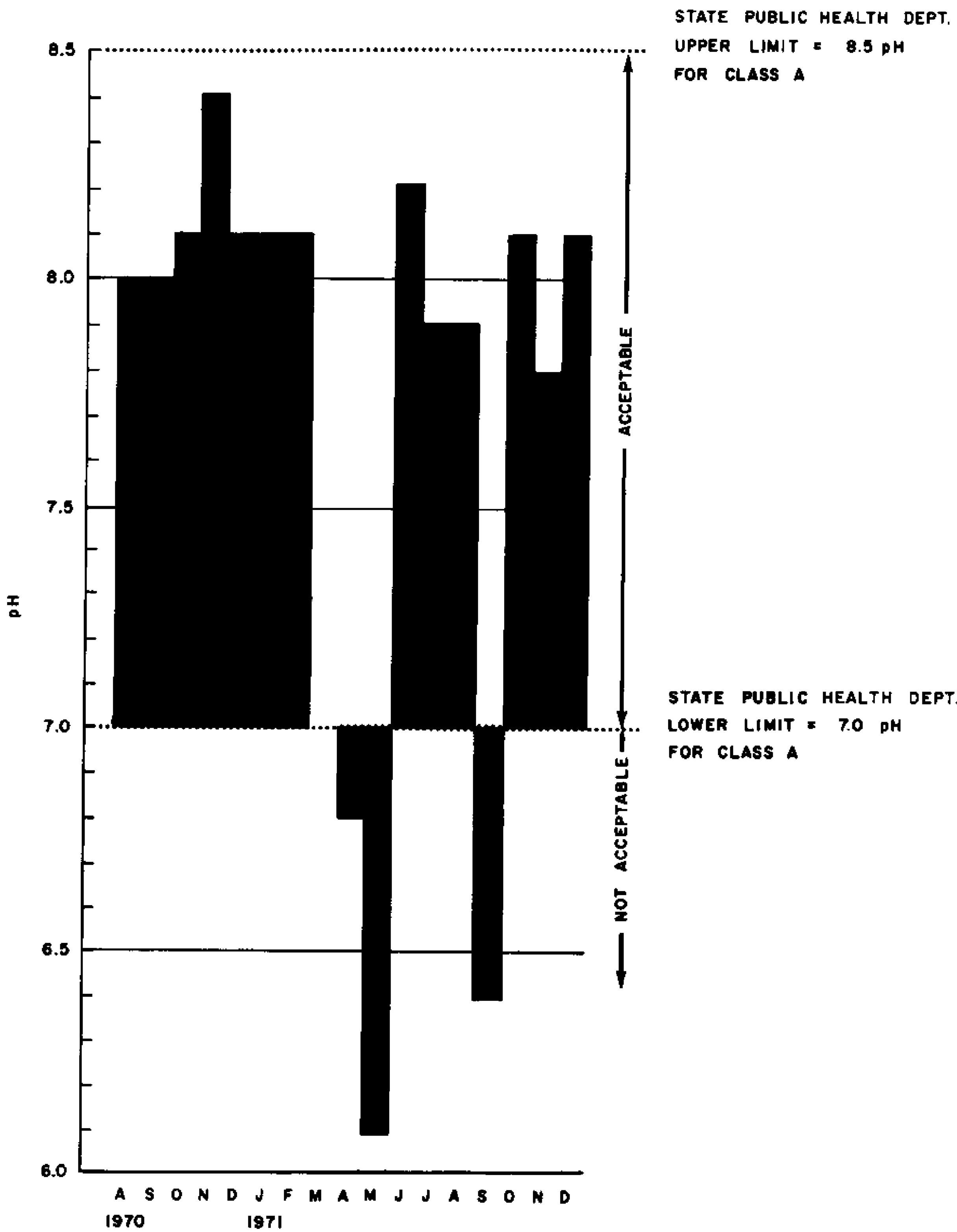


FIGURE 4.13. pH VALUES AT SAMPLING STATION 3, SANDY BEACH, 1970-71.

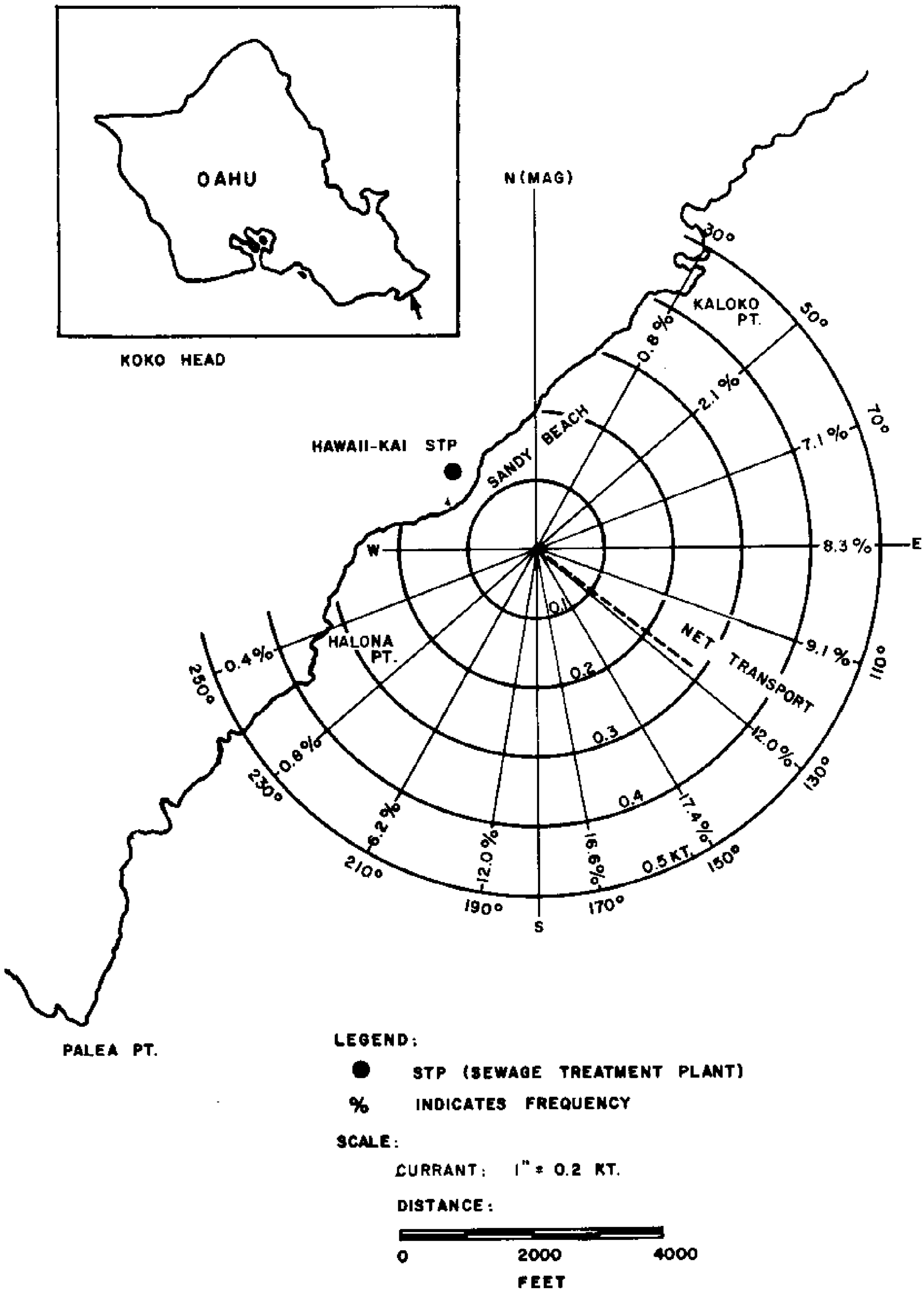


FIGURE 4.14. SURFACE CURRENTS AT SANDY BEACH, NOV. 15-25, 1970 (FROM WQPO).

quarterly. Only one set of data has been obtained thus far in April 1972. The results of this survey are given in Table 4.13. The limited data show

TABLE 4.13. RESULTS OF WATER ANALYSIS OF SAMPLES OBTAINED FROM SANDY BEACH. (SAMPLING DATE: APRIL 15, 1972)

PARAMETERS	STATION NUMBER					
	1	2	3	4	5	6
pH	8.1	8.1	8.1	8.1	8.1	8.1
TOTAL SOLIDS, mg/1	37,106	37,032	38,106	37,900	39,315	38,942
TOTAL CARBON, mg/1	25	28	30	30	28	28
ORGANIC CARBON, mg/1	7	11	14	14	12	12
INORGANIC CARBON, mg/1	18	17	16	16	16	16
TOTAL NITROGEN, mg/1	0.056	0.104	0.041	0.052	0.119	0.104
TOTAL PHOSPHORUS, mg/1	0.034	0.031	0.035	0.026	0.037	0.035
CHLORIDES, mg/1	18,860	18,859	18,861	18,860	18,860	18,860
DDT, ppt	ND	ND	ND	3	ND	2
PCB, ppt	*	*	*	*	*	*

NOTE: ND = NOT DETECTABLE. LINDANE, HEPTACHLOR, HEPTACHLOR EPOXIDE, ALDRIN, DIELDRIN, DDE, DDD, α CHLORDANE, γ CHLORDANE, PCP, SCREENED AND NOT DETECTED, ppt = PARTS PER TRILLION.

* WATER "DIRTIER" THAN PRIOR AREAS AND CONTAIN ORGANIC COMPONENTS WHICH MAY OR MAY NOT BE PCB FRAGMENTARY COMPONENTS

nitrogen values to be less than the state standards, however, phosphorus values are in excess of the standards.

SUMMARY OF SITUATION. Presently available data from the coastal waters at Sandy Beach yield little positive indication of detrimental effects of the wastewater discharge offshore. However, planned increased development of the area together with a prospective near 200 percent in sewage flow make it imperative that the present water quality conditions in the beach area and discharge site are defined to determine effects, if any, on physical, chemical, and biological indicators so that suitable management alternatives, if necessary, may be considered. The combination of monitoring work now being undertaken by the Health Department, the Hawaii Kai Development Corporation (through Sunn, Low, Tom, & Hara), and the Coastal Water Quality Project should be able to provide the required data bank that is presently deficient.

Miscellaneous Studies of Coastal Water Quality Project

MANOA STREAM. An auxiliary study was made of Manoa Valley under the direction of R.H.F. Young, Associate Investigator of the Coastal Water Quality Project, to observe how land use affects the quality of stream water during periods of surface runoff. The study, a thesis project by Ronald Y.K. Lee

(1972), contains data which can be interpreted in terms of the effect of urban land use on coastal water quality.

Manoa Stream and its tributaries drain an area of about 4200 acres extending from the tidal-influenced Ala Wai Canal, a distance of some 6 miles towards the Koolau ridges to an elevation of 3000 feet, and crossing rainfall isohyets ranging from about 20 to 150 inches per year (Ching, 1972). Figure 4.15 shows the location of Manoa Valley and the 6 sampling

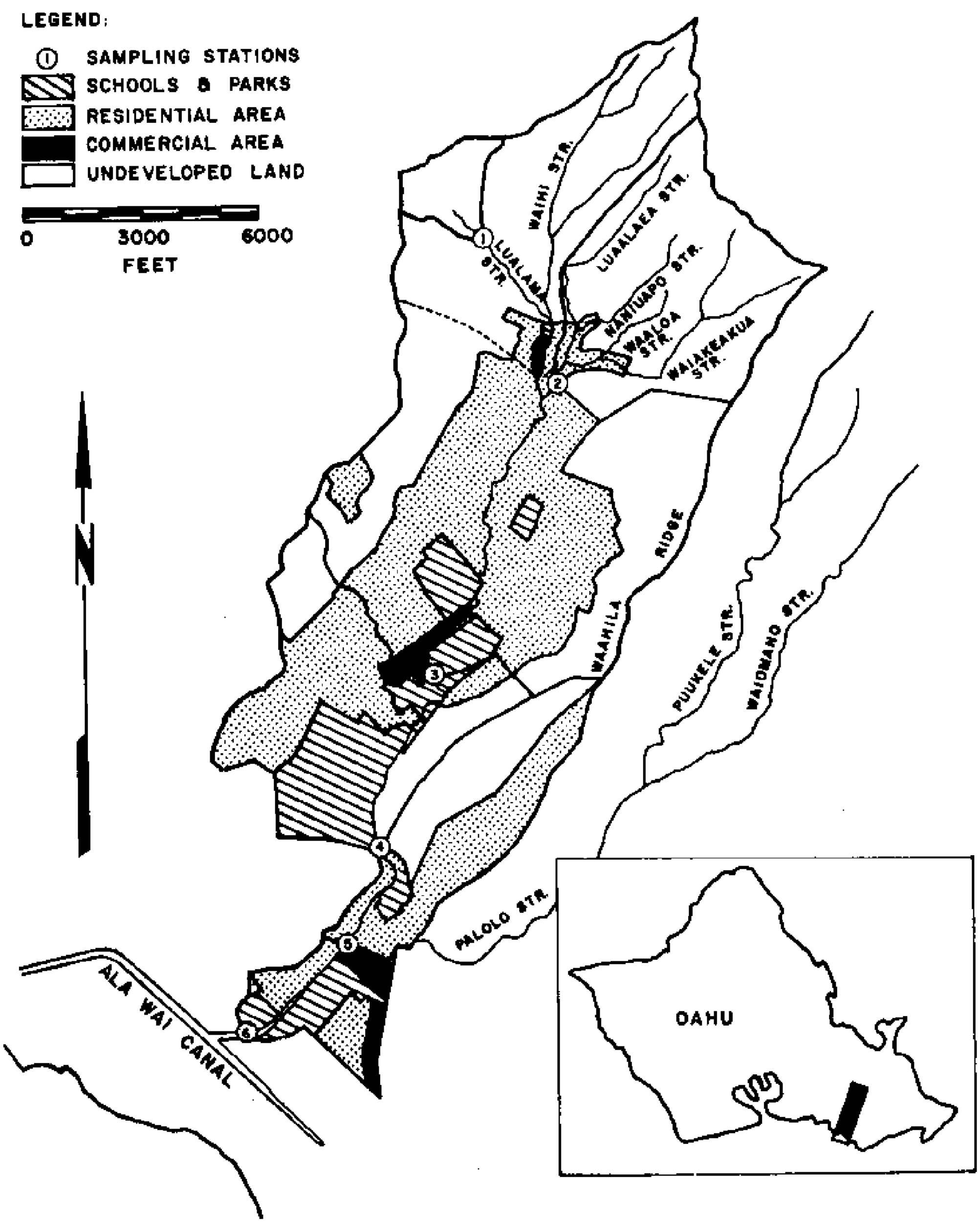


FIGURE 4.15. LAND USE ACTIVITY IN STUDY AREA.

stations used in the study. If residences, schools and parks, and commercial areas are all considered, urban data as presented by Lee (1972 shows the relationship shown in Table 4.14, A.

TABLE 4.14. AVERAGE DAILY STREAM LOADING BASED ON TOTAL DRAINAGE AREA, MANOA STREAM.

	STATION 1	STATION 2	STATION 3	STATION 4
A. URBAN DEVELOPMENT IN MANOA VALLEY				
DRAINAGE AREA (ACRES)	95	680	3001	3581
PERCENT UNDEVELOPED	100	95	67.7	61.6
PERCENT URBANIZED	0	5	32.3	38.4
B. CONSTITUENT	LOADING IN lbs/ACRE/DAY: DRY WEATHER			
CHLORIDES	.605	.432	.284	.346
NITRATE - N	.0235	.0224	.012	.0237
SUSPENDED SOLIDS	.235	.198	.131	.182
TOTAL SOLIDS	3.28	3.14	2.09	2.62
TOTAL PHOSPHORUS	.0086	.0078	.0038	.0042
TOTAL NITROGEN	.0064	.0060	.0040	.0055
DRY WEATHER STREAM DISCHARGE (cfs)	0.56	3.62	8.78	12.07
C. CONSTITUENT	LOADING IN lbs/ACRE/DAY: WET WEATHER			
CHLORIDES	7.64	1.92	2.72	2.93
NITRATE - N	1.34	.31	.35	.54
SUSPENDED SOLIDS	65.0	15.8	14.9	27.5
TOTAL SOLIDS	114.7	31.97	37.6	49.3
TOTAL PHOSPHORUS	.433	.0902	.1145	.135
TOTAL NITROGEN	.1657	.0399	.0485	.1013
WET WEATHER STREAM DISCHARGE (cfs)	11.21	18.56	107.5	149.2

From chemical analyses and flow measurements from August 1970 to May 1971, the load on the stream in lbs/acre/day was computed for both dry and wet weather flows. The results are summarized in Table 4.14. If Station 1 is discounted, the data in Table 4.14 tell an interesting and not unexpected story. First, the quality factor loading on the stream during dry weather when flow is springfed is essentially unrelated to urban activity. However, when surface runoff occurs, data in Table 4.14 show that as the percentage of urbanization increases so does the burden of chlorides, nitrate, total solids, total phosphorus, and total nitrogen. Suspended solids data are somewhat more erratic but the difference between Station 2 and Station 4 is impressive.

Although the data are not extensive the pattern is clear and adds an increment in the growing fund of knowledge of urban land-water quality relationships.

STREET SWEEPINGS. Accumulations of dust, residues from auto tire wear, miscellaneous debris from household activities, and pets characterize city streets, particularly during dry weather. Street sanitation involving regular sweeping of streets removes an appreciable fraction of litter and larger floatable materials which might be of esthetic importance when washed into coastal waters but a very large percentage of the dust is left behind. To gain some concept of the water quality values associated with runoff from city streets studies were made on two streets in downtown Honolulu (King and Maunakea Streets) and on one (Kuhio Avernue) in the Waikiki district of metropolitan Honolulu. The general characteristics of the frontage in the sampling areas are summarized in Table 4.15.

TABLE 4.15. CHARACTERISTICS OF TEST AREAS IN STREET SWEEPINGS STUDY.

STREET AND LOCATION	PROPERTY FRONTAGE	REMARKS
KUHIO AVENUE (2260-2270)	RESTAURANT TWO APARTMENT BUILDINGS DRIVEWAY	INCLUDES 1 PARKING STALL 50 PERCENT OCCUPANCY
KING STREET (102 - 118)	OFFICES DRY GOODS SHOP MUSIC SHOP	INCLUDES 2 PARKING STALLS 75 PERCENT OCCUPANCY
MAUNAKEA STREET	OFFICE TAILOR SHOP CLEANERS - LAUNDRY APARTMENTS, 1ST FLOOR	INCLUDES 1 PARKING STALL 90 PERCENT OCCUPANCY

The procedure was to sweep the same street area each day between midnight and 1:30 a.m., just previous to the time the mechanical sweeping machine covered the same area. In each situation, an area 100 feet along the curb and 8 feet wide was broom swept and the sweepings transferred to large plastic bags. each sample was air dried for one day or at 103°C if wet with rain. Material passing through a 1/8" mesh screen was segregated, weighed, and analyzed in the laboratory for physical and chemical qualities. The average and range of results of daily sampling of several water quality factors for a period of one week are summarized in Table 4.16.

The quantity of sweepings collected each day in all streets tended to decrease as the sampling week progressed, probably because the rate of removal by hand cleaning of the street exceeded the rate of accumulation of debris. A rough average of the amount of sweepings from each street is as follows: Kuhio Avenue--5 lb/day; Maunakea Street--3 lb/day; King Street--1.5 lb/day.

Although the results of the street sweepings study are difficult to assess in terms of coastal water quality, they do show that street flushings may be a significant source of quality factors. This fact is, of course, recognized by the Environmental Protection Agency which is increasingly insisting that storm runoff from urban areas be captured, settled, and perhaps chlorinated prior to discharge to the ocean. Monitoring of storm runoff, however, is probably a more feasible way to assay the non-sewage component of discharge from urban land than is the analysis of street sweeping, but the study does underscore the importance of street

TABLE 4.16. SUMMARY OF ANALYSES OF STREET SWEEPINGS, APRIL 1971.

QUALITY FACTOR	KUHIO AVENUE		KING STREET		MAUNAKEA STREET	
mg/l	AVG.	RANGE	AVG.	RANGE	AVG.	RANGE
H_2O SOLUBLE MATERIAL	25.2	15.4-35.4	22/0	18.0-26.6	24.1	17.2-31.4
VOL. H_2O SOLUBLES	9.3	3.0-18.6	6.5	3.4-9.8	12.8	7.0-18.6
PO_4	0.10	0.07-0.13	0.05	0.02-0.09	0.19	0.14-0.23
NO_3	0.05	0.02-0.07	0.05	0.03-0.07	0.05	0.03-0.07
BOD	10.4	9.3-14.1	12.7	6.8-17.9	19.8	16.5-32.1
COD	25.0	21.7-28.1	27.2	23.7-34.5	30.8	21.7-34.5
CHLORIDES	2.2	1.4-3.2	2.7	1.8-4.0	2.1	1.6-2.6
10^3/100 mg/l	RANGE		RANGE		RANGE	
TOTAL BACTERIA	5000 TO 35,000		880 TO 15,400		38 IO 25,000	
TOTAL COLIFORM	0 TO 3600		0 TO 610		0 TO 1700	
FECAL COLIFORM	0 TO 70		0 TO 200		0 TO 700	

NOTE: ON AT LEAST ONE SAMPLING DAY BACTERIA OF ALL TYPES WERE TOO NUMEROUS TO COUNT, HENCE EXCEEDED BY AN UNKNOWN FACTOR MAXIMUM VALUES SHOWN IN THE TABLE.

sanitation as one aspect of environmental management in the interests of coastal water quality.

chapter 5

Evaluative Aspects of Project

STATUS OF EVALUATIVE STUDIES

Objectives and Rationale

The preceding chapters (Chapters 2, 3, and 4) are concerned with various types of situations, and specific instances of each, from which the Coastal Water Quality Project proposes to identify and evaluate the effect of various land uses on the quality of coastal waters. The overall objective of the study, however, (see Chapter 1) is to interpret these separate evaluations in terms of the changes which are needed in institutional, economic, and social systems to achieve the environmental objectives of society, with particular reference to coastal water quality and coastal water environments. Specifically, it is envisioned that out of an objective analysis of data, collected from many sources and supplemented as appropriate by experimental observations by the Coastal Water Quality Project itself, may come information needed and desired by those who make public policy decisions leading to legislation, institutional arrangements, and specific action programs. For example, water quality standards and criteria should be realistic in concept, feasible of enforcement, and pertinent to the environmental objective they are intended to achieve. In the absence of information, which makes possible a positive linkage between regulatory and administrative pronouncements and the environmental good they are intended to achieve, public agencies have little choice but to get along with interim criteria which may or may not be either effective or pertinent. This limitation is by no means unknown to administrative agencies. In fact, the Water Quality Standards adopted by Hawaii in 1967 specifically states that numbers were adopted on the basis of the best available information and the document provides a mechanism for refining standards as research and experience develop better information.

In addition to the evaluation and interpretation of data noted above, the objectives of the study also include the accumulation and dissemination of information to citizens, legislators, public agencies, and others concerned with coastal water and water environments.

Progress Toward Objectives

During period of this report (July 1971 - August 1972), definite progress has been made toward achievement of project objectives. Data collection from other sources, cooperation with other agencies, personal involvement of project staff in related studies, and the buildup of a reference file on what is known concerning the study areas and situations are well advanced. For example, information on the geology, hydrology, physiography, land use patterns, oceanography, quality of discharges, and marine biology for the situations cited in Chapters 2, 3, and 4 has been collected. With the exception of the sugarcane industry on north kauai (Kilauea Sugar Company), this information is outlined rather than presented in detail in this report because the experimental data against which it must be compared is not yet of a scale adequate to support a full evaluation. In some instances, such as in Kahana Bay (Chapter 2) and South Kauai (Chapter 3), monitoring by the Coastal Water Quality Project over a period of time is yet necessary. In other instances, such as Sand Island, Pearl Harbor, Kaneohe Bay and Mokapu Point (Chapter 4), construction of new sewerage followed by a period of monitoring is essential to an eventual evaluation of land use--coastal water quality relationships. In the interim, no particular objective would be served by including excessive background data in the progress report.

The wealth of background data assembled, however, serves another objective of the project, the dissemination of information, through keeping the staff continuously informed and, hence, constantly prepared to participate in public and official discussions. During the report year an informative release entitled *Project Bulletin* was established and four issues distributed. Written in non-specialized language, this report is widely disseminated to all sectors of the community. Its purpose is to call the attention of its readers to developing concepts of which they should be aware in formulating their individual judgments or in proposing action programs. It is also intended to disseminate pertinent findings of the project which are timely and significant and might be lost to all but a few readers if merely incorporated in a voluminous annual report.

Utilizing background data and information currently being generated by the experimental phase of the studies, participants in the Coastal Water Quality Project appeared in legislative and public hearings to testify on proposed legislation, visited the offices of and offered services to State Senators, including the minority party leaders, Chairman of the Committees on Ecology, Environment and Recreation and Economic Development, and to State Representatives, including the chairman of the Committees on High Education, Housing and Consumer Protection, and Lands. The project participants also prepared statements on the current status of certain impact statements of projects related to water and zone of mixing applications of discharges into coastal waters and contributory streams.

Preliminary Findings

As noted in appropriate sections of the report, results observed support some tentative conclusions which must await further information before they can be finalized. Other results give rise to speculations that suggest increased emphasis on certain factors in the experimental aspect of the program. For example, the esthetic effects of sugar mill wastes at north Kauai disappeared once the discharge of mill wastewater was discontinued. Fish population of the affected area likewise seem to be rapidly increasing. On the other hand, the period of observation has as yet been too short to assess the changes which may occur in the aquatic biota of the area.

Evidence at south Kauai shows that mill waste discharge can be eliminated by land and wastewater management techniques alone. How generally these techniques might be applied to the sugarcane industry in Hawaii, and with what economic dislocations, is not yet known. Other evidence at south Kauai shows that land and water management techniques can confine the discharge of irrigation tailwater except in times of major storms.

Other general observations yet to be verified or refuted by continued monitoring of soil, water, and sediments indicate that DDT in small concentrations is ubiquitous, *i.e.*, that it appears everywhere, including areas where it has never been used as a pesticide. There is also a mounting suspicion as the data from all types of sediments and land areas grow, that such heavy metals as lead and cadmium, and perhaps others, are components of Hawaiian soils in appreciable concentrations. Whether or not this proves to be the case, it suggests an area in which the project must direct more widespread sampling before final evaluations are attempted.

CHANGING ATTITUDES

Need For Constant Awareness

It is a well known adage in research that social attitudes and institutional emphasis can change more rapidly than a scientific basis for such change can be developed through experimental investigations. This may be to the disadvantage of society through loss of interest in supporting research and, hence, results in the long run in the impoverishment of society itself. On the other hand, the change may so restructure institutions or commit society to a cause so difficult to reverse that further research along some specific line produces but little of a useful nature in return for the energy and resource input involved. At that point it no longer matters whether the decision was based on whimsy, illusion, or scientific fact.

Constant awareness of the foregoing reality is especially important to a project like the Coastal Water Quality study in which the major objective is to provide a scientific basis and informed judgment for decisionmaking, yet must in some aspects await the results of experimental or monitoring programs. This does not mean that the project might become non-productive, but it does underscore the importance of continuous evaluation and dissemination of information and the establishment of a public awareness of the presence of informed scientists in the community. In that manner the Coastal Water Project can provide the latest, if not the ultimate, information on matters of coastal water quality and of the relationships to which the project is directed, when decisions must for any reason be made without delay.

In such a situation as outlined above, it is important that the Coastal Water Quality review its experimental program annually to weed out any activities which may have been rendered obsolete by changes in public attitudes or institutions. The importance of such scrutiny is underscored by the rapid change that characterizes the area of environmental management.

Changes in Social Attitudes

During the 1971-72 report year, public concern for the quality of the environment increased in intensity. A greater number of individual citizens initiated citizen lawsuits to block or change various development plans. This generated comment and published articles on the possibility of the emergence of a new legal specialty termed, *environmental law*. It also generated suggestions in some quarters that some degree of restraint might have to be imposed to confine zealots within more defined limits.

The year also witnessed an increasing orderliness in the preparation of required environmental impact statements and a mechanism by which concerned citizens could become involved in the development of such documents at the outset was also provided. It also saw the dawnings of the day when the citizen must come face to face with the effect of his environmental objectives on his personal pocketbook.

The significance of all of this to the Coastal Water Quality Project was to increase the importance of its objectives and to underscore again the importance of constant evaluation to maximize the capability of its participants to review intelligently, upon call, the environmental impact statements generated in Hawaii.

CHANGES IN INSTITUTIONAL ARRANGEMENTS

Integration of Pollution Control Agencies

Since statehood in 1959, the art of instituting social change in Hawaii has developed to a relatively high state with valuable experience being gained in many areas of public policy, including that for water. At both the state and county levels of government, changes in water institutions have occurred more or less as the needs have been felt and as the responsible agencies themselves have seen fit to make changes.

A multi-staged arrangement of water institutions has emerged to control operating decisions in both the public and private sectors. In large part these institutions are carry-overs from early Kingdom and Territorial days, and although in many respects the specific institutionalized rules are uniquely applicable only to the islands, it is nevertheless clear that their development through the political and judicial processes have been strongly shaped by both economic efficiency and equity considerations. In these respects, the nature of the motivating forces that have brought about institutional changes in Hawaii over time are similar to that for other areas.

Since the adoption of the federal-state water quality standards program in Hawaii in late 1967, the need for closer integration of the new water quality regulations with existing water institutions have been increasingly felt in both public and private circles. Over the past five years during which the Standards have been in operation, various technical, financial, and institutional inadequacies have become apparent and several changes ranging from minor modifications in selected provisions in the regulations to major overhaul and even total replacement by a new set of standards have been proposed. A digest of state legislative acts relating to water pollution controls enacted into law since the adoption of the state Water Quality Standards in 1967 is given in Appendix A.

Slow and painstaking improvements have been made through legislative and administrative channels. Statutory measures for state grants-in-aid to local government and for tax relief to private industry through rapid amortization of capital outlays have been enacted into law by the state legislature. Changes in water use classifications and details on enforcement procedures in the water quality regulations have been made by the responsible state agencies. These and other changes institutionalized by the state have all affected the practical economics of water quality control in Hawaii.

Major changes in the broader area of environmental quality control have been enacted by the state following recent national trends. Following the National Environmental Protection Act of 1969, Hawaii enacted its own Environmental Quality Act of 1970 creating in one fell swoop its own Council of Environmental Quality, the Office of Environmental Center at the University of Hawaii. The general functions provided by these three agencies are advisory, coordinating, and technical assistance, respectively. Shortly after these three agencies began operations, a Governer's Executive Order instituted the requirement for environmental impact statements on all proposed projects involving the use of state funds and property. And most recently in the 1972 legislative session, the state legislature passed an Environmental Quality Bill (S.B. 1382-72) which has as its purpose to clarify, consolidate, and make uniform the current statutes which gives authority to the Health Department on matters relating to environmental pollution in Hawaii.

While overlapping in scope with strictly water problems, these new developments involve the total environmental quality concerns of water pollution, air pollution, noise pollution, solid waste disposal, etc,, and thereby have their attention directed broadly toward all living and non-living natural resources of the state. At the same time, however, consideration is given to only the quality dimensions of these resources. In effect, the potential improvements to be gained by these incremental changes are all in the direction of integrating at the state level public controls over the quality aspects of different types of resources--land, water, air, etc. No effort is made to integrate controls over both the quality and quantity aspects of water resources management.

Integration of quality controls across different types of resources and integration of quantity and quality management of a particular type of resource such as water need not necessarily be competing directions of institutional change. However, extreme care should be taken to avoid as much as possible the creation of ineffective and unnecessary administrative bureaucracies and procedures until needs and specific objectives are clearly defined.

In this regard, it is well to point out that the concept of integrating water quantity and quality management across different types of resources. The implementation of these concepts into institutional realities necessarily lags because of political, fiscal, and other considerations (both social and technological). Evidence to this effect is perhaps most visible at institutional levels closest to the operating sectors.

In the mainland, the trend towards unified management is clearly shown for larger cities with populations over 10,000. The results of surveys taken ten years apart in 1959 and 1969 by the American Water Works Association indicate that integration of administrative responsibilities over the years appears to have been affected to varying degrees in specific areas, first through joint fiscal arrangements, then through closer coordination of operations and maintenance, construction, and control center operations.

In Hawaii two counties, the Hawaii and Kauai, have had for a few years now limited fiscal integration through a system of joint billing of sewer service charges and water tolls. The Honolulu Board of Water Supply has recently (1972) adopted a new set of rules and regulations which provides that all plans proposing waste disposal facilities or the use of pesticides must have the written approval if there is a reasonable objective basis to expect that the operation of the proposed waste disposal facility and wastewater therefrom or the use of the pesticide may detrimentally affect the quantity or quality of water resources used or expected to be used for domestic water.

The City and County of Honolulu Charter Review Commission is now addressing itself to the questions of whether or not and, if so, in what manner to bring about a merger between the City's Division of Sewers and Board of Water Supply. Such a merger should provide a major impetus in the direction of closer integration.

This trend is also evident at the state level. Whereas, originally most states had water pollution control authorities vested in traditional public health departments, the 1971 Directory of Agencies of the "Clean Air and Water News" lists only about half of the states (24 including Puerto Rico) with such authorities still vested in strictly public health oriented departments. At least five states, Delaware, Massachusetts, Vermont, West Virginia, and Wisconsin have moved water pollution control powers to natural resources (including water) departments. A larger number of states (19) have apparently gone toward independent boards, commissions, agencies, and authorities.

Most notable among these independent bodies is the case of California where the integration of water quantity and quality management was affected in 1969 through their well known Porter-Cologne Act. Recent attempts in California, on the other hand, to integrate the administrative responsibilities of quality controls over different types of natural resources through the creation of a new Environmental Quality Control Department were soundly rejected. Yet, other states like Oregon, Washington, and Florida have created "new" ecology oriented bureaucracies by consolidating under a new name the expanded environmental quality requirements and old pollution control functions that were previously scattered throughout traditional health oriented departments.

In Hawaii then, the question of proper administration of the Water Quality Standards program which now rests with the State Department of Health may not yet be resolved despite recent testimonies to the contrary before special interim legislative committees. The forces for change continue to manifest themselves strongly at the level where institutions control decisions in the operating sector of the hierarchy of decision levels.

Considerations in Policy Changes

In recently completed final reports of the Oahu Water Quality Program the following major recommendation is made as the first of a series of eight suggestions for improving the financial and institutional aspects of water quality management in Oahu and the state of Hawaii.

> "(1) A managing agency, similar to the California Water Resources Control Board, should be immediately established by the State. It should be empowered with broad authority and provided with adequate staff funds, including the State 25% share of construction grants, to provide impetus to the State Water Quality program."

This recommendation has far-reaching implications not only for water quality management in Oahu, but also, and more importantly, to the broader concerns of an integrated water quantity and quality management scheme for the state as a whole, including the four counties of Honolulu, Hawaii, Maui, and Kauai. Therefore, if Hawaii should follow this recommendation, certain principles which have been worked out through experience in California with their State and Regional Water Resources Control Boards system should be considered in formulating the necessary legislation. Obviously, these principles should be improved and modified to fit the situation in Hawaii. The Quality of Coastal Water Project is in the process of evaluating the merits and limitations of the OWQP's recommendations.

Actions in Water Pollution Control

During the period covered by this report, the Hawaii legislature passed legislation and made institutional changes which broadened the environmental scope of concern, thus departing significantly from the historic national concept of air, water, and land resources as discrete entities to be managed separately by sister agencies. It also took under advisement the recommendation of the OWQP that a new policy be adopted involving a water management agency with broad powers separate from those of the Department of Health. Nevertheless, the State Department of Health continued as the agency responsible for formulating and enforcing water quality standards. Thus it is to any changes in the Health Department's management of water quality that the Coastal Water Quality group must look in evaluating the continued relevance of its own project and in seeking added opportunity to cooperate in solving problems of coastal water quality and water environments.

Of particular note in the past year or two has been the actions of the Health Department in regard to zones of mixing. Chapter 37A, "Water Quality Standards" divides coastal waters into nearshore waters, offshore waters, and those brackish, fresh, and salt waters that are subject to the ebb and flow of the tide. Nearshore and offshore waters are further defined as follows:

> "Nearshore waters" mean all coastal waters lying within a defined reef area, all waters of a depth less than 10 fathoms, or waters up to a distance of 1000 feet off-shore if there is no defined reef area if the depth is greater than 10 fathoms.
>
> "Offshore waters" mean all coastal waters beyond the limits defined for nearshore waters.

Coastal, and all other waters, are further defined in terms of five zones or classes and standards have been established for each class. A summary of existing requirements for the five zones is presented in tabular form in Appendix B.

The foregoing definitions and the quality requirements are of particular interest to the Coastal Water Quality study group because they establish parameters against which to weigh experimental findings as well as serve as guideposts which may well be refined as a result of on-going studies. Together with the permit system which the Health Department administers and the requirement that permits be issued for periods not exceeding five years, the quality requirements also of paramount importance in the planning and design of engineered systems for wastewater management. In this latter context, the designation of the area of the ocean in which mixing of discharged effluent occurs with ambient waters to attain the required dilution is of environmental as well as engineering and economic importance.

As of June 22, 1972, a total of 246 applications for waste discharge permits and zones of mixing were received by the State Health Department. Of these, 186 permits were issued and 31 waste discharges into zones of mixing approved. The actual number of water areas designated as zones of mixing, noted in Table 5.1, however, is somewhat smaller because some zones of mixing accommodate more than one waste discharge outlet.

During the period 1967 to 1972, there have been 52 eliminations of discharges either while under permit or while the application was under review or surveillance. The Department reportedly intends to revoke or deny a total of 15 waste discharge permits because of unacceptable implementation plans to abate the present discharges. Seven contested hearings have been held, four during fiscal year 1972. One contested hearing resulted in a court proceeding and the eventual liquidation of the discharger's operations.

Moreover, the time span within which unsatisfactory discharge must be corrected is a factor in the planning, design, and financing of treatment feasible to exercise its authority to permit "zones of mixing" without comprising the public interest is of great importance.

Pending legislation in water pollution control in the U.S. Congress promises to have even greater impact than any previous legislation in matters of policies through financial and technical means.

OVER ALL EVALUATION OF PROJECT

During the first year of active research, the Coastal Water Quality Project of the Sea Grant Program of the University of Hawaii demonstrated that a multi-disciplinary group can operate effectively and enthusiastically as a research team. The project proceeded according to plan, with scale rather than scope adjusted to its budgetary limitations. It cooperated effectively with other agencies and private enterprises who in turn demonstrated a similar spirit of cooperation and a free exchange of data. Significant progress was made on situations involving the land-coastal environment relationships of sugarcane culture, urban development, and undeveloped land. For reasons explained in the text, not all of these situations achieved the same level of progress during the year. However, the findings of the study continued to be pertinent to the needs of Hawaii and interpretable in terms of the objectives to which the study was directed and on which its funding by the Sea Grant Program was justified.

TABLE 5.1. SUMMARY OF APPROVED ZONES OF MIXING (1972).

APPLICANT	LOCATION	TYPE OF DISCHARGE	DURATION	REQUIREMENTS
1. HAWAIIAN ELECTRIC CO., INC.	HONOLULU HARBOR, OAHU	COOLING WATER (TEMPERATURE VARIANCE)	60 mos. 8/31/71 TO 9/01/76	*MONITORING* RECEIVING WATER: MONTHLY TEMPERATURE AT DESIGNATED STATIONS INFLUENT AND EFFLUENT: HOURLY TEMPERATURE OVER 24 HOURS BENTHIC AND OTHER MARINE LIFE: ANNUAL BIOASSAYS *SPECIAL* NONE
2. MAUI ELECTRIC CO., LTD.	KAHULUI HARBOR, MAUI	COOLING WATER (TEMPERATURE VARIANCE)	12 mos. 9/07/71 TO 9/01/72	*MONITORING* RECEIVING WATERS: MONTHLY TEMPERATURE AT DESIGNATED STATIONS INFLUENT AND EFFLUENT: HOURLY TEMPERATURE OVER 24 HOURS *SPECIAL* FEASIBILITY STUDY OF REUSE OF EFFLUENT FOR AQUACULTURE OR RELATED PURPOSE. REPORT DUE SEPTEMBER 1, 1972.
3. HILO ELECTRIC LIGHT CO., WAIAKEA PLANT	WAILOA BOAT BASIN, HAWAII	COOLING WATER (TEMPERATURE VARIANCE)	36 mos. 9/24/71 TO 10/01/74	*MONITORING* RECEIVING WATER: MONTHLY TEMPERATURE AT DESIGNATED STATIONS INFLUENT AND EFFLUENT: HOURLY TEMPERATURE OVER 24 HOURS BENTHIC AND OTHER MARINE LIFE: ANNUAL BIOASSAYS *SPECIAL* NONE
4. LAUPAHOEHOE SUGAR CO., OOKALA MILL	HAMAKUA COAST, HAWAII	SUGAR MILL WASTEWATER EXCLUDING: TRASH, BAGASSE, FILTER CAKE, SOOT AND ASHES	25 mos. 10/07/71 TO 11/01/73	*MONITORING* RECEIVING WATERS: pH, DISSOLVED OXYGEN, TURBIDITY, TEMPERATURE, TOTAL NITROGEN, TOTAL PHOSPHOROUS, AND MICROBIOLOGICAL CONCENTRATIONS. ONCE EVERY THREE MONTHS WITHIN DESIGNATED ZONE OF MIXING. *SPECIAL* 1. FEASIBILITY STUDY ON NEW HARVESTER. REPORT DUE OCTOBER 1, 1973. 2. ENGINEERING REPORT ON WASTE TREATMENT FACILITIES SHOULD NEW HARVESTOR PROVE INFEASIBLE. REPORT ALSO DUE OCTOBER 1, 1973.
5. PEPEEKEO SUGAR CO., PEPEEKEO SUGAR MILL	HAMAKUA COAST, HAWAII	SUGAR MILL WASTEWATER EXCLUDING: TRASH, BAGASSE, FILTER CAKE, SOOT AND ASHES	25 mos. 10/07/71 TO 11/01/73	*MONITORING* RECEIVING WATERS: pH, DISSOLVED OXYGEN, TURBIDITY, TEMPERATURE, TOTAL NITROGEN, TOTAL PHOSPHOROUS, AND MICROBIOLOGICAL CONCENTRATIONS. ONCE EVERY THREE MONTHS WITHIN DESIGNATED ZONE OF MIXING. *SPECIAL* 1. FEASIBILITY STUDY ON NEW HARVESTER. REPORT DUE OCTOBER 1, 1973. 2. ENGINEERING REPORT ON WASTE TREATMENT FACILITIES SHOULD NEW HARVESTOR PROVE INFEASIBLE. REPORT ALSO DUE OCTOBER 1, 1973.
6. PAAUHAU SUGAR CO., PAAUHAU SUGAR MILL	HAMAKUA COAST, HAWAII	SUGAR MILL WASTEWATER EXCLUDING: TRASH, BAGASSE, FILTER CAKE, SOOT AND ASHES	25 mos. 10/07/71 TO 11/01/73	*MONITORING* RECEIVING WATERS: pH, DISSOLVED OXYGEN, TURBIDITY, TEMPERATURE, TOTAL NITROGEN, TOTAL PHOSPHOROUS, MICROBIOLOGICAL CONCENTRATIONS. ONCE EVERY THREE MONTHS WITHIN DESIGNATED ZONE OF MIXING. *SPECIAL* 1. FEASIBILITY STUDY ON NEW HARVESTER. REPORT DUE OCTOBER 1, 1973. 2. ENGINEERING REPORT ON WASTE TREATMENT FACILITIES SHOULD NEW HARVESTER PROVE INFEASIBLE. REPORT ALSO DUE OCTOBER 1, 1973.

7.	MAUNA KEA SUGAR CO., PAPAIKOU SUGAR MILL	HAMAKUA COAST, HAWAII	SUGAR MILL WASTEWATER EXCLUDING: TRASH, BAGASSE, FILTER CAKE, SOOT, AND ASHES	25 mos. 10/07/71 TO 11/01/73	*MONITORING* RECEIVING WATERS: pH, DISSOLVED OXYGEN, TURBIDITY, TEMPERATURE, TOTAL NITROGEN, TOTAL PHOSPHOROUS, AND MICROBIOLOGICAL CONCENTRATIONS. ONCE EVERY THREE MONTHS WITHIN DESIGNATED ZONE OF MIXING. *SPECIAL* 1. FEASIBILITY STUDY ON NEW HARVESTER. REPORT DUE OCTOBER 1, 1973. 2. ENGINEERING REPORT ON WASTE TREATMENT FACILITIES SHOULD NEW HARVESTER PROVE INFEASIBLE. REPORT ALSO DUE OCTOBER 1, 1973.
8.	HONOKAA SUGAR CO., HONOKAA SUGAR MILL	HAMAKUA COAST, HAWAII	SUGAR MILL WASTEWATER EXCLUDING: TRASH, BAGASSE, FILTER CAKE, SOOT, AND ASHES	25 mos. 10/07/71 TO 11/01/73	*MONITORING* RECEIVING WATERS: pH, DISSOLVED OXYGEN, TURBIDITY, TEMPERATURE, TOTAL NITROGEN, TOTAL PHOSPHOROUS, AND MICROBIOLOGICAL CONCENTRATIONS. ONCE EVERY THREE MONTHS WITHIN DESIGNATED ZONE OF MIXING. *SPECIAL* 1. FEASIBILITY STUDY ON NEW HARVESTER. REPORT DUE OCTOBER 1, 1973. 2. ENGINEERING REPORT ON WASTE TREATMENT FACILITIES SHOULD NEW HARVESTER PROVE INFEASIBLE. REPORT ALSO DUE OCTOBER 1, 1973.
9.	PIONEER MILL CO., LTD.	LAHAINA COAST, MAUI	COOLING WATER FROM MILL POWER PLANT	36 mos. 11/08/71 TO 11/15/74	*MONITORING* RECEIVING WATERS: TEMPERATURE, WITH EACH DISCHARGE INFLUENT AND EFFLUENT: TEMPERATURE, HOURLY THROUGHOUT DURATION OF DISCHARGE BENTHIC AND OTHER MARINE LIFE: BIOASSAYS, BEGINNING OF EACH CALENDAR YEAR FOR OUTLETS USED MORE THAN TWICE (EXCEEDING 24 HOURS) PER YEAR. *SPECIAL* FOR EMERGENCY PURPOSES ONLY ACCORDING TO THE FOLLOWING ORDER OF PREFERENCE: (1) LAUNIUPOKO OUTLET, (2) KANAULA OUTLET, (3) PAPALAUA OUTLET, AND (4) KAPUNAKEA OUTLET.
10.	PIONEER MILL CO., LTD.	UKUMEHAME, WEST MAUI (2 SEPARATE DISCHARGE POINTS)	AGRICULTURAL TAILWATER	37 mos. 11/08/71 TO 12/31/74	*MONITORING* EFFLUENT WATERS: NO CANE TRASH OR OTHER MATERIAL NOT ATTRIBUTABLE TO SALT WATER INFILTRATION. RECEIVING WATERS: pH, DISSOLVED OXYGEN, TURBIDITY, TOTAL NITROGEN, TOTAL PHOSPHOROUS, AND MICROBIOLOGICAL CONCENTRATIONS. *SPECIAL* A SETTLING BASIN SHALL BE CONSTRUCTED AHEAD OF THE PUMP STATION AT POINT "Q2
11.	KEKAHA SUGAR CO., LTD.	KEKAHA, HAWAII	IRRIGATION TAILWATER AND DRAINAGE WATER	49 mos. 12/08/71 TO 01/01/75	*MONITORING* RECEIVING WATERS: pH, DISSOLVED OXYGEN, TURBIDITY, TEMPERATURE, TOTAL NI ROGEN, TOTAL PHOSPHOROUS, AND MICROBIOLOGICAL SURVEILLANCE EVERY SIX MONTHS AT KAIWAIELE OUTLET. *SPECIAL* THREE EQUAL-SPACED SAMPLING POINTS AT 3000 FEET AND 6000 FEET FROM THE POINT OF DISCHARGE SHALL BE USED.

12.	CALIFORNIA AND HAWAIIAN SUGAR CO.	AIEA BAY, OAHU	COOLING WATER (TEMPERATURE VARIANCE)	32 mos. 4/20/72 12/31/74	*MONITORING* RECEIVING WATERS: MONTHLY TEMPERATURE AT DESIGNATED STATIONS INFLUENT AND EFFLUENT: HOURLY TEMPERATURE OVER 24 HOURS *SPECIAL* STUDY OF THE POSSIBLE METHODS AND MODIFICATION OF THE STREAM CHANNEL IN CONJUNCTION WITH C & C CHANNELIZATION PROJECT AND THE USE OF SPRAY DEVICES AND A REPORT DUE JANUARY 1, 1974.
13.	KAUAI ELECTRIC CO.	PORT ALLEN BAY, KAUAI	COOLING WATER (TEMPERATURE VARIANCE)	26 mos. 5/01/72 TO 7/01/74	*MONITORING* RECEIVING WATERS: MONTHLY TEMPERATURE AT DESIGNATED STATIONS INFLUENT AND EFFLUENT: HOURLY TEMPERATURE OVER 24 HOURS ONCE EVERY MONTH *SPECIAL* AN INVESTIGATION SHOULD BE CARRIED OUT FOR THE USE OF AN INJECTION WELL AS A DISPOSAL METHOD FOR ITS COOLING WATERS AND AN ENGINEERING REPORT DUE JUNE 30, 1973.
14.	DEPARTMENT OF PUBLIC WORKS, C & C OF HONOLULU	WAHIAWA AND WHITMORE VILLAGE, OAHU	SEWAGE TREATMENT PLANT OUTFALL	37 mos. 5/12/72 TO 6/30/75	*MONITORING* EFFLUENT WATERS: HOURLY MEASUREMENTS OVER EVERY 24-HOUR PERIOD OF RESIDUAL SHRINE (ppm) *SPECIAL* STUDY TO DETERMINE THE EFFECTS OF THE TREATED SEWAGE DISCHARGE UPON FISH LIFE IN THE WAHIAWA RESERVOIR. REPORT DUE JANUARY 1, 1975.
15.	OLOKELE SUGAR CO., LTD.	KAUMAKAUI, KAUAI	INTERMITTENT ASSIMILATION OF IRRIGATION TAILWATER	109 mos. 5/19/72 TO 7/01/81	*MONITORING* NONE *SPECIAL* REPORT (BY TELEPHONE AND IN WRITING) TO THE KAUAI DISTRICT HEALTH OFFICE OF ANY DISCHARGES INTO THE ZONE OF MIXING, GIVING DETAILS ON THE LOCATION, AMOUNT, NATURE AND TIME OF DISCHARGE
16.	LIHUE PLANTATION CO., LTD.	SOUTH COAST, 5 LOCATIONS, KAUAI	INTERMITTENT ASSIMILATION OF IRRIGATION TAILWATER	109 mos. 5/19/72 TO 7/01/81	*MONITORING* NONE *SPECIAL* REPORT (BY TELEPHONE AND IN WRITING) TO HE KAUAI DISTRICT HEALTH OFFICE OF ANY DISCHARGES INTO THE ZONE OF MIXING, GIVING DETAILS ON THE LOCATION, AMOUNT, NATURE AND TIME OF DISCHARGE, AND ALSO A BRIEF DESCRIPTION OF THE CONDITIONS CAUSING THE DISCHARGE.
17.	MCBRYDE SUGAR CO., LTD.	KAUAI	INTERMITTENT ASSIMILATION OF IRRIGATION TAILWATER	109 mos. 5/19/72 TO 7/01/81	*MONITORING* NONE *SPECIAL* REPORT (BY TELEPHONE AND IN WRITING) TO THE KAUAI DISTRICT HEALTH OFFICE OF ANY DISCHARGES INTO THE ZONE OF MIXING, GIVING DETAILS ON THE LOCATION, AMOUNT, NATURE AND TIME OF DISCHARGE, AND ALSO A BRIEF DESCRIPTION OF THE CONDITIONS CAUSING THE DISCHARGE
18.	STANDARD OIL CO. OF CALIFORNIA WESTERN OPERATIONS, INC.	BARBERS POINT, OAHU	REFINERY EFFLUENT WATER (NUTRIENTS, TURBIDITY, TEMPERATURE)	55 mos. 5/23/72 TO 12/31/76	*MONITORING* EFFLUENT WATERS: BI-WEEKLY ANALYSIS OF TURBIDITY, pH, BOD, SETTLEABLE SOLIDS, SUSPENDED SOLIDS, TOTAL NITROGEN, TOTAL PHOSPHOROUS, TEMPERATURE, PHENOLS, SULFIDES, QUANTITY OF WASTEWATER *SPECIAL* ANNUAL UNDERWATER INSPECTIONS AND SAMPLING WITHIN THE DESIGNATED LOCATIONS.

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APPENDICES

APPENDIX A. SUMMARY DIGEST OF HAWAII STATE LEGISLATIVE ACTS RELATING TO WATER POLLUTION CONTROL ENACTED INTO LAW SINCE THE ADOPTION OF THE STATE WATER QUALITY STANDARDS IN 1967.

1969 REGULAR SESSION, FIFTH STATE LEGISLATURE

Act No. 20 (SB 17, SD 1) WATER POLLUTION CONTROL.
Amends the water pollution control law by authorizing the director of health to apply to any court of competent jurisdiction to enjoin any violation thereof. Effective May 13, 1969. (SSCR 59, 124; HSCR 278)

Act No. 117 (SB 18, SD 1) WATER POLLUTION CONTROL.
Authorizes the director of health to make grants of state funds and to coordinate the same with federal funds for the construction of water pollution control projects, such grants to be made on the basis of certain criteria including: conformance with the state water pollution plan assurance by applicants of the proper operation and maintenance of the projects, and payments by applicants of at least 20 per cent of the estimated project cost. Authorizes the director of finance to issue general obligation bonds in the amount of $1,500,000 up to June 30, 1970, for the purpose of fulfilling matching state fund requirements and to advance funds from the general fund to meet incurred costs, such amounts to be reimbursed to the general fund upon issuance of general obligation bonds or receipt of federal funds. Effective June 24, 1969. (SSCR 60, 332; HSCR 735)

1970 REGULAR SESSION, FIFTH STATE LEGISLATURE

Act No. 132 (SB 1132, SD 1, HD 1) OFFICE OF ENVIRONMENTAL QUALITY CONTROL.
Creates: (1) an office of environmental quality control in the office of the governor, headed by a single executive appointed by the governor; (2) an ecology or environmental center within the University of Hawaii; and (3) an environmental council, not to exceed 15 members representing the community.

Requires the director of the office of environmental quality control to: (1) coordinate all state governmental agencies in matters concerning environmental quality; (2) direct the attention of the State to ecological and environmental problems through the center and the council; (3) develop and arrange a system for monitoring conditions in the State; (4) conduct research or arrange for research in the field of ecology and environmental quality; (5) encourage public acceptance of legislative and administrative actions involving ecology and environmental quality; (6) recommend long-range programs and legislation; (7) initiate public educational programs; and (8) offer advice and assistance to private industry and governmental agencies.

Structures the center at the University so that membership shall be composed of those members of the University community that are actively concerned with ecological and environmental problems and directs the center to stimulate, expand, and coordinate education, research, and service efforts the University intthe environmental and ecological area.

Directs the council to serve as liaison between the director and the general public and to make recommendations to the director. Effective June 22, 1970. (SSCR 170-70, 488-70, 722-70; HSCR 828-70)

Act No. 133 (SB 986, SD 1, HD 1) POLLUTION CONTROL DEVICES, TAX AMORTIZATION.
Permits the amortization of pollution control facilities on an accelerated amortization schedule; provided that the facility was constructed or acquired prior to December 31, 1969, and is placed in service before January 1, 1975. Includes any water or air pollution control facility certified by the state water and air pollution control agency as being in conformity with the state program or requirements. Requires written notice to the department of taxation of election to take such amortization before the filing data of the return for the first taxable year for which the election is made. Requires filing with the department of taxation at the time of the election, the certification of approval and such other documents as are required. Effective June 22, 1970 for taxable years beginning on or after January 1, 1970. (SSCR 548, 642-70, 779-70; HSCR 818-70)

Act No. 138 (SB 1405, HD 1, CD 1) POLLUTION CONTROL, APPROPRIATION.
Appropriates $325,911 to the department of health for the following purposes: (1) for air pollution control, $119,984; (2) for community noise control, $32,191; (3) for water pollution control, $173,736. Effective July 1, 1970. (SSCR 480-70; 730-70; HSCR 829-70; SC 28; HC 27)

Act No. 143 (HB 1291, HD 3) WATER POLLUTION, PENALTY.
Adds a penalty provision of $500 a day to the water pollution law, each day being a separate offense, with the violations being enforced by the department of health. Effective June 22, 1970. (HSCR 330-70; 405-70, SSCR 902-70)

Act No. 157 (HB 657, HD 1) REIMBURSEMENT TO THE CITY AND COUNTY OF HONOLULU FOR COSTS OF GENERAL AND SEWER IMPROVEMENTS IN THE CITY AND COUNTY OF HONOLULU, APPROPRIATION.
Appropriates $1,178,310.94 to be funded by the sale of general obligation bonds to reimburse the city and county of Honolulu, for the costs of general and sewer improvements advance by the city and county for certain public and exempt lands within various improvement districts. Effective June 23, 1970. (HSCR 220, 271, 396-70; SSCR 1024-70)

1971 REGULAR SESSION, SIXTH STATE LEGISLATURE

Act No. 105 (SB 846, SD 1, HD 1) POLLUTION CONTROL COSTS, CONSTRUCTION PROJECTS.
Provides that all public contracts shall include provisions for the control of pollution which may be encountered in the execution of the contract and which work shall be paid on a

force account basis. Effective May 25, 1971. (SSCR 573, 593; HSCR 861)

Act No. 199 (SB 66, SD 1) DEPARTMENT OF HEALTH DEPUTY, EXEMPT FROM CIVIL SERVICE.
Provides for one additional deputy in the department of health, who shall be exempt from the civil service law, to administer all environmental health programs within the jurisdiction of the department. Effective June 21, 1971. (SSCR 515; HSCR 783)

1972 REGULAR SESSION, SIXTH STATE LEGISLATURE

Act No. 45 (SB 1806, SD 2, HD 1) STATE QUALITY GROWTH POLICY, DEVELOPMENT AND IMPLEMENTATION.
Provides for the development of a quality growth policy for the State by the office of the governor. Considerations in the development of the policy should include: (1) examination of impact of proposed urban development; (2) relationship between short-term and long-term environmental quality; (3) irretrievable commitment of resources through urban development; and (4) alternatives to minimize adverse environmental effects as balanced against economic development. The quality growth policy should include a comprehensive policy framework for future growth and identification of growth objectives and operational constraints to further such objectives. Effective May 15, 1972. (SSCR 233-72, 504-72; HSCR 692-72, 744-72)

Act No. 100 (SB 1382, SD 1, HD 2) ENVIRONMENTAL QUALITY.
Repeals the various chapters related to different types of pollution in the Hawaii Revised Statutues. Adds a new chapter codifying all laws on environmental quality and establishes uniform provisions for each area of pollution. Clarifies the power of the director of health and provides him with the authority to control air, water, noise and any other form of pollution found in this State. Allows fees to be established for the issuance of permits and variances. Gives the director rule making powers subject to the Administrative Procedures Act. Provides for public inspection of reports submitted to the department on discharges of waste under certain conditions. Establishes procedures for obtaining permits and variances.

Authorizes the director to issue cease and desist orders. Establishes penalty procedures. Gives the director the power to act in case of emergency or a threat to the health and safety of the community. Allows the director or his authorized representative to enter and inspect any building which is a suspected source of pollution. Provides for injunctive relief, appeal proceedings, and other technical provisions for air, noise, water, and solid waste pollution. Effective three months after May 22, 1972. (SSCR 270-72, 510-72; HSCR 669-72)

APPENDIX B. SUMMARY TABULATION OF WATER QUALITY REQUIREMENTS ACCORDING TO THE VARIOUS CRITERIA AND WATER USE CLASSES ESTABLISHED UNDER THE HAWAII QUALITY STANDARDS.

CLASSIFICATION OF WATER ACCORDING TO USES	CRITERIA								
	MICROBIOLOGICAL REQUIREMENTS (COLIFORM COUNTS)	pH (UNITS)	NUTRIENTS MG/L		DISSOLVED O_2 MG/L	TOTAL DISSOLVED SOLIDS (TDS) SALINITY AND CURRENTS	TEMPERATURE (°F)	TURBIDITY (SECCHI DISC OR EQUIVALENT AS "EXTINCTION COEFFICIENT")	RADIONUCLIDES
			TOTAL P	TOTAL N					
CLASS AA									
OCEANOGRAPHIC RESEARCH PROPAGATION OF SHELLFISH AND MARINE LIFE CONSERVATION OF CORAL REEFS AND WILDERNESS AREAA AESTHETIC ENJOYMENT NATURAL PRISTINE STATE, WILDERNESS CHARACTER, NO ZONES OF MIXING.	MEDIAN COLIFORM BACTERIA: < 70/ 100 ML ANY SAMPLE ≤ 230/100 ML	±.5 FROM "NATURAL CONDITIONS", BUT WITHIN 8.0 - 8.5 FROM OTHER THAN NATURAL CAUSES FRESH TIDAL WATER ≥ 7.0	≤.020	≤.10	>6.0	TDS ≥28,000 MG/L NO CHANGES IN CHANNELS, IN BASIN GEOMETRY OF THE AREA, OR IN FRESH WATER INFLUX SHALL BE MADE WHICH WOULD CAUSE PERMANENT CHANGES IN ISOHALINE PATTERNS OF MORE THAN ±10% OF "NATURALLY OCCURRING VARIATION" OR WHICH WOULD OTHERWISE AFFECT BIOLOGICAL AND SEDIMENTOLOGICAL SITUATION.	TEMPERATURE OF RECEIVING WATERS SHALL NOT CHANGE MORE THAN 1.5 °F FROM "NATURAL CONDITIONS"	±5% FROM "NATURAL CONDITIONS"	RADIOACTIVITY IN WATER SHALL NOT EXCEED 1/30TH OF THE MPC_w VALUES GIVEN FOR CONTINUOUS OCCUPATIONAL EXPOSURE IN NATIONAL BUREAU OF STANDARDS HANDBOOK NO. 69. NO RADIONUCLIDE OR MIXTURE OF RADIONUCLIDES SHALL BE PRESENT AT CONCENTRATIONS GREATER THAN THOSE SPECIFIED BY THE U.S. PUBLIC HEALTH SERVICE, PUBLICATION NO. 956, AS REVISED IN 1962, AS ACCEPTABLE DRINKING WATER.
CLASS A									
RECREATIONAL-(FISHING, SWIMMING, BATHING, OTHER WATER-CONTACT SPORTS.) AESTHETIC ENJOYMENT ...SHALL NOT ACT AS RECEIVING WATERS FOR ANY EFFLUENT WHICH HAS NOT RECEIVED THE BEST PRACTICABLE TREATMENT OR CONTROL COMPATIBLE WITH THE STANDARDS ESTABLISHED FOR THIS CLASS.	MEDIAN COLIFORM BACTERIA: ≤1000/100 ML, NOT MORE THAN 10% OF SAMPLES >2,400/100 ML FECAL COLIFORM: ARITHMETIC AVE. ≤200/100 ML (DURING ANY 30-DAY PERIOD) NOT MORE THAN 10% OF SAMPLES >400/100 ML (IN PERIOD AS ABOVE	±0.5 FROM "NATURAL CONDITIONS", BUT WITHIN 7.0 - 8.5 FROM OTHER THAN NATURAL CAUSES	≤.025	≤.15	≥5.0	--	TEMPERATURE OF RECEIVING WATERS SHALL NOT CHANGE MORE THAN 1.5 °F FROM "NATURAL CONDITIONS"	±10% FROM "NATURAL CONDITIONS"	THE CONCENTRATION OF RADIOACTIVE MATERIALS PRESENT IN FRESH, ESTUARINE, AND MARINE WATERS SHALL BE LESS THAN THOSE THAT WOULD REQUIRE RESTRICTIONS ON THE USE OF ORGANISMS HARVESTED FROM THE AREA IN ORDER TO MEET THE RADIATION PROTECTION GUIDES RECOMMENDED BY THE FEDERAL RADIATION COUNCIL.

CLASS B									
SMALL BOAT HARBORS-(COMMERCIAL, SHIPPING, AND INDUSTRIAL) BAIT FISHING AESTHETIC ENJOYMENT ...SHALL APPLY ONLY TO LIMITED AREA NEXT TO BOAT DOCKING FACILITIES IN BAYS AND HARBORS.	FECAL COLIFORM: ARITHMETIC AVE. ≤400/100 ML (DURING ANY 30-DAY PERIOD) NOT MORE THAN 10% OF SAMPLES >1000/100 ML (IN SAME 30-DAY PERIOD AS ABOVE)	±0.5 FROM "NATURAL CONDITIONS", BUT WITHIN 7.0 - 8.5 FROM OTHER THAN NATURAL CAUSES	≤.030	≤.20	≥4.5	--	TEMPERATURE OF RECEIVING WATERS SHALL NOT CHANGE MORE THAN 1.5 °F FROM "NATURAL CONDITIONS"	±20% FROM "NATURAL CONDITIONS"	SEE NOTATION FOR CLASS AA & A.
CLASS 1									
DRINKING WATER FOOD SUPPLY ABSOLUTE MINIMUM OF POLLUTION (ALL FRESH WATER STREAMS, WHETHER PUBLICLY OR PRIVATELY OWNED, USED FOR DOMESTIC, CULINARY, OR FOOD PROCESSING PURPOSES.)	FECAL COLIFORM: ARITHMETIC AVE. ≤20/100 ML (DURING ANY CALENDAR MONTH)	--	--	--	--	--	--	--	SEE NOTATION FOR CLASS AA.
CLASS 2									
BATHING, SWIMMING, RECREATION GROWTH AND PROPAGATION OF FISH AND OTHER AQUATIC LIFE AGRICULTURAL AND INDUSTRIAL WATER SUPPLY ...SHALL NOT ACT AS RECEIVING WATERS FOR ANY EFFLUENT WHICH HAS NOT RECEIVED THE BEST PRACTICABLE TREATMENT OR CONTROL COMPATIBLE WITH THE STANDARDS ESTABLISHED FOR THIS CLASS (ALL FRESH WATER STREAMS AND RIVERS NOT INCLUDED IN CLASS 1.)	MEDIAN COLIFORM BACTERIA: ≤1000/100 ML NOT MORE THAN 10% OF SAMPLES >2,400/100 ML FECAL COLIFORM: ARITHMETIC AVE. ≤ 200/100 ML (DURING ANY 30-DAY PERIOD) NOT MORE THAN 10% OF SAMPLES >1000/100 ML (IN SAME 30-DAY PERIOD AS ABOVE)	6.5 - 8.5	--	--	≥5.0	--	TEMPERATURE OF RECEIVING WATERS SHALL NOT CHANGE MORE THAN 1.5 °F FROM "NATURAL CONDITIONS"	--	SEE NOTATION FOR CLASS AA & A.

SOURCE: ADAPTED FROM CHAPTER 37-A WATER QUALITY STANDARDS, PUBLIC HEALTH REGULATIONS, DEPARTMENT OF HEALTH, STATE OF HAWAII.

APPENDIX C. PROJECT BULLETINS ISSUED.

quality of coastal waters

PROJECT BULLETIN

Project Bulletin No. 1/February 1972 L. S. Lau, Principal Investigator

THE FIRST ISSUE...

This is the first issue of a bulletin to be released at timely intervals by the Quality of Coastal Waters Project of the Sea Grant Program of the University of Hawaii. The Project is intended to identify, develop, and evaluate the critical physical, chemical, and biological yardsticks, as well as the rational bases for judgement, needed by society in formulating effective public policies, in organizing regulatory agencies, and in planning and financing systems for protecting the coastal waters in Hawaii. To this end, specific investigations are under way to establish the relationship between land use and land management practices and the quality of adjacent coastal waters and biota. Thus water quality is viewed as but one of the many environmental factors to be considered in reaching decisions relative to the development of land for urban, industrial, or agricultural purposes, and in establishing the methods of development which will do most in achieving the environmental goals of society. Similarly, a knowledge of land use-water quality relationships provides a basis for selecting appropriate wastewater treatment process and facilities.

The Project is of a multi-disciplinary nature involving scientists from a wide variety of backgrounds, such as water resources, sanitary engineering, public health, microbiology, ecology, zoology, soil science, biochemistry, oceanography, planning, and economics. Cooperating with direct participants in the Project are the leaders of other related projects within the University, as well as such public agencies as the State Health Department, the City and County of Honolulu, and the federal Environmental Protection Agency.

Scientific and environmental findings of the Project are to be released as major reports from time to time. In the interim it is intended that the Bulletin will present discussions of timely information, viewpoints, and developments which individuals and groups faced with a need to make decisions on matters affecting the environment might find helpful.

In this issue, Dr. L. Stephen Lau, Principal Faculty Investigator of the Project and Director of the Water Resources Research Center of the University, discusses a recent profound and crucial change in environmental relationships which does not yet seem to be adequately recognized. In subsequent issues Dr. Lau and other engineers and scientists active in the Project will discuss a wide range of topics pertinent to environmental management.

The Role of Coastal Water Quality in Environmental Management

As our CWQ study of scientific reports proceeds, and our review continues of situations in the State of Hawaii where man's activities on the land may adversely affect coastal water quality, there is mounting evidence that the 1972 role of water quality in environmental management is little understood. The phrase "Water Pollution" continues to comprise two flag words which generate a predictable reaction, the nature of which was established long before the advent of the current broadly based public interest in environmental protection. The result is that in the minds of the public, water quality is being assigned too great a task in environmental control.

(Continued on page 2)

sea grant program ● water resources research center

University of Hawaii

(CWQ, continued from page 1)

The most common overleading of the concept of "water pollution" is that of protecting it as the principal reason for opposition to development of tidal and shoreline areas by local citizens, organized conservation groups, or others who for any reason do not believe that specific proposed developments achieve the greatest environmental potential of the area. There are many reasons why people might, and do, oppose shoreline developments. The desire of humans to be undisturbed when their own situation is pleasant and comfortable is well known and almost universally understood. Other factors may be traffic congestion and noise, loss of open space, loss of recreational facilities, destruction of existing resource values, loss of community character and identity, etc. In some combination these factors should provide the basis for decision concerning the way a specific land resources might best be used. Water quality, of course, is among the important factors to consider, but to single it out is the controlling one is to take refuge in past history, to ignore the realities of the present, and in the long run almost certainly to fail.

There is no gain saying that, historically, waste water disposal has often been a haphazard undertaking and in many cases has led to the destruction of other resource values of the area before its "pollutional" effects were recognized or, at least, before they become intolerable to people. However, to assume that population growth in an area today will lead to a magnification of past or present intolerable conditions is badly to misread the temper and the direction of America today. Both public opinion and the actions of government and public institutions make it amply clear that the nation is in no mood to permit water quality deterioration to become the limiting factor in our freedom to realize the full potential of our resources. In this circumstance it ill behooves the opponents of shoreline developments to base their case heavily on water quality merely because "pollution" still evokes a conditioned reaction by the public and the press.

Because the mood of America today embraces a broad concept of environmental objectives which far transcends water quality alone, a balanced basis for judgement of the resource potential and of the capabilities of areas such as coastal zones is not far from becoming a reality. This fact should be taken into consideration by proponents as well as opponents of shoreline development schemes. Just as it is not enough to base opposition on the dismal past record of water quality management, so is it not enough today to justify land development schemes on the prospect that water quality will not be affected. A combination of many environmental and social factors will figure in the final decision. Thus it may be concluded that the time is ended when the lone spectre of water pollution can be raised effectively to block a land development proposed, or dispelled to justify it.

Having declared our national intention to put water pollution in its proper place, and rallied public support of such a concept, does not necessarily accomplish that result. However, assuming for the purpose of this discussion that we do indeed intend effectively to manage the quality of our water resources, there are several things yet needed to achieve the necessary capability. Most important, beyond the realm of economics and technology, are the following:

1. Sufficient knowledge of the relationship of land use to water quality and water environments to make possible an accurate assessment of appropriate control measures in any specific situation.

2. Institutional and regulatory arrangements adequate to manage all environmental aspects of a situation with the degree of certainty which we expect to attain in relation to water quality.

It is to the realization of these capabilities that the work of the Coastal Water Quality Project of the Sea Grant Program of the University of Hawaii is dedicated.

Detergent Phosphates in Hawaii

QUALITY of COASTAL WATERS

PROJECT BULLETIN

Project Bulletin No. 2/March 1972

L. S. Lau, Principal Investigator

As noted in the issue of February 1972 which launched the Bulletin, its purpose is to present discussions of timely subjects by participants in the Quality of Coastal Waters Project of the Sea Grant Program of the University of Hawaii. In this manner it is intended that information, viewpoints, and developments ordinarily lost to the public in lengthy annual reports may be promptly brought to the attention of public officials and citizens concerned with decisions on matters affecting the environment. Attention is directed to the subject of the environmental significance of phosphates in detergents in Hawaii in this issue.

So much has been written and said on the subject of phosphates and of detergents as a source of phosphates that the reader may wonder what there is to be gained from any further consideration of it. There is, however, a lesson to be learned from the phosphate story which might well be applied to other aspects of the problem of environmental control which from time to time excites citizens and so leads to demands for precipitous action that later proves unwise.

In the case of phosphates, prior to late 1971, organized citizen groups anxious to further the cause of improving the quality of our environment, on a nationwide basis, singled out phosphates as the number one cause of water pollution and identified detergents as the true culprit. Legislation was proposed in every hand and some states and many localities sought to end water pollution by outlawing phosphates in detergent formulations. Elected officials at all levels of government, understandably anxious to be identified as leaders in the programs desired by their constituents, prepared a rash of bills, only to get caught in an unpleasant situation when the Federal Environmental Protection Agency (EPA) reversed its stand on phosphates as builders in detergents.

Fortunately for public servants in Hawaii, they had not gone very far in acceding to public pressure when the EPA reversed its stand on the necessity for outlawing phosphates as a pollution control measure. Nevertheless, the pressure was there and a lack of public understanding of the role of phosphates in the quality of Hawaii's coastal waters prevailed. To an important degree the current lull in excitement over phosphates is the result of evidence that non-phosphate detergents are unacceptable. In that case, the anti-phosphate campaign may simply be in recess and may emerge again later based on the same original lack of information. For this reason, now seems an appropriate time to take a sober look at the question of detergent phosphates in Hawaii and so be prepared to meet the future with more understanding and less emotionalism than characterized the past.

Phosphates and Detergent Formulations

What is popularly called a "detergent" consists principally of a surface active agent (surfactant) plus a "builder". The surfactant is a long chain molecule, one end of which is soluble in water and the other is soluble in oil. Thus when soiled clothing is placed in water containing a surfactant the molecule's solubility preference makes it act somewhat like a rivet to fasten the grease to the water. It is then only necessary to agitate the soiled clothing and the grease is removed. Unfortunately, this simple routine works best when water is alkaline. Water itself is not pure; it contains dissolved chemicals (ions) which seriously interfere with the effectiveness of the surfactant. It is the purpose of the builder to supply alkalinity and sequester interfering ions. For this purpose phosphate compounds serving as builder are essential.

Non-phosphate detergents were manufactured and publicized to take advantage of the public misconception of phosphate as a water pollutant. Such formulations used carbonates and silicates, often called "precipitating builders" because they combine with calcium ions in hard waters forming precipitates that may build up in the cloth being washed. Such detergents are highly alkaline (pH between 10.5 and 11 versus pH between 9 and 10.5 for phosphate detergents). Some detergents manufactured with metasilicates had pH higher than 11 and were found to cause skin corrosion and eye damage. These were banned in March 1971. Silicate builders can also damage the porcelain bowls used in washing machines.

There appears to be no viable alternative to the use of phosphate-based detergents that does not present some health or environmental hazards. The use of ordinary household soaps or castile soaps would be adequate for cleansing purposes because of the softness of the water supplies in Hawaii; however, such products themselves contain approximately 20 percent phosphates. Reverting to the use of "Grandma's" lye soap presents the same alkaline hazards as found with carbonate and silicate-based detergents. Thus, the banning of detergents would be detrimental. It is therefore important to examine in some detail the phenomena associated with phosphates in the aquatic environment.

Phosphates in Surface Waters

In the presence of a source of carbon, such as carbon dioxide, the principal fertilizers used by aquatic plants are nitrogen and phosphorus, just as is the case with land plants. Of course, small amounts of such elements as iron, magnesium, and other metals are needed to accompany these two major fertilizer elements. Aquatic plants use from 8 to 15 atoms of nitrogen to 1 atom of phosphorus and when phosphorus is in short supply, they find other ways to get along.

Domestic sewage is the principal source of phosphorus, about one-half of which comes from detergents. Interestingly enough, if that half were absent, there still remains enough phosphorus in sewage to match all the nitrogen present in this 15 to 1 ratio. This makes nitrogen the limiting factor, so who cares if there should be excess phosphorus?

The answer is that if sewage is so poorly treated that oxygen is depleted in the water which receives it, algae of a type (blue-green) which can take nitrogen from the atmosphere will find the nitrogen needed to match the excess of phosphorus. Thus, the phosphorus is incorporated in an objectionable excess of algal (plant) growth in an environment where oxygen is short and putrefaction produces odors and unsightliness. This, then, is the basis for the popular notion that phosphorus is a "pollutant" and therefore its use in detergents should be banned.

Two factors combine to make the foregoing prospect more academic than serious. First, the standards of water quality now in force require a dissolved oxygen content that essentially eliminates the possibility of the nitrogen fixing algae. Second, the degree of treatment of sewage required to meet the dissolved oxygen, toxicity, clarity, and other water quality standards require processes that precipitate phosphorus. In fact the federal Environmental Protection Agency has recognized phosphorus removal rather than new detergent formulations as the practical way to deal with whatever problems phosphorus may generate.

Phosphate and the Quality of Hawaiian Waters

In general, estuarine and marine waters are limited in their ability to grow plants (algae) by nitrogen rather than phosphorus. A survey of 11 streams discharging into Kaneohe Bay showed that about 55 percent of the flow into the Bay was nitrogen poor. Increases in phosphorus in Kaneohe Bay have been identified over the sewer outfalls. Its effect, however, is uncertain and soon to be eliminated by discharge of the sewage effluent to the ocean where phosphorus already abounds.

Conclusions

There seems to be no safe alternative to phosphates in detergent formulations, and by far the easiest way to deal with phosphates is its removal, essentially as a by-product of other processes necessary in sewage treatment. Should be specter of phosphates as "pollutants" rise again, the extensive documentation from which the foregoing summary is drawn can be made available to all concerned.

Receiving Water Quality Criteria Concepts

QUALITY of COASTAL WATERS
PROJECT BULLETIN
Project Bulletin No. 3/April 1972 L. S. Lau, Principal Investigator

by Gordon L. Dugan, Project Faculty

Society, in general, and Hawaii, in particular, are presently deeply concerned with producing an effluent that will not deteriorate the quality of the receiving water. Essentially this has been a basic concern since man constructed the first hydraulic conduit to convey his waste products from the immediate vicinity of his waste-generating urbanized living conditions to convenient receiving waters (both surface water and ground water). The query then began to emerge as to what burden the receiving water can assimilate without creating undue detrimental conditions to the aquatic ecosystem.

Without appearing to oversimplify the only partially understood complexities of the aquatic ecosystem in addition to the multitude of situations that have arisen as a result of waste disposal practices, professions involved in monitoring these practices have essentially resorted to using the "black box" approach, that is, measuring certain quality parameters of inputs and outputs. Although the "black box" approach may appear very crude, it is usually the only practical method that can be employed from the standpoint of economics and overall time required. The main problem then is to determine what, how many, how often, how accurate, and where to measure these parameters and what they mean. However, the problem is further complicated by the continually changing ideas as to what constitutes detrimental conditions, which recently seems to be moving in the direction of increasing strictness.

Undoubtedly, the first consideration that was given to a body of water receiving wastes was the attitude "out of sight, out of mind." However, numerous historical cases indicate that in many locations it was soon not out of sight, odor, taste, or smell. From this situation, the concept of dilution and assimilation of wastewater, treated or untreated, into a given volume of natural water was advocated. Thus, the first standards to protect the quality of receiving waters were developed.

The subtle differentiation between the interrelated terms, "criterion" and "standard," as separately employed by numerous agencies as well as individuals tend to boggle the mind. In the present context the word, "criterion," will be used to imply a definitive tool that can be modified as conditions warrant or as new knowledge becomes available and the word, "standard," will be used to imply a generally inflexible value.

The dilution concept of wastewater disposal was popular around the turn of the century. However, as the wastewater load began to increase due to increased population and production, it became obvious that the assimilative capacity of many receiving waters was insufficient to cope with the increased load and, in time, undesirable conditions would be created in the receiving water. To alleviate a large portion of the burden to the receiving waters, partial treatment, prior to discharge into the receiving waters, became a general rule in most developed countries.

As a result of gradually adopting the practice of wastewater treatment prior to discharge into receiving waters, two general types of water pollution control standards emerged: the "receiving water standard" and the "effluent standard." The former includes not only the previously developed receiving-water dilution standard, but also the concept of actual concentration limits for the receiving water. The latter involves a restriction of the strength or amount of pollutants to be discharged or else specifies the degree of treatment. Both "standards" were primarily derived from rivers, a situation which is atypical of the receiving waters of Hawaii. However, the characteristics and limitations of the methods of deciding what constitutes receiving water parameters for Hawaii were primarily based on the experience of mainland conditions due to the lack of sufficient local data at the time the standards were established.

Waste assimilation has been traditionally considered as one of the major beneficial uses of natural waters. The "trade-off" between the degree of treatment and the degree of departure allowed from the natural quality of receiving waters has been largely governed by the monetary expenditures citizens are willing to bear to further reduce the pollution load prior to the discharge of wastewaters into receiving waters.

In essence, the dilution concept is still used to reduce the concentration of "treated effluents" from wastewater treatment facilities that discharge into a body of water inasmuch as the remaining pollution of the treated effluent still needs to be assimilated in the receiving waters. Therefore, as far as final discharge is concerned, it is apparent that an "effluent standard" is essentially an extension of the dilution requirement concept, which in turn is itself one type of receiving water standard.

U.S. Senate Bill S.2770, currently under consideration, proposes the goal of the total elimination of all effluent discharges into the nation's waterways by 1985, unless the discharger can demonstrate that alternative disposal methods cannot be implemented at a "reasonable cost." The important aspect of the bill is the concept that wastewater assimilation is not considered a beneficial use of the receiving water.

Disregarding the remote economic feasibility of adopting the zero discharge concept as proposed in the foreseeable future, at least for the majority of the industries, serious consideration has to be given to developing a reasonable receiving water quality criteria that will protect, if not enhance, the total aquatic ecosystem.

The measurement of water quality as determined by the physical, chemical, and microbiological parameters of the water, classically:

1. Determines if sufficient dissolved oxygen exists for aerobic aqualife,
2. Ascertains the salinity of the water,
3. Indicates disease potential of the water,
4. Evaluates nuisance and aesthetic aspects, and
5. Gives regulatory agencies evaluation yardsticks.

However, contemporary receiving water quality standards using classical quality determinations essentially do not relate to the "quality of life" in a water body (beyond dissolved oxygen) regardless of whether the "quality of life" is impoverished or enriched. Since the mid-1960's, water pollution control agencies have become increasingly aware that a high degree of removal of oxygen demanding materials (BOD_5) does very little to remove aquatic growth nutrients that lead to eutrophication. For example, the alleged major precursors of aquatic growth, nitrogen and phosphorus, are usually only reduced by 20 to 30 percent in a secondary treatment facility. This is assuming sufficient alkalinity is available so that a carbon source is not limiting and, the necessary trace elements and biostimulants are present.

To consider the "quality of life" in a receiving water, allowance should be made for changes in the natural dynamics of the aquatic ecosystem. Excess concentrations in one or more of the parameters during certain portions of the year may be normal seasonal variations and not indicators of failure of wastewater treatment. Very little background statistical data exists concerning normal seasonal baseline receiving water conditions. However, baseline data is essential if meaningful "quality of life" parameters are desired.

With the relatively recent concern over eutrophication, nutrient removal or tertiary treatment has been widely advocated and practiced on a demonstration scale in numerous locations. Phosphate can be removed fairly easily with efficiencies of greater than 95 percent. Nitrogen compounds, however, are fairly difficult and expensive to remove effectively. Thus, with the exception of aquaculture, the effluents from a tertiary facility would be expected to have a high nitrogen to phosphorus ratio which may result in a relatively low algal growth rate when assayed by an algal growth potential test. However, a relatively low algal growth in an effluent can be misleading if no consideration is given to the receiving water. For instance, if the phosphorus-poor tertiary treated effluent is discharged to a receiving water that has an abundant supply of phosphorus, a far greater algal growth may result through the synergistic effects of the combined tertiary effluent and the receiving water than was possible in the two separate waters independently.

Although the objective of wastewater treatment is to produce an effluent that will not adversely deteriorate the quality of the receiving water, the present philosophy appears to be the reduction of concentrations of the individual constituents in wastewater to a level that is technologically and economically feasible and assume that the receiving water can assimilate the unremoved constituent portion. This approach, while appearing to be commendable, disregards the "quality of life" aspect of the receiving water. A more logical approach may be an attempt to discharge wastewater that is nutritionally compatible with the receiving water. This practice should tend to develop a "balanced" diverse aquatic ecosystem. A nutritionally unbalanced "highly treated" wastewater effluent discharged into a body of water that does not contain a sufficient quantity of the deficient constituents or lacks the volume for adequate dilution will tend to develop an unbalanced aquatic ecosystem, which restricts the number of species, and may eventually lead to undesirable conditions. Thus, it is theoretically possible that when the "quality of life" in the receiving water is considered along with the intended use of the receiving water, a less expensive wastewater treatment process may provide the most optimum approach to environmental protection.

A DEFINITION: best practicable treament or control in Hawaii water quality standards

QUALITY of COASTAL WATERS

PROJECT BULLETIN

Project Bulletin No. 4/May 1972 L.S. Lau/Principal Investigator

by Doak C. Cox

The Water Quality Standards of the State of Hawaii (Public Health Regulations Chapter 37-A) refer to "the best practicable treatment or control" in relation to: (a) effluents discharged to Class A waters (coastal waters protected for recreational use), to Class B waters (the waters of harbors), and to Class 2 waters (fresh waters other than those used for drinking and food processing); (b) discharges containing soil particles to any waters; and (c) discharges which result in violations of the specific or basic standards for any waters and whose legal accomodation is being considered through the establishment of zones of mixing. The meaning of the phrase, "zones of mixing," became a critical issue during 1971 in the course of public hearings on the establishment of zones of mixing by the Department of Health. Three different interpretations were put forward, at least implicitly, by those who presented testimony.

These three interpretations can be arranged in a spectrum with two more at the extremes that were hinted at either in testimony or in public discussion of the issue. In this spectrum, a degree of treatment or control would be the "best practicable" if it constituted:

1. The most practical from the purely private economic standpoint of the discharger.
2. The most practical from the overall public economic standpoint, but considering only material and not non-material aspects.
3. The most fitting from the standpoint of overall public welfare, including non-material as well as material aspects.
4. The most extreme within the limits of available technology.
5. Total elimination, or some degree of treatment or control beyond present technology.

Because the divergence of interpretation actually held up a decision by the Director of Health as to one set of zones of mixing which were being considered and appeared to make other decisions quite problematical, the Univeristy of Hawaii Environmental Center issued a report (Cox, D.C., "The meaning of best practicable treatment or control in the Hawaii Water Quality Standards." U.H. Environmental Center, 13 September 1971, 7 pp.) analyzing the various interpretations. The report concludes that, in the context of the Hawaii water quality standards, the phrase "best practicable treatment or control" must be interpreted to mean that extent of treatment or control which is made feasible by present technology and which is best from the standpoint of overall long-term human welfare. Subsequent decisions of the Director of Health concerning zones of mixing appear to indicate the acceptance of this interpretation.

The arguments used in the reports were based on:

1. Dictionary meanings of the words "practicable" and "best" which are somewhat ambiguous but tend to support the preferred definition rather

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than any, either more or less extreme, as to degree of treatment or control.

2. The statutory authority back of the water quality standards which clearly relates to public health, safety, and welfare.

3. The usages of the phrase throughout the Water Quality Standards themselves, which indicate that "the best practicable" means of treatment or control is not absolute for any discharge but depends upon the uses of the waters to which the discharge is made and suggests that it is not necessarily the most extreme feasible means.

4. The history of the zones-of-mixing provision in the Water Quality Standards from which a one-time provision for acceptance of lesser degrees of treatment or control was eliminated so as to require "best practicable treatment" in the sense recommended.

5. The responsibilities of the Director of Health to represent the overall long-term interests of the public without partiality to either environmental preservationist views or private economic interests.

The following were particularly noted:

1. The whole thrust of environmental legislation and regulation indicates recognition of public concerns with non-material aspects of environmental quality in addition to material aspects, such as economic ones.

2. These concerns cannot rationally be restricted to the local ecological effects of discharges but must be extended to the overall environmental consequences of proposed controls, which may in some cases, be more deleterious with more stringent than with less stringent degrees of control.

3. The concerns cannot be limited to short-term effects but must involve long-term considerations as far as the state of knowledge permits.

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