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THE QUALITY OF COASTAL WATERS: SECOND ANNUAL PROGRESS REPORT

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Water Resources Research Center

University of Hawaii, Honolulu, Hawaii

QUALITY OF COASTAL WATERS

SECOND ANNUAL PROGRESS REPORT

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UNIVERSITY OF HAWAII, HONOLULU, HAWAII

THE QUALITY OF COASTAL WATERS:

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Project Principal Investigator
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Year 05

THE QUALITY OF COASTAL WATERS: SECOND ANNUAL REPORT

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ABSTRACT

This report summarizes the results of the second year of investigative and evaluative work of the University of Hawaii's Sea Grant Program project, "Quality of Coastal Waters." The general objectives of this multidisciplinary project are to identify, develop, and evaluate the critical physical, biological, and rational parameters needed in formulating effective policies, institutions, and systems for protecting the quality of coastal waters in Hawaii. To this end, the attainment of eight specific objectives is assigned to faculty specialists participating in the 14 activities which comprise the Project. These specialists also assist the Principal Investigator in planning the work and in interpreting the results.

Research activities for the project year consisted principally of field and laboratory studies of coastal waters initiated in the first project year but with increased emphasis on biota and sediment. Assistance was rendered to the State Department of Health in the revision and updating of the State Water Quality Standards.

Kahana Bay was selected for study as a coastal water area under the influence of relatively undeveloped land. Land contribution of nutrients to the bay via Kahana Stream and all nonpoint routes was found to be small despite the perennial nature of the surface and subsurface discharges. However, the nitrogen and phosphorus levels measured for Kahana Bay waters and in the contiguous open ocean water exceeded the levels allowed under its state Class AA water classification. Coliform organism concentrations met the Class A rather than Class AA standards. Thus, the Kahana Bay water quality tends to satisfy the Class A standard rather than the Class AA standard.

Heavy metals, especially lead, copper, zinc, chromium, and nickel, appeared consistently and within a range of a few to a few hundred ppm in the bay sediments, stream sediments, and watershed soils. The ubiquitous nature of their presence is related to the parent rocks from which the soils and sediment are derived. However, mercury and cadmium were only occasionally detected in the sediments and when detected, occurred at only within a range of a fraction of to a few parts per million. DDT was detected in the range of a few parts per trillion in the Kahana Bay sediment together with only periodically detected and very low levels of dieldrin, DDE, α and γ chlordane. In the Kahana Bay water both heavy metals and DDT were detected but only at levels similar to open ocean water, i.e., a fraction of, or a few parts per

billion for the heavy metals, and only a few parts per trillion for DDT.

The project's approach to revealing the effects of urban land development is selection of single predominant type of urbanization of land to reveal the cause-effect relation. Recreational use of coastal land and water in Waikiki and domestic urban use of water and the abutting land in Hawaii Kai Marina and east Maunalua Bay furnish such situations. Domestic sewage is collected and removed from the areas.

Investigative results for the Hawaii Kai area and Maunalua Bay showed a general trend to improvement in water quality from the marina to the near-ocean bay waters. Nitrogen levels in the bay and only the near-ocean station were within the Class A state standard by which the water bodies are classified but phosphorus levels exceeded the standard elsewhere. All heavy metals were consistently present in the coastal sediments in the parts per million level. The levels of the ubiquitous pesticides analyzed, DDT, dieldrin, and PCP, (the latter is used primarily for termite control in house construction), were at least one order of magnitude higher than in the Kahana Bay sediments, thus reflecting intensive urban activities associated with a relatively new and growing residential development.

In the Hawaii Kai Marina and coastal waters, heavy metals were detected in the usual minimal parts per billion level as in open ocean water, and DDT, dieldrin and PCP were in the usual parts per trillion range. A turbid water plume in Maunalua Bay was occasionally identified and apparently was related to currents and roiling bottom sediments rather than any liquid discharge. A biota study of the bay waters was completed and detailed.

Coastal water quality data obtained for the Mamala Bay waters off Waikiki in support of a conjunctive study by Chave for the Corps of Engineers and coliform monitoring by the Department of Health are reported. In general the data satisfied state requirements for Class A waters except for phosphorus. Coral abundance was generally less toward Diamond Head than toward Ala Wai Canal, which is the only major drainage canal intercepting the surface runoff from the valleys and discharging into Waikiki coastal waters. From the findings, there is little evidence which would attribute any specific water quality effect solely to the presence of intense recreational activity at Waikiki.

Sandy Beach represents a rather complex situation and departs from the project approach: the open ocean coast beach being popular, the land use *changing from rural and undeveloped to residential urban development, and above all, the coastal water receiving treated domestic effluent. Shoreline water quality data were obtained to complement the studies undertaken by the consulting firm of Sunn, Low, Tom, and Hara, and the routine monitoring by the State Health Department. Results for the project area showed clear shoreline water similar to Waikiki but with higher nutrients than Kahana Bay water and the state Class A standard levels. However, the study by the consulting firm of the offshore condition adjacent to the Hawaii Kai sewer outfall showed that there is little significant effect to the coastal water and benthos from the discharge of treated wastewater off Sandy Beach.*

A baseline survey of benthic biota, particularly coral and micromollusc abundance and diversity, and fish was performed for Kailua Bay, the proposed Mokapu outfall site, and the existing Kailua sewer outfall. While the greatest abundance and species diversity of the fish were not near the outfall, the highest standing crop of micromolluscs is near the outfall. The occurrence of micromolluscs is comparable with the patterns in other areas of similar depth and substrate.

Nonpoint discharge studies of sugarcane production and milling wastes were continued but at a reduced scale 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 in 1971. Untreated mill wastes were found to be the major contributing factor to the presence of coliforms, sediments, trash, and bagasse. The effect was largely an extensive visible plume in the coastal waters and debris in both the water and on the beach. 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 wastes and sediments. Herbicides used in sugarcane culture did not appear in coastal waters. A striking aesthetic improvement of the coastal water and the beach quickly followed the cessation of mill waste discharge. Coastal water qualitites continued to improve: phosphorus decreased to better than Class AA standards, DDT and PCP were detectable only at parts per trillion level. The rapid improvement is attributed to both the cessation of mill waste discharge and the heavy sea. Beach and ocean sediments continue to harbor about the same level of heavy metals but contain a much decreased amount of nutrients. Fish have reappeared rapidly since 1973. No *apparent changes in micromolluscs have been observed since the cessation of mill operation. Tentative conclusions of the continued Kilauea investigative studies are: no evidence of eutrophication in coastal water, adverse effects of discharge mostly transitory, and epibenthic communities more influenced by waves, currents, and coastal topography than by mill waste discharge.*

Studies were continued in south Kauai to assess the effect of changed operation 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, the coastal waters of Wahiawa Bay showed an anomalously high nitrogen content while no pesticide residues were found in the offshore water except for the one to two parts per trillion DDT which seems to be present everywhere.

Evaluative summaries were detailed for several key quality parameters in water and sediment. Heavy metals were ubiquitous and in parts per million range in coastal sediment in Hawaii. This suggests that if standards for the level of heavy metals in dredge spoil were to be set, care should be taken not to fix unrealistic levels that cannot possibly be attained. In the coastal waters, heavy metals also occur but only in the parts per billion range, a level quite comparable to the level in ocean water. Conjunctive studies of mercury uptake in an aquatic food chain from the water and sediment were continued and detailed.

Of the insecticides, the presence of DDT in sediments is ubiquitous. In Maunalua Bay and Hawaii Kai sediments, dieldrin, and α *and* γ *chlordane are found frequently and with highest concentration in the low parts per billion range. Their occurrence may be attributed to prior and current continous use of these chemicals in the abutting land area and the poor sediment circulation within the Hawaii Kai Marina. In coastal waters insecticides were generally undetectable or at only a few parts per trillion. PCP, like DDT, seems to occur ubiquitously.*

Herbicide residues in West Loch of Pearl Harbor and Kaiaka Bay were studied. Atrazine and ametryne do not appear to be a problem, however, because of its persistence in soils, diuron can be found in coastal sediments because eroded agricultural soils are transported with storm runoff.

Kahana Bay water contains about the lowest amounts of nutrients in coastal waters. The state standards for nitrogen and phosphorus were exceeded in all areas except for Kilauea, in the case of nitrogen, and McBryde, in the case of phosphorus.

The use of mircomolluscs as an indicator organism was reported with a differentiation noted in species between coastal areas affected primarily by silting compared to areas affected primarily by nutrient input. In the former situation Bittium zebrum *becomes the major fauna component and standing crops and diversity values are conspicuously depressed. In the latter case, the community changes towards dominance by suspension feeding forms which depend on primary productivity of the water columns. Also associated strongly with silted reef flats is* Obtortio pupoides. *The responses of an ecosystem to land-generated effects are changes in structure from a grazing herbivore environment with associated frondose algae to either a rubble associated ecosystem with few species or to a eutrophic state with many suspension feeders and low diversity.*

The principal changes in institutional arrangements noted in the project year are those resulting from the passage of the Federal Water Pollution Control Act Amendments PL 92-500. The effects of this legislation will be far-reaching and result in changes which include: new discharge permit requirements, reporting of operating and monitoring results for wastewater treatment facilities, a minimum requirement level of secondary treatment for municipal wastewaters, and industrial waste treatment effluent guidelines. The full impact of these and other changes is not yet apparent although some delays have incurred in regulatory actions and attempts to implement legislation.

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Chapter 1

INTRODUCTION

NATURE OF REPORT

The report herein presented is the second in a series of Annual Progress Reports describing and evaluating the findings of the Quality of Coastal Waters project of the Sea Grant College Program of the University of Hawaii. It concerns project activities during the period 1 September, 1972 to 31 August, 1973 (05 Sea Grant Year). Because the research it reports is a continuation of work described in the *First Annual Progress Report* (Lau 1972), the reader is presumed to be familiar with, or to have access to, the first report. Consequently, such matters as the need for study, organization for study, and methodologies are not herein presented in detail. Instead, they are summarized in the narrative and only to a degree sufficient to make the report self-contained and its findings understandable.

ORGANIZATION OF PROJECT

The Quality of Coastal Waters project is organized as a multidisciplinary study structured into 14 areas of activity under L. Stephen Lau, Director, Water Resources Research Center, as the principal investigator. Each project activity is headed by an associate investigator. Together all investigators comprise a Project Control Group which coordinates the several activities, determines the appropriate scale and duration of each activity within the limits of budget and project objectives, and evaluates the project findings. Individual activities are designed to bring the highest possible level of competence to bear upon each aspect of the study. For example, the concentration of heavy metals in soils, sediments, flowing water and coastal water, and inorganic life is determined by specialists in the detection and evaluation of metals in the environment; other specialists are concerned with pesticides, human health, response of aquatic biota, chemical pollutants, etc.; still others are concerned with such matters as the economic, institutional, sociological, planning, and informational objectives of the project.

The project was designed to relate land development to the quality of coastal waters by studying typical situations in which quality factors are influenced by identifiable land use and land management practices. Undeveloped land was selected as the basic situation against which to compare other situations in which land is dedicated to sugarcane culture and milling, general agriculture, urban communities, or industry. Comparisons between situations involve both the nature of the activity upon the land, and the chemical, physical, and biological pollutants which flow from the land with surface runoff and sediments, or are discharged as wastewater by man. The effect of these discharges is then measured in terms of the concentration of pollutants in adjacent coastal waters and sediments, and of the nature and responses of aquatic biota or communities in such coastal waters.

RATIONALE OF PROJECT

Several aspects of the rationale underlying the project are pertinent to an understanding of the organization of the project, its objectives, and the evaluation of findings presented in the annual reports.

Relative to the overall Sea Grant Program, of which the project is a part, it is expected by the granting agency (NOAA) and the Director of the Program for the University of Hawaii, that:

1. The various projects which make up the Program should be coordinated parts of a clearly defined whole.
2. The program and its projects should concern real problems of environmental management and control and of the potential of marine resources.
3. Sea Grant studies should be coordinated with other studies and projects within the community and the University, to avoid wastage of effort and to maximize the utility and significance of the Sea Grant findings.

Relative to the Quality of Coastal Waters project, the further rationale is specifically that:

1. Decisions are being made, or are about to be made, which establish federal and state policy, revise institutional arrangements, and set the immediate goals and timetable for engineered systems for environmental control.
2. Although environmental control decisions are essentially political in nature, they do reflect to some degree the existing and foreseeable capabilities of technology and science. However, in no sense do they admit of the time frame which the scientist might wish in order that his judgements be based upon a thorough understanding of the interactions of natural phenomena and systems.
3. Society's decision to act now means that the QCW project can contribute most effectively through:
   a) Compiling, supplementing, and evaluating data on the sources, nature, and effects of pollutants reaching coastal waters.
   b) Making its evaluations continually known to legislators, planners, and public officials, as well as to the scientific community.
   c) Informing citizens so that public opinion and the causes it engenders may emerge from understanding rather than from transient emotionalism.
4. Any individual situation selected for study cannot be expected to define the limits of all situations of that specific type. For example, the biota of waters fronting on undeveloped land may vary widely from place to place and be subject to influences more subtle than those to which the project is sensitive. Nevertheless, there should be sufficient difference between the effects on coastal waters of land used for various purposes to provide a basis for intelligent control measures in specific situations.

OBJECTIVES AND APPROACH OF STUDY

The general objective of the project is to identify, develop, and evaluate the critical physical, chemical, biological, and rational parameters needed in formulating effective institutions, policies, and systems for protecting the quality of coastal waters in Hawaii.

Specific objectives related to the principal objectives cited above include the following:

1. To delineate the relationship between water quality standards and the quality and ecology of receiving water environments.
2. To reveal the benefits of waste water management.
3. To recommend the measures and institutional changes needed to protect coastal waters.
4. To assess the social, economic, and political impacts of such recommendations.
5. To provide an informational and educational service on coastal water quality to all sectors of the community.

To attain these objectives the project was organized as outlined in a preceding section. Both experimental and evaluative aspects were found necessary. The approach in the experimental work was to identify the origin of, and to measure the amounts and effects of, selected pollutants reaching coastal waters via sediments and man-modified water discharges. Such data in themselves are scientifically revealing and interpretable in terms of engineered systems and land management alternatives.

The approach in the evaluative phase was to combine the experimental findings with those of companion studies and with information available from numerous agencies, to clarify the social, economic, and institutional roadblocks and incentives to coastal water quality management.

THE FIRST ANNUAL REPORT

The first year's (04 Sea Grant Yr: Sept. 1, 1971 to Aug. 31, 1972) progress report details an appraisal of coastal water pollution problems in Hawaii, including the available quality and land use data for the field sites selected for investigation in the project: Kahana (undeveloped land), Sandy Beach, Waikiki, and Hawaii Kai (urban development) on Oahu; and Kilauea and McBryde Plantations (sugarcane culture and milling) on Kauai. Particular emphasis was placed on the investigation at Kilauea because it provided an opportunity for a "before and after" study of the effects on waste water discharge as the mill ceased operations in November 1971 after over 90 years of continuous activity. Also completed in the first year was a special survey of the agricultural chemicals used in Hawaii and the factors contributing to their transport to estuaries, as well as several lesser studies revealing the effects of sugarcane culture and urban land development upon discharge of pollutants.

Results of the first year's research suggest that some of the effects of man's activities may be more apparent than real, although the local conditions have considerable significance in defining the total impact. Illustrative of this is the fact that the coastal outfall plume of the canemill waste water discharge at Kilauea Plantation on Kauai disappeared when mill operations ceased. Moreover, the fish catch in the affected area began to increase rapidly. Secondary-treated sewage discharged into Kaneohe Bay on Oahu showed evidence of being harmful ecologically over a long time span, but of an acceptable marine quality. In contrast, raw sewage discharged at

Sand Island is the cause of ecological damage within only a limited area, and also considered definitely unacceptable. Other results show a widespread distribution of DDT in soils and sediments as well as in water. Appreciable concentrations of certain heavy metals were found in quality standards -- nutrients and coliforms -- are exceeded even in waters of highest classification under pristine conditions.

SCOPE OF THE SECOND ANNUAL PROGRESS REPORT

The second year's report (05 Sea Grant Year: Sept. 1, 1972 to Aug. 31, 1973), herein presented, is concerned with the continuation of all the field and evaluative studies begun during the first project year (04 Sea Grant Year). Its major focus, however, is on the Kahana (undeveloped land) situation, and on Hawaii Kai (developed and developing urban land), with principal emphasis on the biological aspects of the research. Data are included for the urbanized situations involving Waikiki, southern Oahu, and Sandy Beach, southeastern Oahu, prior to termination of field work at the two sites during the second year of study (05 Sea Grant Year). Further results on sugarcane situations at north and south Kauai, reported in detail in the *First Annual Progress Report* (Lau 1972), are reported for both the Kilauea and McBryde Plantation sites. Results of conjunctive and of supplemental studies are reported, particularly on the fate of Mirex in the coastal waters of Maui, Molokai, Oahu, and Kiholo Bay on Hawaii.

Chapter 2

COASTAL WATER QUALITY AND UNDEVELOPED LAND

KAHANA BAY

Introduction

Even under the most pristine of conditions, the biota of an estuary or a bay exists in an environment which reflects some basic equilibrium between land development and coastal water quality. Because the extremes of climatic conditions result in wide fluctuations especially after a rainstorm in the amount of suspended and dissolved mineral and organic matter, as well as in the volume of fresh water which carries it from the land, these equilibria are necessarily dynamic. And because bathymetric and oceanographic factors likewise affect a coastal water environment, no single land-water situation can represent the full range of coastal water conditions which might exist in Hawaii if all of its land area were still in a state of nature undisturbed by man. Nevertheless, if even the overall effects of land development by man are to be identified and intelligently minimized, it is necessary to have some fundamental frame of reference.

Pursuant to the foregoing rationale, and with realization of its limitations, Kahana Bay was chosen as a typical situation where the activities of nature, rather than those of man, upon the land are the major determinants of how discharges from the land affect the quality of abutting coastal waters. Both the comparatively pristine conditions of the Kahana Stream drainage basin and its convenient geographical proximity to the Manoa campus of the University of Hawaii support such a selection.

In utilizing Kahana Bay as the principal control situation against which to evaluate the results of other land development situations -- agricultural, industrial, and urban -- it is understood 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. However, justification for making what the scientific purist might well consider an extremely rough preliminary evaluation is drawn from the fact 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 cause versus effect, even though it may highlight only the dangers of unenlightened action or inaction, is a useful guide to progress. Within such a rationale Kahana Bay was judged suitable as a control situation for the study.

Location of the Study Area

The geographical location of Kahana Bay and its drainage area, which comprise the study area herein reported, is shown in Figure 2.1. Included in the figure are other data pertinent to sections of the report which follow.

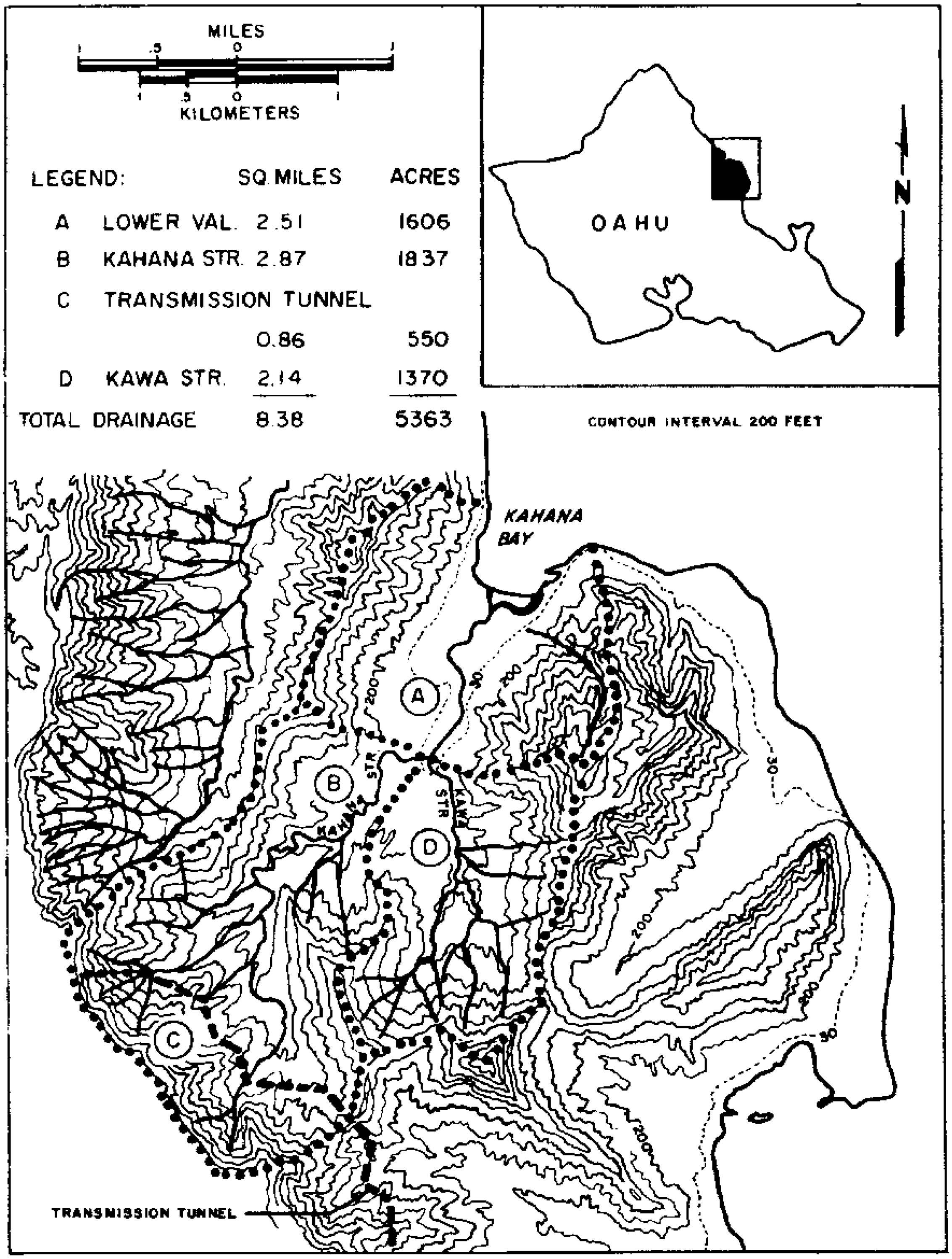


FIGURE 2.1. LOCATION AND DRAINAGE AREA, KAHANA BAY.

Historical Notes

Like all valleys in Hawaii with a perennial stream, Kahana has had a history of occupation since earliest Hawaiian times. The environment of the valley was especially conducive to the Hawaiian way of life and in pre-discovery times probably sustained about 20,000 people (Bishop Museum, reported in the Honolulu Star Bulletin, March 1, 1973). The broad, flat swampy lower portion of the valley would be ideal for taro and other water-loving crops, and the abundance of perennial flow all the way to the 800-foot (243.84 m) elevation and the relatively gentle slopes below this level would allow agricultural terracing along the main and tributary streams to within a mile of the crest of the Koolau Range.

The first men from the western world to view Kahana were the members of Captain Cook's expedition who sailed along windward Oahu in February of 1779, following the death of Cook at Kealakekua Bay on the island of Hawaii. Captain King, who replaced Cook as leader of the voyage, in describing windward Oahu, and especially the region of Kahana, from a vantage point some distance off the coast recorded: "the coast, to the northward, is formed of detached hills, rising perpendicularly from the sea, with broken summits; the sides covered with wood, and the vallies between them of a fertile and well cultivated appearance" (King 1785, p. 86). And later, summarizing the voyage from Kaneohe to Waimea Bay as: "...the banks of this river [Waimea], and indeed the whole we saw of the Northwest part of Woahoo, are well cultivated, and full of villages; and the face of the country is uncommonly beautiful and picturesque" (King 1785, p. 87). When King made his observations, the Hawaiian use of land and water was probably in a non-destructive balance with the environment. But not many years after the discovery, exploitation of the land induced by non-Hawaiian economic motives initiated environmental changes that are still taking place.

Vancouver, the second great English explorer to visit Hawaii, introduced grazing animals to the islands just over a decade after Cook's original discovery. These animals alighted in an ecosystem that had experienced no greater mammalian ravages than those wrought by rats, pigs, and dogs. The fertile valleys were open to grazing and the fragile natural biota suffered from the experience. Over the next century and a half the forests of the accessible portions of Kahana were continuously ravaged by cattle and goats. Not long after the introduction of these exotic animals the native Hawaiian sandalwood tree became an important item of commerce, and its ruthless harvesting further decimated and destabilized the forests.

By the middle of the nineteenth century the symbiotic equilibrium between Hawaiian agriculture and the natural environment had faltered and by the last quarter of the century had given way to an agriculture based on rice. The broad lower portion of Kahana Valley with its abundance of water and heavy soils was covered with rice paddies. By the turn of the century, however, locally grown rice was being displaced by inexpensive rice imported from California. In 1910 the lower part of the valley became part of Kahuku Sugar Company and was planted with sugarcane for the next 25 years. The plantation railroad was extended to the valley, and an artesian well was drilled near the mouth of the stream.

In the meantime the sugar plantations in arid leeward Oahu had become interested in the perennial waters draining from the windward Koolau Mountains, and to divert this water had started in 1913 to bore through the range between Waiawa Valley on the leeward side and Waiahole on the windward. A tunnel through the range was completed in 1916, and by 1921 a collection tunnel had been constructed along the windward side of the range at an elevation ranging from 700 to 800 ft (213.36 to 243.84 m) from Waiahole to the middle of the Kahana basin. The average collection from Kahana Valley amounted to 7 mgd (26,495 cu m/day) until 1929, when a development tunnel striking normal to the mountain range was started at the 800-foot (243.84 m) elevation near the head of the valley.

Construction of the development tunnel took place between April 1929, and January 1931. The tunnel has a length of 1975 ft (601.98 m), strikes S66°W, about normal to the strike of the dike zone and the range crest, and yields a dependable flow of nearly 4 mgd (15,140 cu m/day). Between 1929 and 1936 an enormous quantity of water drained from storage behind the dikes, but by the end of 1936 drainage had reached the equilibrium base, and the total average output of surface and tunnel water to the collector system totalled only 7 mgd (26,495 cu m/day), exactly the same as had been obtained before construction of the tunnel.

The abandonment of sugarcane cultivation in about 1930 and the control of cattle grazing in the forested regions during this century have resulted in a new enivonmental equilibrium asserting itself in the valley which, superficially at least, would appear to resemble the closed conditions of the original forest. In World War II and for some years thereafter, the valley was used on a small scale as a military training ground, but since about 1950 the upper 3 mi (4.827 km), of a total length of 4 mi (6.436 km), of the valley has suffered little more intrusion than the occasional hiker, pig-hunter, or scientific investigator. The lower part of the valley is occupied by about 30 families who raise some cattle and farm to a limited extent, but the present use is minimal in comparison to the intensive cultivation of the early Hawaiians and the later Oriental rice farmers. The State is in the process of negotiating for the purchase of the entire valley which is destined to become a public park.

Kahana Valley has a total area of 8.38 sq mi (21.70 sq km). From the seacoast to the Koolau Range crest, the distance is 4 mi (6.436 km), and the average elevation of the Koolau crest margin is about 2500 ft (762.0 m).

Climate

Kahana lies within the windward climatological province and includes both the lowland and mountain subdivisions. The valley recieves a bountiful rainfall throughout the year, the annual averages ranging from 60 in. (152.40 cm) at the most seaward promontaries to nearly 300 in. (762.0 cm) near the crest of the Koolau Range. Rainfall increases nonlinearly inland, probably exponentially with distance toward the crest, as a consequence of orography. A long-term rain gage at Kahana tunnel (800-foot [243.84 m] elevation) shows an annual average of 240 in. (609.60 cm), and an annual median of 258 in. (655.32 cms) (Taliaferro 1959). The maximum rainfall recorded at the gage was 355 in. (901.70 cms) in 1927.

Temperatures are equable with a sea level annual average of 74°F (23.31°C). At elevations above 800 ft (243.84 m), the integrated average temperature must equal 65°F (18.32°C), the temperature of the water that drains from the Kahana development tunnel. The minimum temperature in the valley probably falls between 50°F (10°C) and 55°F (12.77°C), and the maximum in the neighborhood of 90°F (32.19°C). Normal relative humidity ranges from 65 to 80 percent.

The dominant winds are tradewinds from the northeast and occur 80 to 90 percent of the time. These winds flow off the relatively stable high pressure anticyclone lying about 30 degrees north latitude of the Hawaiian archipelago. During the winter months, November through March, the anticyclone weakens and is occasionally replaced by cyclonic circulation which may bring storms, either as cold fronts from the northern quadrants or large tropical depressions (Kona) from the south.

Total rainfall and its distribution is dominated by thermal contrasts and trade wind flow which carries moist marine air across the land and up the mountain slopes, resulting in orographic uplift. Cooling causes condensation and rain from the clouds. The nonlinear increase in rainfall with distance inland is manifested by very large increases over short distances, particularly within the valley. The fact that at the Kahana Tunnel rain gage, August, when air flow is almost exclusively anticyclonic, is the wettest month illustrates the dominance of orographic phenomena in accounting for the largest share of the annual rainfall.

The median rainfall for August at the tunnel is 23 in. (58.42 cm) (Taliaferro 1959) and for July, the second wettest month, it is 22 in. (55.88 cm). March, a transitional month as the weakened anticyclone of the winter months becomes stronger, follows with a median of 20 in. (50.80 cm). Next in order are April, February, November, May, January, June, September, and finally October, the driest month, with a median of 14 in. (35.56 cm).

While trade wind flow produces most of the annual rainfall, the most intense rainfalls derive from cyclonic storms. These storms tend to uniformly blanket the valley, and this feature, coupled with the high intensity of the rainfall, results in large instantaneous volumes of runoff. Erosion and sediment movement is more pronounced during the ensuing floods than during the relatively modest runoff from trade wind rains. The probable maximum 24-hour rainfalls given in Wu (1967) suggest the intensities of the rainfall and subsequent floods: the 100 year 24-hour expectable rainfall at the crest of the range is 22 in. (55.88 cm) and at the coast, 15 in. (38.10 cm); the probable absolute 24-hour maximum in the valley is 50 in. (127.00 cm).

The highest average stream flow in the basin as shown by the records of USGS gage 16296500 occurs in March, April and May, when the average daily runoff falls between 50 and 60 cfs (80 and 136 cu m/min) as compared to the annual average of 35.9 cfs (61.03 cu m/min) USGS 1971). The lowest average daily flows (about 25 cfs or 42.5 cu m/min) are in July, August, and September.

Instantaneous maximum flows, based on the six-year record given in Water Supply Paper 1937 (USGS 1971) are most common in April and May, with the greatest instantaneous flow of 5430 cfs (9231 cu m/min) having occurred in April of 1963. The average maximum for April is 1750 cfs (2975 cu m/min) and for May, 942 cfs (1601.4 cu m/min). The average maximum in August is only 134 cfs (227.8 cu m/min), and in September, 148 cfs (251.6 cu m/min). It is obvious from these statistics that floods are not a function of the total average monthly rainfall (since August records the highest average) but of the origin of the rain. Although the trade winds produce the most rainfall throughout the year, cyclonic storms cause maximum instantaneous stream runoff. Also, the greatest runoffs are not associated with the winter months of December through February, but with the transitional months (March, April, May) that lead to deep summer (June, July, August, September) and those (October, November) that pass from summer to winter.

Geology

All of Kahana Valley falls within the dike region associated with the major rift zone of the Koolau Volcano. The rift zone trends northwestward from the main caldera of the volcano centered approximately in the Kailua area of windward Oahu. The subaerial portion of the Koolau Volcano was formed in the interval between 2.6 and 1.8 million years ago (Doell and Dalrymple 1973).

The primary rocks of Kahana Valley consist of basalts and olivine basalts of the Koolau volcanic series. Uncompacted recent sediments occur in stream channels and a semi-indurated older alluvium is found in the valley at lower elevation. Near the coast a wedge of deltaic-marine sediments overlies the basalt. The dominant geologic feature in the valley is the dike zone. To the southeast of Kahana the dikes strike predominantly N55°W from the caldera region but the strike direction changes to about N35°W in Kahana. The dikes are chemically identical to the volcanic flow rocks.

The dike region may be divided into two components called the dike complex and the marginal dike zone. The essential difference between these components is the frequency of occurrence of dikes across the trend of the rift; the complex has many more dikes per given distance than the marginal zone. In some areas the transition from one to the other is gradual and thus boundaries are loosely defined. In general, however, the change from the closely spaced dikes of the dike complex to the widely spaced dikes of the marginal zone is marked, allowing rather precise boundaries to be mapped.

DIKE COMPLEX. The dike complex is widest at the caldera and gradually narrows northwestward. In Kahana Valley it has a width of at least 6600 ft (2011.68 m) and extends from elevation 270 ft (82.30 m) in the stream to the range crest.

The nature of the dike complex is best exhibited in tunnels that strike normal to the trend of the dikes. Kahana Tunnel cuts 28 single dikes and 12 bands of multiple dikes in its length of 1900 ft (579.12 m). The measured total thickness of dike rock in the tunnel is 578 ft (176.17 m), or 30 percent of the total exposed rock mass. The average width of single dikes is 5.5 ft (1.68 m), and the maximum width 10 ft (3.05 m). Multiple dike bands are much wider, averaging 55 ft (16.76 m).

MARGINAL DIKE ZONE. In the marginal dike zone no more than about 10 percent of the rock mass consists of dikes. Thus, a large mass of lava flows occur between dikes or bands of dikes. In Kahana Valley the marginal dike zone includes the entire lower valley and extends offshore.

COASTAL PLAIN. The lower reach of Kahana consists of a small coastal plain underlaid by a wedge of marine and deltaic sediments covering the marginal dike zone. The bounding ridges of the valley, however, are sediment-free and plunge directly into the sea. The platform of sediments extends into Kahana Bay.

The marine-deltaic sediments are restricted to elevations below about 30 ft (9.14 m). They extend approximately 5000 ft (1524.0 m) inland and have a maximum cross-valley width of about 3000 ft (914.40 m). The sediments consist of alluvium, deltaic muds, and marine muds and calcareous layers, of which fossil coral reefs may be a component. They form a caprock over the underlying basalt aquifer. In lower Kahana a single well penetrated 160 ft (48.77 m) of sediments before reaching the Koolau volcanic series.

VALLEY ALLUVIUM, TALUS, AND BRECCIA. Above an elevation of approximately 30 ft (9.14 m), coinciding with the Waimanalo Stand of the sea, the sediments consist of talus and stream-laid alluvium. These sediments may be conveniently combined in the term "taluvium" because they are intimately connected in mode of formation and deposition.

An older, compacted taluvium occurs in main stream valleys to elevations of several hundred feet; overlying it are loose, obviously more recent sediments. The older taluvium predates the marine-deltaic sediments at the mouth of the valley and probably underlies them. It thickens seaward but is probably less than 50 ft (15.24 m) thick at its maximum. The younger taluvium is everywhere in the stream valleys as a discontinuous thin layer of unconsolidated debris, ranging from silt to boulders.

Patches of breccia have been mapped in Kahana Tunnel, and in Kahana Stream at elevations between 150 and 200 ft (45.72 and 60.96 m). The breccia is a highly compacted, indurated mass composed of angular rock fragments in a compacted fine-grain matrix. Its significance and overall extent have not yet been elucidated.

SOILS. The soils of Kahana Valley have been described by Swindale (1966). The soils range from undifferentiated lithosols on steep slopes to heavy marine-deltaic muds in the lower valley. All soils above an elevation of about 30 ft (9.14 m), that is, higher than the last persistent positive sea level stand (Waimanalo Stand) of about 125,000 years ago, are moderately to well drained. Below 30 ft (9.14 m) the soils are generally poorly drained.

The soils derived from parent basalt and its colluvium are well structured, porous, and permeable. The most extensive representative of these soils belongs to the Waikane Series, a well-drained latosol covering 2600 acres or 1053.0 ha (about 50 percent) of the drainage basin. Other well-drained differentiated soils (excluding lithosols) total an additional 223 acres (90.32 ha). Poorly-drained soils, in particular the Kaena series and Hanalei series, cover 364 acres (147.42 ha or 6.4 percent of the valley, and lithosols cover the remainder of the basin. Evidence of former taro and rice agriculture in the lower valley is illustrated by the occurrence of 76 acres (30.78 ha) of dark gray, poorly-drained paddy soil.

Geomorphology

As indicated in Figure 2.1, Kahana Valley, the largest valley in windward Oahu, reaches four miles from Kahana Bay to the top of an amphitheater pali whose maximum elevation is nearly 2700 ft (822.96 m) at the crest of the Koolau Range. Sharp ridges parallel to the stream and normal to the range crest form the lateral boundaries of the valley. The stream drains a total area of 8.38 sq mi (21.70 sq km).

Kahana is a deep, U-shaped valley, which is steep and rugged at its inland margin but broad and flat near the sea. Kahana Bay is the submerged portion of the ancient Kahana Valley. The present estuary of the stream is a mile (1.61 km) long, up to 250 ft (76.20 m) wide, and covers approximately 14 acres (5.67 ha).

Within the valley many small tributaries drain into two main branches that merge to form a single large stream about 2 1/2 mi (4.02 km) inland. A large tributary, Kawa, joins the main channel about one mile (1.61 km) above its mouth.

The valley can be divided into four natural sectors for descriptive hydrologic purposes. The sectors are bands parallel to the coast except for Kawa Valley, which is an entire drainage basin. At the headwaters of the valley, the region between elevation 800 ft (243.84 m) and the crest of the Koolau Range, may be called the Upper Valley. This region encompasses the extremely steep slopes above the Waiahole Ditch system and has an area of 0.86 sq mi (2.23 sq km). The region between the 30-foot (9.14 m) elevation, where the USGS stream gage is located, and the tunnel system may be called the Mid Valley, and has an area of 2.88 sq mi (7.46 sq km). The stream slope in this portion of the valley is less than 5°. Kawa Valley, which encompasses 1.90 sq mi (4.921 sq km), may be treated as a separate sector because of its size and discreteness. The Lower Valley, stretching from the bay to elevation 30 ft (9.14 m), consists of 2.41 sq mi (6.24 sq km) of a flat, broad plain which includes the estuary. In addition to these four sectors, 0.33 sq mi (.85 sq km) of headlands drain directly to the bay rather than to Kahana Stream.

DYNAMIC EQUILIBRIUM. All of the valleys of windward Oahu from Kahana to the ancient caldera near Kailua have a mature U-shape bounded by a steep pali at their headwaters. The valleys north of Kahana are less well developed and, in fact, appear to be geomorphologically considerably younger than Kahana and the valleys to the southeast. This poses a fundamental problem in unravelling the erosional history of the island because the basic conditions of erosion, rainfall and rock type, are similar for Kahana and the windward valleys to the northwest and southeast of it, and it has been assumed that no age hiatus occurred in volcanic activity between the two sectors. The considerable difference in valley shape between the apparently mature valleys and the less developed ones is clearly illustrated in Figure 2.2 which shows the longitudinal profiles of several windward valleys, including Punaluu, which lies immediately adjacent to Kahana on the north. Whereas Kahana has a relatively smooth profile, that of Punaluu is unsymmetrical and the channel throughout its midsection lies considerably above the channel of Kahana. Nevertheless, Kahana and Punaluu are geologically and climatologically similar. A possible reason for the difference in the valley shapes may depend on the location of the dike complex; in Kahana and to the southeast of it the dike complex lies to the windward of the range crest, while it pinches out near the crest at Punaluu and does not occur any farther to the northwest. Under erosional attack the dike complex may be less stable than either the marginal dike zone or regions of normal flow lavas.

The shape of Kahana Valley, according to traditional geomorphic concepts, suggests that it is a mature valley served by a graded stream. This static description may be enhanced by relating the valley to the concept of dynamic equilibrium (Leopold and Langbein 1962), which asserts that the action of a stream in eroding and depositing sedimentary debris is such that the total work done is minimized. Restated in its most simple form, dynamic equilibrium is equivalent to input-output continuity. Thus, over a long period of time the quantity of material that is eroded within the basin will equal the quantity that moves out of the basin. Over short time intervals the shape of the basin continuously readjusts to a least work shape, which according to Leopold and Langbein is expressed as an exponential longitudinal profile when base level dominates the adjustment of the valley, as it does in Hawaii.

Figure 2.2 illustrates the equilibrium condition of Kahana Valley. Throughout most of the valley the longitudinal profile follows a single exponential trend, although toward the crest and near the distal margin of the stream the profile sharpens. The crest region is probably too steep to be in equilibrium, perhaps because it falls within the dike complex, while at the distal end of the profile it is likely that the stream profile is steeper than in mid-valley as a result of transitory adjustment to the low sea level of the Flandrian Regression (-100 meters) of circa 15,000 years before present. For comparison, the profile of a valley (Waiahole) to the southeast of Kahana is plotted, as are profiles for Punaluu and Kaluanui to the northwest.

The geomorphic maturity of Kahana Valley implies that the sediment which is carried to the bay by the stream is predominantly in suspended form and secondarily as fine grain bed load. Large sedimentary particles caused by mass washing within the valley must be reduced to fine particles before the sluggish stream can transport them from the basin. The estuary acts as a holding basin for the fine sediments, which are flushed to the bay during high stream flows.

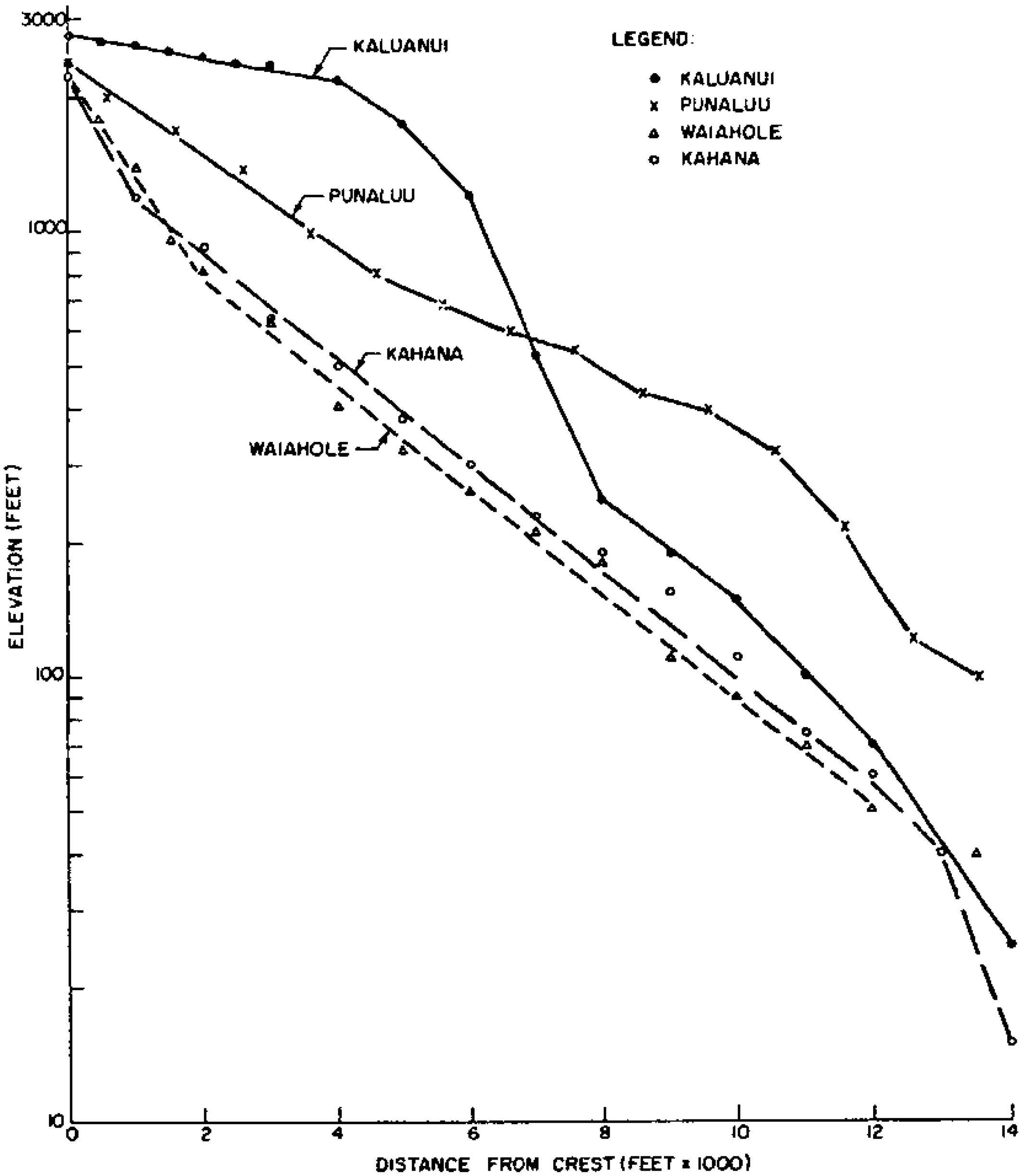


FIGURE 2.2. LONGITUDINAL PROFILES, WINDWARD OAHU; PROFILES TAKEN AT RIGHT ANGLES TO N 35° W DIKE TREND.

The nature of erosional products leaving the valley has changed with time. During the period of isostatic adjustment (sinking) of the island, mass wasting under disequilibrium conditions dominated erosional output. Later during eustatic changes in base level, mass wasting occasionally dominated, such as during the Kaena Stand (100 ft or 30.48 m) of the sea of approximately 450,000 years ago, but geomorphic equilibrium was approached until by the time of the Waimanalo Stand (25 ft or 7.62 m) of about 125,000 years before the present, fine grain sedimentation was characteristic. As mass wasting decreased in volume, chemical erosion has become the source of much of the erosional output from the drainage basin.

Hydrology

As explained in the section on climate, rainfall in Kahana is bountiful, ranging from an average of 60 in (152.4 cm) per year at the most seaward headlands to 300 in (762 cm) per year at the crest of the range. The average annual isohyets increase nonlinearly, msot probably exponentially, with distance from the sea toward the crest. Trade wind orography produces more of the total rain than does cyclonic circulation. The trade wind rainfall is characterized by showers, which although not as intense as cyclonic rain, occur more persistently throughout the entire year.

It is not certain that all of the unevaporated or untranspired rain that falls within the topographic limits of the drainage basin eventually finds a way to Kahana Bay; some infiltration may move as groundwater to the leeward of the crest, and another fraction may flow to Waikane Tunnel of the Waiahole System lying to the southeast of Kahana. In either case the quantity leaving the surface drainage limits of the basin would be small, probably within error of hydrologic budgeting. On the other hand, it is likely that groundwater drains to Kahana from Punaluu Valley in a significant amount.

SURFACE WATER. Kahana Stream is the largest stream on the windward side of Oahu. It originates in the dike complex and runs across the marginal dike zone, normal to its trend, before emptying into Kahana Bay. In dissecting the dike complex and marginal dike zone the stream acts as a drain for dike-impounded groundwater. As a result, it is a continually gaining stream from headwaters to mouth.

All of the stream and groundwater above the 800-foot elevation is collected in the transmission tunnel of Oahu Sugar Company's Waiahole Ditch system and removed from the valley. The 800-foot (243.84 m) contour is the approximate limit of the smoothly increasing gradient of the stream; above 800 ft (243.84 m), the headwaters consist of step-like cascades which flow only during rainy periods.

The deep position of Kahana Stream relative to the valleys to the north, in particular Punaluu Valley, enables it to capture a significant amount of the dike water that passes below the Punaluu channel. Relative to a base line along the coast, parallel to the dike trend, the comparable elevations of Kahana and Punaluu Streams approximates the expression:

$$H_k = .0062\ H_p^{1.635}$$

where H_k is the elevation of Kahana Stream and H_p the corresponding elevation of Punaluu Stream. For example, whereas the channel of Punaluu Stream is at the 400-foot elevation, the Kahana Stream elevation is only 110 ft. This relationship is most applicable in the mid-portion of each valley.

The fact that Kahana is a much deeper stream than Punaluu well into the dikes zones makes it a highly efficient drain of underflow from the Punaluu region. In much of the windward area there are two chief zones of natural dike water discharge. The higher occurs at elevations from about 600 to 800 ft (182.88 to 243.84 m), the upper limit of talus slopes, and represents overflow from dike compartments; the lower zone occurs at about 200 ft (60.96 m) and represents underflow from dike compartments where the relatively impermeable plaster of weathered talus is breached. While a significant portion of the groundwater component of Kahana Stream originates from the lower zone of dike discharge, a very large fraction of the base flow of Punaluu Stream comes from the higher zone.

Continuous measurements of surface flow in Kahana have been made since 1958 at USGS gage 16296500 located at elevation 30 ft (9.14 m) about 6000 ft (1828.8 m) from Kahana Bay. The Honolulu Board of Water Supply has made numerous measurements of stream flow at the 115- and 145-foot (35.052 and 44.196 m) elevations from 1958 through 1962 and at other elevations in 1927-28. In reporting on the suitability of Kahana for groundwater development, Mink (1964) summarized all flow measurements calculated as the 90 percentile flow, the minimum flow expectable 90 percent of the time. The 90 percent flow (Q_{90}) was selected as the standard of comparison because it indicates the average base flow of the stream free of storm runoff. Table 2.1 is taken from Mink's 1964 report.

Table 2.1 clearly indicates the increase in base flow of Kahana Stream as elevation decreases. Using the USGS gage as the standard, ratios and absolute values of Q_{90} for drainage areas above given elevations are listed, as are the changes that take place between the given elevations. The greatest gain in flow occurs between 300 and 115 ft (91.44 and 35.05 m), where, over a drop in elevation of 185 ft (56.398 m), 52 percent of the Q_{90} at the gage is accumulated.

Kawa Stream adds a Q_{90} of 1.6 mgd (6056 m^3/day) to the mainstream below the USGS gage, but between the confluence and the bay less than 1 mgd (3785 m^3/day) is added to base flow because the deep sediments of the lower valley retard discharge of groundwater into the stream.

Figure 2.3 is a flow-duration curve for Kahana Stream at the USGS gage station (Mink 1964). Although it is based on fewer measurements than now available, its general form and statistical parameters are likely to closely approximate a curve based on the longer period of record. The average flow at the gage for the period of measurement through 1971 is 24.8 mgd (93,868 m^3/day).

FLOODS. Earlier it was pointed out that the highest instantaneous flows

TABLE 2.1. SUMMARY OF THE 90 PERCENTILE (Q_{90}) STREAM FLOW OF KAHANA STREAM.

ELEVATION[a] (ft)	AVERAGE RATIO OF FLOW AT GAGE[b]	RATIO DIFFERENCE BETWEEN POINTS	Q_{90}[c] (mgd)	FLOW BETWEEN POINTS (mgd)	NUMBER OF MEASUREMENTS[d]	REMARKS
30	1		9.50		DAILY	USGS GAGE 2965.
		.15		1.42		
115	.85		8.08		43	
		.10		.95		
145	.75		7.13		45	
		.10		.95		
180	.65		6.18		1	
		.15		1.42		
220	.50		4.75		2	
		.08		.76		
270	.42		4.00		10	
		.09		.85		
300	.33		3.15		6	SIX MEASUREMENTS EACH ON RIGHT AND LEFT BRANCHES.
		.17		1.62		
420	.16		1.53		1	ONE MEASUREMENT EACH ON RIGHT AND LEFT BRANCHES.
		.11		1.05		
570	.05		.48		1	ONE MEASUREMENT EACH ON RIGHT AND LEFT BRANCHES.
		.05		.48		
800[e]	0		0			UPPER LIMIT OF WATER SOURCE.
MISCELLANEOUS						
15	1.2		11.40			KAWA STREAM CONTRIBUTES 1.6 mgd. LOWER KAHANA 0.3 mgd.
30 (KAWA)	.17		1.60		15	KAWA (OR EAST KAHANA) STREAM.

SOURCE: MINK 1964.

[a] FROM USGS MAPS OR ALTIMETER READINGS, EXCEPT AT USGS GAGE STATION.

[b] RATIOS WERE COMPUTED FOR EACH MEASUREMENT, THEN AVERAGED. BWS MEASUREMENTS AT THE GAGE STATION WERE USED WHERE POSSIBLE.

[c] Q_{90} AT EACH POINT OBTAINED BY TAKING Q_{90} AT THE GAGE STATION (9.5 mgd) TIMES THE AVERAGE RATIO AT THE POINT.

[d] ALL MEASUREMENTS AT 115 AND 145 FEET HAVE BEEN TAKEN SINCE 9/1/60 BY THE BWS. MEASUREMENTS AT 570, 420, AND 300 FEET TAKEN BY THE BWS IN 1927-28. AT 270 FEET, FOUR MEASUREMENTS TAKEN BY THE USGS SINCE 1960, AND SIX OBTAINED BY BWS IN 1927-28. MEASUREMENTS AT 220 AND 180 FEET TAKEN BY THE USGS SINCE 1960.

[e] ALL WATER ABOVE 800 FEET IS DIVERTED TO THE WAIAHOLE WATER SYSTEM. AVERAGE FLOW FOR KAHANA PORTION IS 6.9 mgd.

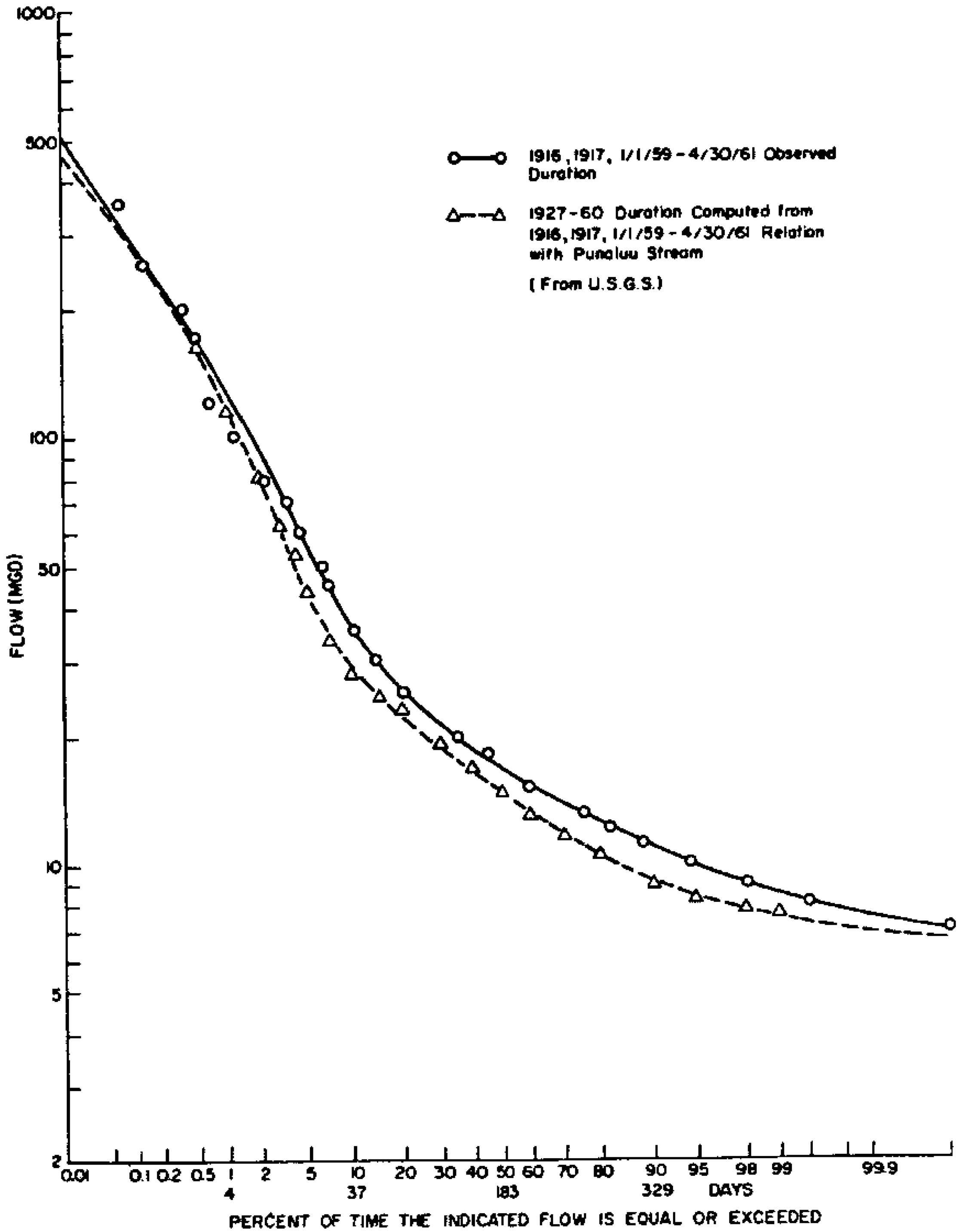


FIGURE 2.3. FLOW DURATION CURVE OF KAHANA STREAM, 30-FOOT ELEVATION.

(floods) in Kahana most often occur in the months of April and May, the period of transition as the anticylcone northeast of the archipelago moves toward its stable summer position. However, storms giving rise to floods may occur anytime throughout the year. Maximum instantaneous flows measured at the USGS gage for the period 1960-1971 are given in Table 2.2 (Nakahara and Ewart 1972).

TABLE 2.2. MAXIMUM FLOWS USGS GAGE 16296500, KAHANA ELEVATION 30 FEET.

WATER YEAR	DATE	FLOW (cfs)(mgd)
1960	05/12	1580 (1021)
1961	10/17	1810 (1170)
1962	11/01	3510 (2269)
1963	04/15	5430 (3510)
1964	07/25	3060 (1978)
1965	02/04	4120 (2663)
1966	11/14	3110 (2010)
1967	08/09	3780 (2443)
1968	12/08	4180 (2702)
1969	12/01	4620 (2986)
1970	01/27	2950 (1907)
1971	11/25	3780 (2443)

It is noteworthy that only the months of February, June, and September do not record the maximum for any year.

From the data in Table 2.2 the probable recurrence interval of floods of given magnitudes may be computed by using the relationship

$$T = \frac{N + 1}{M}$$

where T equals recurrence interval in years; N equals number of years of record; M equals relative flood magnitude, obtained by assigning the highest annual flow a value of 1 and numbering serially the others in order of magnitude. By plotting the log of each flood magnitude against the log of its computed recurrence interval and drawing a line of fit, flood frequencies may be estimated beyond the period of record (Fig. 2.4).

Another way of estimating flood frequencies is by use of the log-Pearson Type III method. Data and computations for Kahana using this method are given in Table 2.3 (from Progress Report 36, State of Hawaii Department of Land and Natural Resources), and are also plotted on Figure 2.3.

The two methods agree reasonably well within the data limits but diverge appreciably for times beyond 10 years. The expected 100-year flood by the first method is 10,000 cfs (17,000 m^3/min), but only 6211 cfs (10,588.7 m^3/min) by the log-Pearson II method.

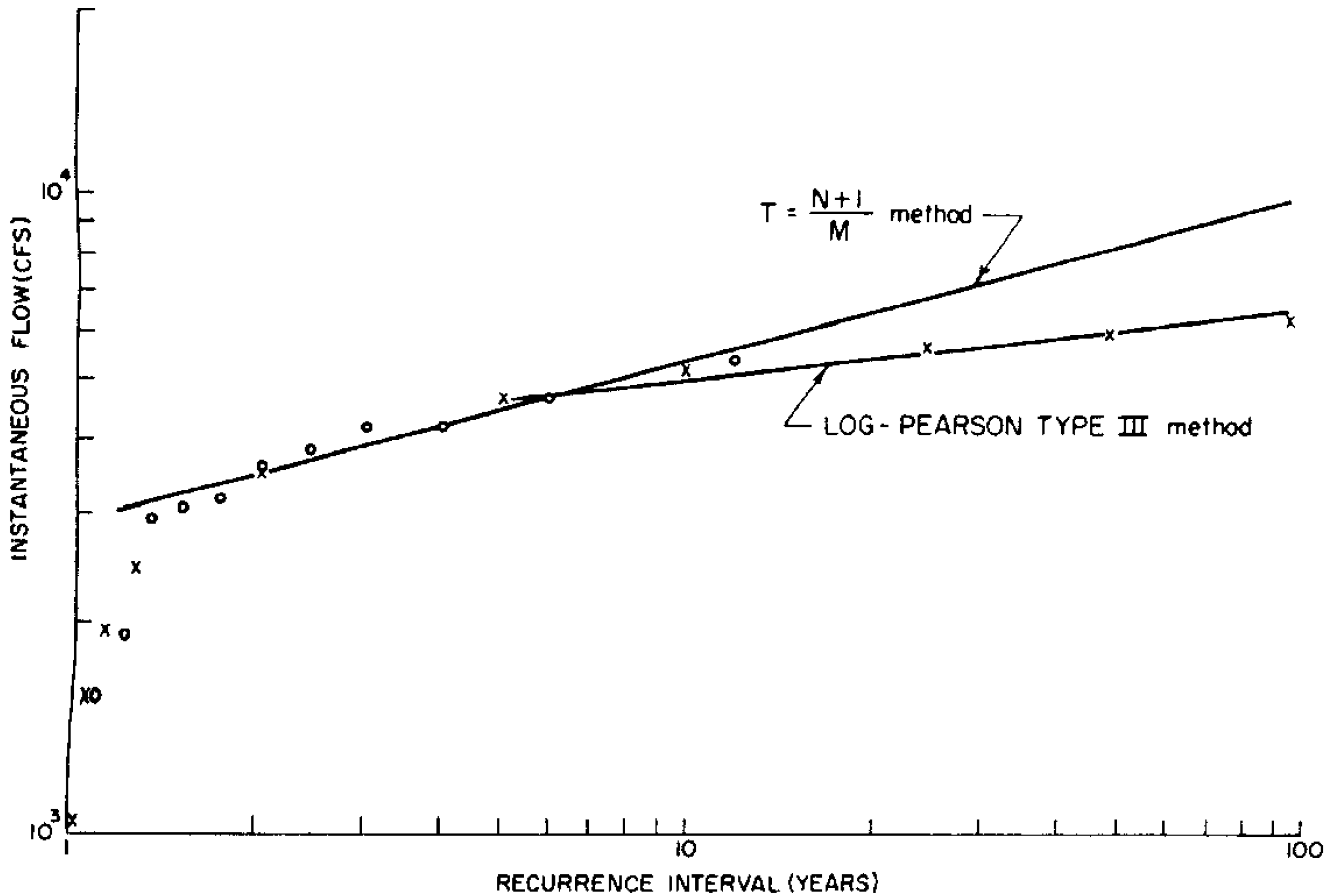


FIGURE 2.4. PROBABLE FLOOD FREQUENCIES OF KAHANA STREAM, GAGE STATION 16296500.

TABLE 2.3. FLOOD FREQUENCIES KAHANA STREAM: LOG-PEARSON TYPE III METHOD.

EXCEEDENCE PROBABILITY	RECURRENCE INTERVAL, yrs	MAGNITUDE cfs	(mgd)
.9900	1.01	1006	(650)
.9500	1.01	1578	(1020)
.9000	1.11	1948	(1259)
.8000	1.25	2450	(1584)
.5000	2.00	3524	(2278)
.2000	5.00	4627	(2991)
.1000	10.00	5164	(3338)
.0400	25.00	5680	(3872)
.0200	50.00	5975	(3862)
.0100	100.00	6211	(4015)
.0050	200.00	6404	(4140)

SOURCE: DEPARTMENT OF LAND & NATURAL RESOURCES PROGRESS REPORT 36, 1970.

It is somewhat surprising that the maximum recorded flood in Kahana on a unit area basis, 1452 cfs/sq mi (953.964 $m^3/min/km^2$), is less than for Waikane, 4000 cfs/sq mi (2628.0 $m^3/min/km^2$), where the average annual rainfall is much smaller. Even the projected 100 yr flood in Kahana would be less on an areal comparison than the maximum flood already recorded in Waikane.

Wu (1967) suggested a formula for the 100-year flood in windward Oahu based on watershed area, stream length, watershed height, and probable 100-year maximum 24-hour rain. When applied to Kahana, however, the computed value is 29,050 cfs (49,385.0 m^3/min), which is considerably in excess of predictions made by standard methods.

GROUNDWATER. All of the groundwater in Kahana Valley occurs within the dike zones. Near the coast local Ghyben-Herzberg conditions probably occur within the marginal dike zone.

Dike water refers to groundwater occurring in aquifers bounded by dikes. The confining dikes may range from being nearly completely impermeable to being quite leaky. Normally the dikes effectively restrain the movement of water through them until a head builds up that forces flow through natural openings such as fractures. The rate of flow through these openings may be too low, however, to drain all of the water moving through the compartment, in which case the water level increases until it overflows the compartment which has been truncated by erosion. The compartment is used in the sense of a prism of flow rocks bounded laterally by parallel dikes but open at either end. Water moves preferentially along the trend of the dikes. Under natural conditions an average steady state prevails in which water moving through a given unit cross-section between dikes is balanced by the quantities that overflow the section, pass through the restraining dikes, and continue down the trend.

Dike water is subdivided into that which occurs within the dike complex and that in the marginal dike zone. The groundwater of the dike complex is restrained in permeable flow rock intersected by many dikes, causing innumerable small aquifers. In the marginal dike zone the aquifers between dikes are relatively large but well-bound.

Both the dike complex and the marginal dike zone carry large quantities of groundwater. Above the 800-foot (243.84 m) elevation, which lies in the dike complex, all of the water passes into the Waiahole system. Of the average 6.9 mgd (26,116.5 m^3/day) that leaves the valley via the transmission tunnel, 3.8 mgd (14,383.0 m^3/day) is groundwater from the development tunnel.

The dike complex extends from the crest of the range down to about the 270-foot (82.296 m) elevation in the mid-valley. Between elevations 800 and 270 ft (243.84 and 82.30 m), the dike compartments are saturated but a plaster of talus and alluvium in conjunction with many intersecting dikes prevents easy discharge into the streams. Small swamps are common on flat areas between streams because the water table is at the surface. From this part of the dike complex the Q_{90}, which may be considered the groundwater component of stream flow, is about 4 mgd (15,140 m^3/day).

The rocks of the marginal dike zone are saturated with water, some of which does not discharge into Kahana Stream but leaves the area as underflow either into the caprock sediments or the sea. The upper portion of the zone between the 30- and 270-foot (9.144 and 82.296 m) elevation contribute about 5.5 mgd (20,817.5 m^3/day) to Q_{90} at the USGS gage. Kawa Stream is almost entirely in the marginal zone.

Below the approximate 30-foot elevation, the stream flows over marine-deltaic caprock sediments and no longer drains the marginal dike zone. The underlying dike compartments are saturated and leak into the caprock and the sea. Continuity with the sea exists and therefore a small Ghyben-Herzberg lens occurs along the coast within the marginal dike zone. Active springs of the shoreline show chlorides of up to 100 ppm, while the range in a well (405) drilled through the caprock into the basalt varies from 30 to 50 ppm.

Hydrologic Budget

A gross water budget for Kahana Valley is given by Takasaki et al. (1969), but for computations of mass output of dissolved solids and of sediments to the bay a more refined hydrologic analysis had to be made for this study. Hydrologic budgeting is based on averages over reasonably long periods and balances input of water against output, assuming no change in either ground- or surface water storage over the averaging period. In Kahana Valley limited measurements of the input variable, rainfall, and good measurements of an output variable, surface flow, are available. Rainfall has been recorded at the 800-foot (243.84 m) elevation for more than 40 years and occasionally near the seacoast. Continuous surface water measurements have been made at the USGS gage at the 30-foot (9.144 m) elevation since 1958 and at the Kahana Tunnel at 800 ft (243.84 m) since 1929. Many miscellaneous stream flow measurements have also been made in the valley; the first on record was in 1911 (Lippincott 1911). All of the other variables in the hydrologic equation, as well as much of the rainfall and flow volumes, have had to be inferred.

The topographic and hydrologic boundaries of Kahana Valley do not coincide; groundwater moves into the valley chiefly from Punaluu and flows from the upper valley to the leeward side of the Koolau Range and probably also to Waikane Valley. The input-output equation for the drainage basin is:

$$P + U_i = ET + D + I + U_o$$

in which P is rainfall over the basin, U_i is underflow into the valley from outside the surface drainage boundaries, ET is evapotranspiration, D is direct runoff, I is infiltration, and U_o is underflow from the valley. At the mouth of the valley the total surface water flow, S, is composed as follows:

$$S = aD + bU_i + cI$$

where a, b, and c are fractions. Not all of D discharges to the sea because a portion is diverted to the Waiahole system. Groundwater flow to the bay consists of fractions of U_i and I.

Because of the water development project at the head of the valley and the location of the USGS continuous flow measurement station relatively close to the inland edge of the estuarine portion of the stream, for hydrologic budget purposes the valley can be conveniently divided into four major units and a minor one, which consists of headlands draining directly to the bay. The major units are:

1) The Upper Valley, bounded by the Waiahole transmission tunnel running along the 800-foot (243.84 m) contour elevation and the crest of the range, totalling 0.86 sq mi (2.227 km^2). All of the surface water, except during periods of heavy flooding, flows to the transmission tunnel; most of the groundwater drains to Kahana Tunnel but some also moves to the leeward side of the Koolaus and some to Waikane Valley. Flows have been diverted from this part of Kahana since 1916.

2) The Mid Valley, consisting of 2.88 sq mi (7.459 km^2) and extending from the 30-foot elevation (9.144 m) to 800 ft (243.84 m) as measured in the stream channel.

3) The Kawa Stream Valley, with an area of 1.9 sq mi (4.921 km^2) and an elevation range from 25 ft to 2265 ft (7.62 to 690.372 m). Kawa meets the main Kahana Stream a short distance below the USGS gage. Numerous miscellaneous stream flow measurements have been made at the mouth of Kawa Stream.

4) The Lower Valley, comprising 2.41 sq mi (6.242 km^2) including Kahana Stream between the bay and the Kawa-Kahana confluence. This sector includes the estuary and the stream underlaid by sediments which thicken toward the coast. Stream flow measurements are extremely difficult to make in the estuary, although a few miscellaneous measurements are available.

The headlands that drain directly into the bay have a total area of 0.33 sq mi (0.8547 km^2). They contribute surface runoff and groundwater flow from small Ghyben-Herzberg lenses into the bay.

Figure 2.5 is a flow diagram of the budget components for each sector showing the relationships among the sectors and to the ultimate flows to Kahana Bay. In computing the components measured quantities were used where available, and elsewhere inferred values based on hydrologic analogies were employed. All components are given in mgd (million gallons per day).

Rainfall was computed from an isohyetal map (Board of Water Supply 1963, p. 25). Evapotranspiration was derived from the relationship given by Takasaki et al. (1969, p. 22), in which pan evaporation is indicated as decreasing nonlinearly with rainfall. Evapotranspiration is assumed equal to pan evaporation, a relationship established for sugarcane where adequate water is available to meet potential requirements of the cane. The rainfall throughout Kahana is considered high enough to provide sufficient moisture to satisfy potential evapotranspiration demands. In the Upper Valley direct runoff and groundwater flow have been continuously recorded in the transmission tunnel for more than five decades.

For the Mid Valley total runoff is recorded on a USGS gage. Groundwater flow into the valley from outside its topographic boundaries was computed as the difference between the sum of the total runoff and evapotranspiration, and the total rainfall. The miscellaneous stream measurements in Kawa Valley and the Lower Valley were correlated with the longer record at the Kahana station to yield estimates of flow. For the areas directly tributary to the bay, groundwater flow was approximated from the Darcy equation, assuming a head of 5 ft (1.524 m) and a hydraulic conductivity of 1000 ft/day (304.8 m/day).

Geochemistry

Kahana Valley consists of a monolithologic terrain except for marine detritus in the Lower Valley. Parent rock is exclusively basaltic in composition; the only lithologic products not derived from Koolau basalt are calcareous marine sediments near the bay and in the caprock wedge at the mouth of the valley. The normal weathering sequence culminating in latasolic soils prevails except below the approximate 30-foot (9.144 m) elevation where marine submergence has given rise to heavy plastic soils.

Warm temperatures and high rainfall weathered parent rock containing few resistant minerals have produced saprolite thicknesses of up to 100 ft (30.48 m) in favorable locations. Saprolite is thin, or transitory, on the steep slopes at the head of the valley and along the lateral ridges. Also, as the gradient of the stream channel increases toward the Upper Valley it incises the saprolite to reach fresh rock.

The parent basalt is composed predominantly of calcic plagioclase, pyroxene, olivine, magnetite, ilmenite, some apatite, and varying percentages of glass. An average analysis for the Koolau basalt is given in Table 2.4 (Visher and Mink 1964, p. 87). None of the silica in Hawaiian basalts occurs in free oxide form as quartz or its polymorphs.

During the weathering process, silica and the alkalies and alkaline earths are readily leached, leaving a saprolite composed largely of hydrated oxides of iron and aluminum, with kaolinite clays where marine submergence

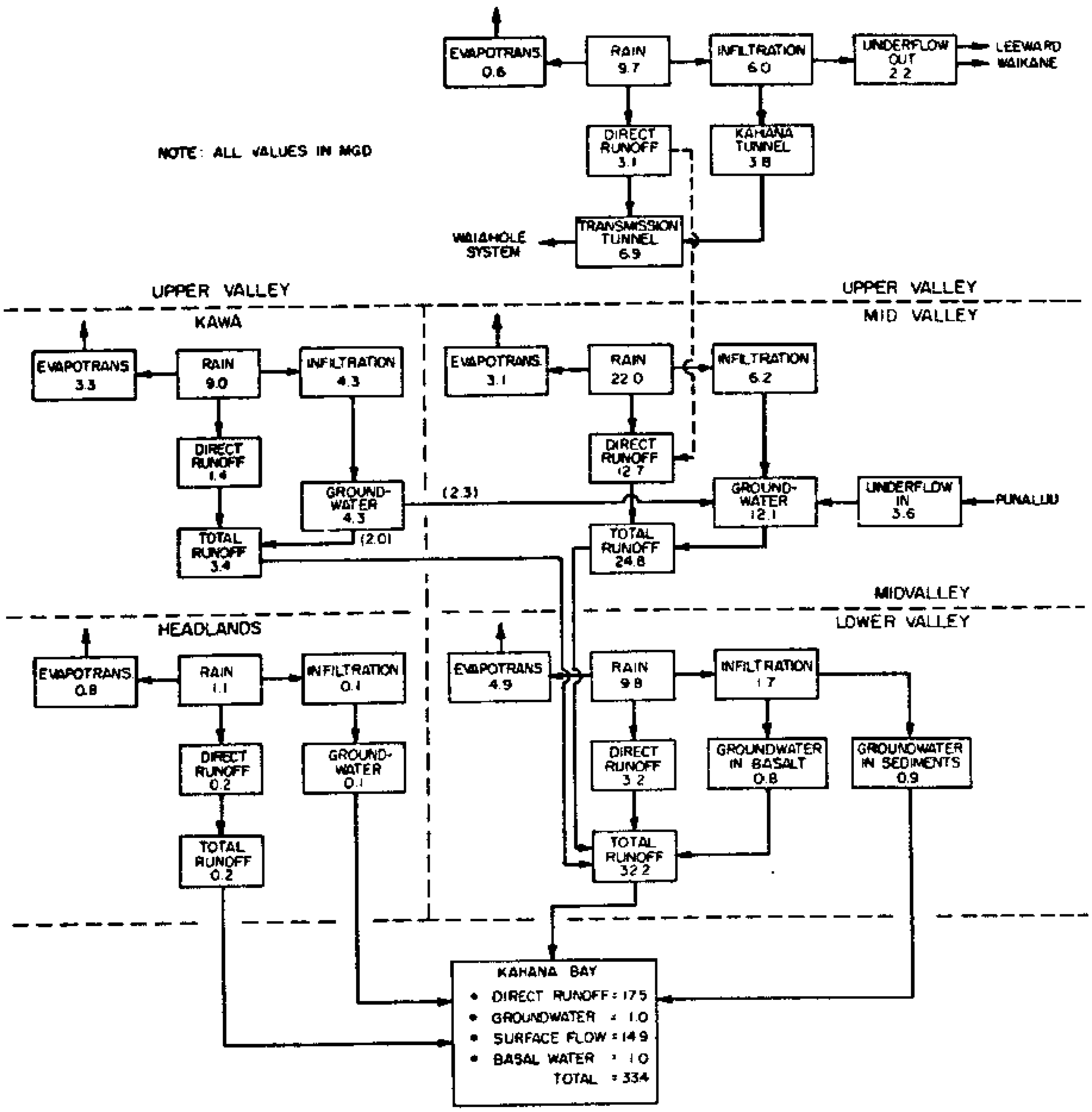


FIGURE 2.5. HYDROLOGIC BUDGET OF KAHANA VALLEY, OAHU.

had not occurred, or a complex mixture of montmorillonite and kaolinite, and other clay forms as illite where it had occurred. Patterson (1971, p.14), in studying the Koloa basalt on Kauai, a basalt similar to the Koolau basalt but somewhat less silicic, reported that the minerals composing the thoroughly weathered rock (saprolite and soil) are principally gibbsite, goethite, hematite, kaolins (chiefly halloysite and metahalloysite), and magnetite, with lesser amounts of ilmenite, anatase, maghemite, and amorphous inorganics. The average analysis of the Koloa basalt given by Patterson (1971, p. 28) is also listed in Table 2.4.

TABLE 2.4. REPRESENTATIVE CHEMICAL ANALYSES OF BASALTIC ROCKS.

CONSTITUENT	KOOLAU[a] BASALT PERCENT	KOOLAU[b] BASALT PERCENT
SiO_2	50.45	42.27
TiO_2	2.33	2.69
Al_2O_3	14.94	10.90
Fe_2O_3	3.28	4.32
FeO	7.55	8.66
MnO	.08	.13
MgO	7.67	12.77
CaO	9.17	11.67
Na_2O	2.84	2.85
K_2O	.35	.83
H_2O+	.79	1.31
P_2O_5	.27	.69

[a] VISHER AND MINK 1964.
[b] PATTERSON 1971.

Several heavy metallic elements occur in significant quantities in parent basalt and more obviously in its weathered products. Table 2.5, in part summarized from Patterson (1971, p. 33), lists heavy metals in parent Koloa basalt, in its saprolite cover, and in the amorphous gel fraction of the saprolite. From the table it appears that chromium concentrates in the saprolite, probably remaining in resistant magnetite and ilmenite grains, whereas much of the copper, nickel, and lead are leached away. However, lead is complexed in the amorphous gel, which probably accounts for its sometimes unusually high concentration in suspended sediments. The heavy metal content of Kahana soils is also given in Table 2.5.

Other evidence of the rather high concentration of certain heavy elements in basalts and their residual products in Hawaii is available in reports of studies done at the Agricultural Experiment Station, University of Hawaii. Chang and Sherman (1953) reported nickel content of Hawaiian soils ranging

TABLE 2.5. HEAVY METAL CONCENTRATIONS IN PPM IN BASALT AND ITS WEATHERED PRODUCTS.

	KOLOA BASALTS	KOLOA SAPROLITE DEPTH >20 ft[a]	KOLOA SAPROLITE DEPTH <20 ft[a]	AMORPHOUS GEL[a]	KAHANA SOILS[b]
Cr	400	860	560	30	24 - 112
Cu	290	80	33	150	29 - 190
Ni	840	580	250	150	178 - 449
Pb	12	3	0.5	30	34 - 94

[a] PATTERSON 1971.
[b] PRESENT STUDY.

from 98 to 661 ppm; Fujimoto and Sherman (1959) reported copper concentrations of 16 to 357 ppm; and Nakamura and Sherman (1958) reported chromium concentrations of 230 to 9000 ppm.

SUMMARY OF FINDINGS

Water and Sediments From Kahana Stream

To evaluate the amount and variation of water and sediments, and the nature and concentrations of quality factors transported by these two vectors, three approaches were utilized in the study: 1) mathematical models, 2) data from the US Geological Survey and from other researchers, and 3) the QCW project program of sampling and analysis.

Two types of water, direct surface runoff and dike water, drain to Kahana Stream and hence into the bay. Direct runoff is rainwater that either moves over the surface or through the thin surface mantle of forest debris and soil to the stream. Dike water is groundwater within the dike zone. These types of water also drain the Waiahole Stream in the Upper Valley. From the headland boundaries of the bay a small quantity of basal water flows directly into the sea.

FRESH WATER DISCHARGE. For the purpose of the project, no systematic program of measurement of fresh water discharge from Kahana Stream was undertaken reliance being placed upon the ongoing gaging by the USGS, and upon the findings of others, notably Mr. John Mink. Statistics on the amount and variation of fresh water discharge to Kahana Bay via Kahana Stream, are presented in a previous section of this chapter (Climate p. 6), and are summarized in Table 2.6

Observed and computed flow duration curves for Kahana Stream at the 30-foot elevation (9.144 m) have also been presented (Fig. 2.3). From such data a general concept of the amount and seasonal variation in fresh water discharge to Kahana Bay is derived. The effects of such discharge on the

TABLE 2.6. VARIATION IN KAHANA STREAM DISCHARGE, 1971.

TYPE OF OBSERVATION	TIME	DISCHARGE (cfs)
INSTANTANEOUS MAXIMUM	APRIL 1963	5430
AVERAGE MAXIMUM	APRIL	1750
AVERAGE MAXIMUM	MAY	942
AVERAGE MAXIMUM	AUGUST	134
AVERAGE MAXIMUM	SEPTEMBER	148
HIGHEST DAILY AVERAGE	MARCH, APRIL, MAY	50 - 60
ANNUAL AVERAGE	CALENDAR YEAR	35.9
LOWEST DAILY AVERAGE	JULY, AUG., SEPT.	24.8

SOURCE: USGS DATA, 1971.

quality of water, and hence on the biota of the bay, however, depends both upon its function in diluting bay water and the burden of dissolved and suspended solids it carries. This in turn is dependent upon the relative amounts of groundwater (dike water) and surface runoff in the discharge because the two are by nature significantly different in composition.

The groundwater component of surface runoff is essentially equivalent to the average base flow of the stream. The 90 percentile flow on the flow duration curve is often a good estimate of base flow. For Kahana at the USGS gage the 90 percentile flow is about 10 mgd (37,850 m^3/day), but the hydrologic budget (previously computed herein) indicates that the groundwater component of total flow averages about 12.1 mgd (45,798.5 m^3/day). This latter value is hereinafter used in computing mass outputs. In such computations the Upper Valley groundwater flow is measured at the portal of Kahana Tunnel, and direct runoff is obtained as the difference between total flow measured in the transmission tunnel at the southeast boundary of the valley and the flow at Kahana Tunnel. Groundwater and direct flow are estimated in the Lower Valley.

CHEMICAL COMPOSITION OF KAHANA STREAM DISCHARGE. In Kahana Stream, as in any state of nature situation, it may be anticipated that the groundwater will be higher in dissolved minerals than is direct runoff, and that the concentration of the various mineral elements in the stream will vary with flow rates. From the data previously presented in Table 2.4, the general nature of solids in outcropping groundwater may be anticipated.

The dissolved load in direct runoff could be expected to vary inversely with rainfall. The forest mantle is rinsed of dissolved chemicals, including soluble products of biodegradation of organic matter, as rain falls and flows through it; thus it may carry an organic fraction not found in the groundwater. However, at high volumes of discharge nearly pure rain water flows to the stream. Rain in Hawaii, incidentally, has a composition in which the concentration ratios approximate those of sea water, reflecting the sea salt nuclei around which moisture collects to become rain drops. Sea salt nuclei also are carried into the valley in normal air and deposited on trees, other vegetation, and the ground.

The equation of mass output for the dissolved constitutents in Kahana Stream water is:

$$M = C_t W_t = C_g W_g + C_d W_d \tag{1}$$

in which M is the mass of the constituent, C_t = the percent of the constituent in the total weight of solution W_t; C_g is the percent of the constituent in the weight of the groundwater component, W_g; and C_d is the rercent in the weight of direct runoff component, W_d. Equation (1) may be cast in the more adaptable form:

$$C_t = \frac{C_g Q_g + C_d Q_d}{Q_g + Q_d} \tag{2}$$

in which the Q = flow rates expressible in appropriate units such as mgd, and C = concentrations, generally expressed as ppm.

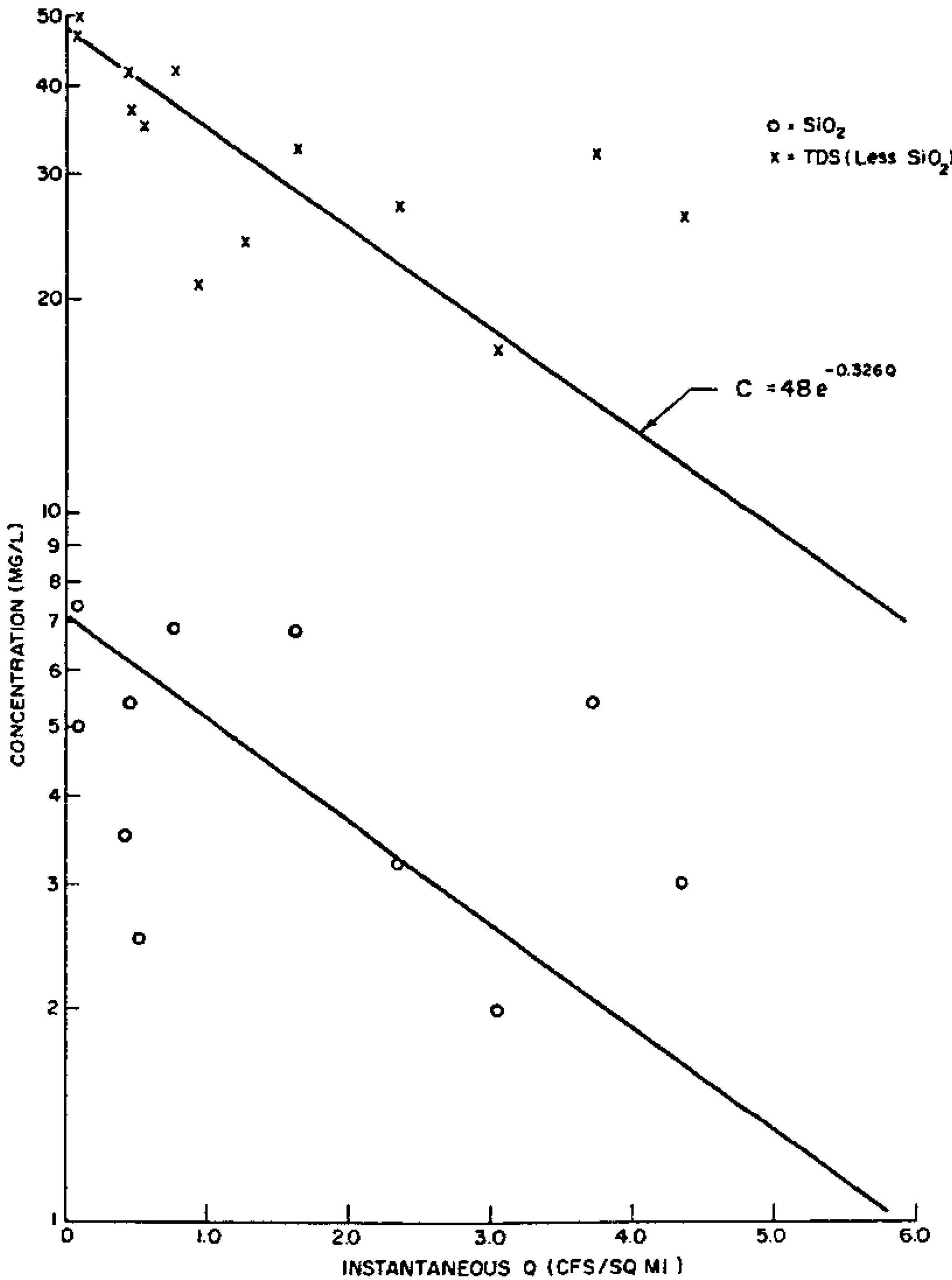
The concentrations in the direct runoff component should fit an exponential decay curve if the rinsing phenomenon is applicable. Data obtained from USGS records (USGS 1970) appear to confirm the decay relationship between concentration and instantaneous flow for nondike streams in the forest regions of the Conservation Zone. Table 2.7 lists 16 analyses for streams in the wet mountains of leeward Oahu for which all flow derives from direct surface runoff. The rainfall in these stream basins is comparable to that in Kahana. Figure 2.6 is a plot of silica and total dissolved solids concentrations as a function flow, showing reasonable fits to exponential decay curves.

In the rinsing model, the mass output is determinable from the following:

$$C_t = \frac{C_g Q_g + [C_{do} \exp (-aQ_d)]}{Q_g + Q_d} \tag{3}$$

in which the expression $[C_{do} \exp (-aQ_d)]$ is the decay in concentration with increasing flow, C_{do} being the concentration at the start of direct runoff. By using equation (3) with appropriate values for the groundwater in conjunction with the flow duration curve for the Mid Valley, a value of 78 ppm was calculated for the average TDS (less silica). However, if the considerably less tedious technique of using single flow averages and average concentrations as given in Table 2.7 along with equation (2) is employed, the computed TDS average is 78.7, almost identical to the rinsing hypothesis value. Thus to determine the mass output of the direct runoff component, it is reasonable to employ equation (2) with average concentrations and flows.

Concentrations in the groundwater of the dike zone are treated as invariable, as is the flow component. Two analyses of Kahana Stream at comparatively low flows is given by the USGS (1970), but apparently the flows did not consist strictly of dike water (Table 2.8). Estimation of the composition of dike water by a statistical approach utilizing low flows at numerous windward streams between Punaluu and Luluku is summarized in



DATA FROM WATER RESOURCES DATA FOR HAWAII, USGS 1970

FIGURE 2.6. DISSOLVED SOLIDS CONCENTRATION VS. FLOW IN NONDIKE STREAMS OF OAHU.

Table 2.8. Presumably the low flows of these dike streams as shown in the table will closely reflect dike water composition. Utilizing in equation (2) the stream flow averages given in Table 2.8 as the mean composition of dike water and the listed Kahana averages as combined direct runoff-groundwater flow, the groundwater component of Kahana at the gage station is computed as 11.9 mgd (45,041.5 m^3/day), very close to the 12.1 mgd (45,798.5 m^3/day) obtained from the hydrologic budget.

The composition of the small amount of basal water that flows directly into the bay is taken from Visher and Mink (1964). A summary of chemical composition of waters that flow from Kahana drainage basin is given in Table 2.9. Because of the very high rainfall in the Upper Valley the dike water of Kahana Tunnel is treated separately from the Mid Valley. For completeness, the composition of rainwater based on analyses given in Visher and Mink (1964, pp. 82, 84) and Patterson (1971, anal. [10 and 11] p. 29) is also included in the table.

A summary of the mass output computations of dissolved constituents given in pounds per day, based upon the analyses given in Table 2.9 and the hydrologic budget, is provided in Table 2.10. The Upper Valley is included even though its waters do not ordinarily reach Kahana Bay. The Mid Valley is also treated as a separate unit because a good record of flow measurements exists. Part 3 of the table, summarizing drainage to Kahana Bay, is most relevant to the evaluation of coastal waters.

The total dissolved material which discharges to the bay on an average daily basis is relatively small, particularly with reference to the nutrient constituents, NO_3^- and $PO_4^{\equiv}$. Only 8 lbs (3.63 kg) of phosphate and 115 lbs (52.21 kg) of nitrate are carried to the bay in solution. Of the other constituents, only SiO_2 could be said to perhaps enrich the waters of the bay; the remaining elements occur in much greater concentrations in sea water than in fresh effluent. It should be recognized, however, that discharge is variable and therefore no day is identical to any other.

The dissolved load of rock-derived constituents that appears in the waters draining from the valley clearly indicates the importance of chemical erosion in the wet mountain regions of Hawaii. Silica best illustrates the phenomenon because practically all of the dissolved silica in the draining waters is derived from the rocks. By weight silica makes up about 50 percent of the rock mass. Thus, the approximately 4600 lbs (2088.40 kg) of silica (Upper Valley plus discharge to Kahana Bay) that leaves the valley daily in solution reflects the dissolution of about 60 cu ft (1.68 cu m) of rock, based on a rock specific gravity of 2.4.

Rates of landscape denudation by chemical erosion in the very high rainfall areas can be illustrated by computing the time that would be necessary to remove the mountain mass in the Upper Valley by solution only. The mountain above the Waiahole System has a volume of about 30 x 10^9 cu ft; the rate of silica removal in solution is about 750 lbs/day (340.5 kg/day), equivalent to the solution of 10 cu ft (.28 m^3) of rock. Thus to chemically erode the mountain under present rates of erosion would require about 8 million years.

The foregoing summary of chemical constituents of Kahana basin discharges (Table 2.9) relates primarily to soluble minerals which appear in the earth's crust or are deposited on the surface as nuclei of raindrops. To supplement the data the QCW project initiated a program of monthly sampling and analysis of water obtained from Kahana Stream at the upper end of the Mid Valley section of the drainage basin (see Station 6, Fig. 2.11). Results of analyses for selected parameters, some of which are indicative of the organic load on the stream, are presented in Table 2.11 for the period March 1972 through June 1973. They show a lower concentration of nitrogen and phosphorus than was estimated in Table 2.9 for the Mid Valley water. Values reported for total solids, chlorides, and conductivity in Table 2.11, however, are not consistent within themselves, especially in the sample of 5/14/72 when an exceptionally high value of chloride was reported. Nevertheless, the data on volatile solids, organic carbon, nitrogen, and phosphorus describe a water relatively low in organic matter. The predominance or dissolved volatile solids in the total volatile solids suggests that such organic matter as was present was to a considerable degree bio-stabilized. As for the nutrient concentration, the data support the evidence gained from analysis of the USGS data (Table 2.9) that only a relatively small amount of nutrients and mineral salts are contributed to the bay by water flowing from the undeveloped land of the Kahana drainage basin.

HEAVY METALS. Because of their particular significance as toxic chemicals, the heavy metals are singled out for especial consideration as chemical constituents of Kahana Stream. From Table 2.5 it is clear that Hawaiian basalts are a rich source of heavy metals, particularly chromium, copper, nickel, and lead, and that they yield residues having comparable concentrations. The values for Kahana soils shown in the table, together with the ability of surface runoff to erode soils, make it important to determine whether heavy metals reach Kahana Bay in water or in sediments. Analyses show that the solubility of heavy metals under the prevailing environmental conditions of Kahana Stream is very low. Only minute traces of such metals appear in the fresh water. Table 2.12 presents results of analyses of Kahana Stream water sampled at the USGS gage in Mid Valley.

Assuming the highest value of each element as the content of the average daily flow, discharges to heavy metals to Kahana Bay would range from 0.8 lbs/day (.36 kg/day) of chromium to 2.4 lbs/day (1.09 kg/day) of zinc.

The mechanism of transport from the valley probably resembles the modes of travel described by Gibbs (1973, pp. 71-73) for the Amazon and Yukon Rivers. He described five modes of travel and found that the relative movement of heavy metals in both basins is very similar. Table 2.13 from Gibbs (1973, p. 72) summarizes data for the Amazon River. The dominant mode for chromium and copper is in crystalline sediments, representing original parent rock minerals, while for nickel it is as a precipitated compound, probably accompanying iron in an iron hydroxide.

From evidence such as the foregoing it is concluded that for evaluating the significance of heavy metals in the quality of water and life in Kahana Bay attention must be turned to the sediments.

TABLE 2.7. CHEMICAL ANALYSES OF FLOW IN NONDIKE STREAMS, EQUIVALENT TO DIRECT SURFACE RUNOFF.

USGS GAGE NO.	STREAM	CONCENTRATIONS IN ppm											FLOW cfs/m
		SiO_2	Ca	Mg	Na	K	HCO_3	SO_4	Cl	F	NO_3	TDS(LESS SiO_2)	
200000	NORTH FORK KAUKONAHUA	2.3	.7	.9	4.5	.3	5	1.0	9.0	.1	.3	22	11.59
204000	NORTH FORK KAUKONAHUA	7.4	1.3	1.6	6.3	.4	9	1.6	11	.1	.5	35	
208000	SOUTH FORK KAUKONAHUA	3.2	1.2	1.3	5.4	.6	9	1.0	10	0	.2	21	2.34
"	"	5.4	1.4	1.8	6.2	.5	12	0	11	0	0	32	3.11
"	"	2.5	2.0	1.2	7.8	.5	8	2.4	15	.1	0	35	.52
211000	POAMOHO	3.0	.8	1.1	5.6	.4	6	2.0	10	0	.4	26	4.36
"	"	6.8	1.1	1.5	6.4	.6	4	1.6	12	.1	.5	33	1.62
212800	KIPAPA	7.4	2.2	2.5	8.7	.9	14	3.0	15	0	0	47	.07
"	"	2.0	.6	.7	3.5	.4	4	1.4	6.0	.2	.4	17	3.03
"	"	5.4	1.6	1.9	7.1	.8	9	1.6	14	.1	0	37	.44
325000	KAMANANUI	3.5	1.6	2.2	8.3	.8	11	3.4	16	.1	.6	42	.42
"	"	6.9	1.4	1.9	8.6	.8	8	2.4	16	.1	.1	42	.77
330000	KAWAINUI	5.0	2.8	2.7	9.3	.9	.18	3.0	17	.1	.4	50	.10
"	"	4.6	2.2	2.1	8.4	.8	12	2.4	16	.1	.1	43	.26
345000	OPAEULA	1.5	.7	1.0	5.5	.5	4	3.0	10	0	.3	24	1.28
"	"	1.9	.7	1.0	4.9	.6	4	0	9.0	.1	.5	21	.91
AVERAGE		4.3	1.4	1.6	6.7	.6	8.6	1.9	12	.1	.3	33	

SOURCE: USGS 1970

TABLE 2.8. CHEMICAL ANALYSES OF MINIMUM FLOWS IN DIKE WATER STREAMS.

GAGE NO.	STREAM	CONCENTRATIONS IN ppm											cfs	mgd
		SiO_2	Ca	Mg	Na	K	HCO_3	SO_4	Cl	F	NO_3	TDS(LESS SiO_2)		
284500	WAIHEE	25	8.9	6.0	13	1.0	56	3.6	17	.2	1.1	104	7.9	5.1
270700	LULUKU	24	8.0	5.3	12	.9	50	3.6	17	.2	0	96	.81	.52
275000	HAIKU	24	8.2	5.6	12	.8	54	3.0	16	.1	0	97	1.2	.78
283000	KAHALUU	23	8.0	5.4	12	.8	5.3	1.0	16	.1	0	93	.18	.12
284000	WAIHEE	25	6.6	4.0	11	.8	46	3.0	14	.1	0	88	5.5	3.6
294900	WAIKANE	24	7.4	6.4	14	.7	56	3.2	20	.2	0	104	2.8	1.8
303000	PUNALUU	26	6.2	5.1	9.9	.8	45	4.0	14	.1	0	88	4.4	2.8
AVERAGE		24	7.6	5.4	12	.8	51	3.1	16	.1	0	96		
296500	KAHANA	18	6.0	4.1	10	.5	40	2.0	14	.1	0	75	24	15.5
"	"	18	5.0	3.9	10	.5	38	2.4	13	.1	.3	73	29	18.8
AVERAGE		18	5.5	4.0	10	.5	39	2.2	14	.1	.15	74		

SOURCE: USGS 1970

TABLE 2.9. SUMMARY OF AVERAGE CHEMICAL COMPOSITION FOR FRESH WATERS OF KAHANA VALLEY DRAINAGE BASIN.

TYPE	SiO_2	Ca	Mg	Na	K	HCO_3	SO_4	Cl	F	NO_3	PO_4	TDS
RAINWATER[a]	.1	.8	.9	3.4	.2	1	1.9	6.5	.1	.4	.1	15.4
KAHANA TUNNEL[b]	13	7.2	4.5	6.5	3.1	(51)*	4.3	(14)*	.1	.5	(.02)*	104
DIRECT RUNOFF	4.3	1.4	1.6	6.7	.6	8.6	1.9	12	.1	.3	(.02)*	37.5
MID VALLEY DIKE WATER	24	7.6	5.4	12	.8	51	3.1	16	.1	(.5)*	(.02)*	121
BASAL WATER[c]	36	8.0	6.0	20	2.0	65	5.5	22	.07	1.1	.20	165

[a] VISHER AND MINK 1964, pp. 82, 84
[b] H. T. STEARNS 1935, p. 361
[c] VISHER AND MINK 1964, p. 90
* ESTIMATED

TABLE 2.10. MASS OUTPUT OF DISSOLVED CONSTITUENTS FROM KAHANA VALLEY.

I. WAIAHOLE SYSTEM, UPPER VALLEY. AREA = 0.86 SQ. MI. ALL WATER LEAVES VALLEY AT 800 FEET ELEVATION. DOES NOT DISCHARGE TO BAY.

COMPONENT	mgd	ALL CONSTITUENT VALUES IN lbs/day											
		SiO_2	Ca	Mg	Na	K	HCO_3	SO_4	Cl	F	NO_3	PO_4	TDS
RAIN	9.7	8.1	64.6	72.7	274	16.2	80.8	154	525	8.1	32.3	8.1	1244
DIRECT RUNOFF	3.1	111	36.2	41.3	173	15.5	222	49.1	310	2.6	7.7	.5	968
KAHANA TUNNEL	3.8	412	228	14.2	206	98.1	1614	136	443	3.2	15.8	.6	3292
UNDERFLOW AIR	2.2	238	132	82.5	119	56.8	935	78.8	257	1.8	9.2	.4	1906
TOTAL FLOWS[a]		761	396.2	266	498	170	2771	264	1010	8	33	2	6166

II. MID VALLEY. AREA = 2.88 SQ. MI. DOES NOT INCLUDE ANY FLOW FROM UPPER VALLEY.

COMPONENT	mgd	ALL CONSTITUENT VALUES IN lbs/day											
		SiO_2	Ca	Mg	Na	K	HCO_3	SO_4	Cl	F	NO_3	PO_4	TDS
RAIN	22	18	147	165	623	37	183	348	1191	18	73	18	2822
DIRECT RUNOFF	12.7	455	148	169	709	64	910	201	1269	11	32	2	3967
GROUNDWATER													
1. KAHANA DRAINAGE	6.2	1239	393	279	620	41	2634	160	826	5.2	26	1	6249
2. KAWA UNDERFLOW	2.3	460	146	104	230	15	977	59	307	2	10	1	2309
3. PUNALUU UNDERFLOW	3.6	720	228	162	360	24	1530	93	480	3	15	1	3614
TOTAL GROUNDWATER	12.1	2419	767	545	1210	80	5141	312	1613	10	51	3	12172
TOTAL FLOWS[a]		2874	915	714	1919	144	6051	513	2882	21	83	5	16139

III. DRAINAGE TO KAHANA BAY. DOES NOT INCLUDE UPPER VALLEY.

COMPONENT	mgd	ALL CONSTITUENT VALUES IN lbs/day											
		SiO_2	Ca	Mg	Na	K	HCO_3	SO_4	Cl	F	NO_3	PO_4	TDS
A. VIA KAHANA STREAM													
DIRECT RUNOFF	17.3	620	202	231	966	87	1239	274	1729	14	43	3	5404
DIKE WATER	14.9	2979	943	670	1489	99	6330	385	1986	12	62	3	15018
TOTAL	32.2	3599	1145	901	2455	186	7569	659	3715	26	105	6	20422
B. DIRECT TO BAY													
DIRECT RUNOFF	.2	7	2	3	11	1	14	3	20	0	1	0	63
BASAL WATER	1.0	300	67	50	167	17	542	46	183	1	9	2	1375
TOTAL	1.2	307	69	53	178	18	556	49	203	1	10	2	1438
GRAND TOTAL	33.4	3906	1214	954	2633	204	8125	708	3918	27	115	8	21860

[a] EXCLUDING RAIN

TABLE 2.11. WATER QUALITY FACTORS, KAHANA STREAM, MAR.-DEC. 1972 TO JAN.-JUNE 1973.

PARAMETER	03/18/72	05/14/72	07/17/72	09/14/72	10/31/72	11/22/72	12/20/72	01/17/73	02/28/73	04/24/73	06/20/73
pH	7.4	--	7.2	7.3	6.8	7.7					
TOTAL SOLIDS	78	85	90	--	131	86	210	308	242	208	148
TOTAL VOLATILE SOLIDS	20	20	45	--	33	86	82	36	18	8	84
SUSPENDED SOLIDS	--	--	4.8	--	0.6	46.0	3.0	5.2	--	2.0	2.5
VOLATILE SUSPENDED SOLIDS	--	--	2.5	--	1.7	1.0	3.0	3.0	--	1.0	0.4
TURBIDITY	--	25.0	1.7	—	1.7	1.4	1.7	2.7	1.6	1.3	1.4
CHLORIDES	25	--	15	--	--	72	25	30	20	10	15.0
TOTAL NITROGEN	0.073	0.040	0.069	--	0.063	0.073	0.066	0.067	0.073	0.070	0.206
TOTAL PHOSPHORUS	0.016	0.012	0.002	--	0.008	—	0.014	0.003	--	0.002	0.016
ORGANIC CARBON	--	11.7	2.5	--	6.0	2.5	2.0	1.5	4.6	1.9	2.3
CONDUCTIVITY	--	160	111	--	88	490	320	440	188	250	198

[a] ALL VALUES EXCEPT pH AND CONDUCTIVITY IN mg/l.

TABLE 2.12. HEAVY METAL CONCENTRATIONS IN KAHANA STREAM WATER MAR. 1972-JUNE 1973.

CONSTITUENT	RANGE OF CONCENTRATION (ppm)
Pb	ND TO 0.010
Cu	0.001 TO 0.011
Zn	ND TO 0.024
Cd	ND TO 0.003
Hg	ND
Cr	ND TO 0.014
Ni	ND TO 0.019

TABLE 2.13. PERCENTAGES OF THE TOTAL AMOUNTS OF FE, NI, CO, CR, CU, MN TRANSPORTED IN THE AMAZON RIVER.

MECHANISM	Fe	Ni	Co	Cr	Cu	Mn
SOLUTION AND ORGANIC COMPLEXES	0.7	2.7	1.6	10.4	6.9	17.3
ABSORBED	0.02	2.7	8.0	3.5	4.9	0.7
PRECIPITATED AND COPRECIPITATED	47.2	44.1	27.3	2.9	8.1	50
ORGANIC SOLIDS	6.5	12.7	19.3	7.6	5.8	4.7
CRYSTALLINE SEDIMENTS	45.5	37.7	43.9	75.5	74.3	27.2

SOURCE: GIBBS 1973

SEDIMENTS DISCHARGED BY KAHANA STREAM. Measurements of the sediment load of Kahana Stream are not sufficient to make possible direct computations of the sediment discharged to the bay. In recent years the USGS initiated continuous measurements of suspended sediments elsewhere on Oahu and has compiled a record of miscellaneous measurements as well. However, none of these direct measurements have been made on Kahana Stream. Therefore, an estimate of the sediment output of the stream is herein made in the manner discussed in the following paragraphs.

The drainage basins on Oahu are small and often uniquely different from each other, but most streams may be broadly categorized as either dike zone streams, most prevalent on windward Oahu, or flank flow streams, of which the streams in the Pearl Harbor region are the best examples. Dike zone streams are usually perennial throughout their lengths; flank flow streams are perennial only in their high rainfall reaches. Kahana is a dike zone stream and consequently to infer its sediment discharge characterisitics of other dike zone streams for which measurements are available must be employed. In *Water Resources for Hawaii and Other Pacific areas*, published by the U.S. Geological Survey in 1970, sediment discharge measurements were reported on two windward dike zone streams for a wide range of flow rates. These streams, Maunawili (gage 16260500) and Kamooalii (gage 16270500), though imperfect analogues of Kahana, resemble the latter much more closely than do the streams of leeward Oahu where most other sediment measurements have been made.

The discussion on geomorphology, presented in a previous section, emphasized that Kahana is a mature valley in dynamic equilibrium with erosional processes. In the Mid Valley, stream gradient is low, 5 degrees or less, and in the lower valley it is nearly flat, suggesting that sediment discharge to the bay is predominantly in suspended form. Colbourn (1971, pp. 50 and 111) states that the mean grain size of detritus in the bay is smaller than "coarse" and that the stream load that enters the bay has a mean size $\leq 3\phi$. It is improbable that a significant quantity of bed load would be able to move through the estuary to the bay, and it is therefore reasonable to ignore it in computing sediment output.

Suspended sediment as a function of the flow rate may be expressed empirically by the general equation:

$$S = aQ^b$$

where S is suspended sediment load, Q is the flow rate, and a and b are constants. At high flows the actual suspended load is less than implied by the formula, and at very low flows (base flow) it exceeds the calculated amount.

The above relationship plots as a straight line on log-log paper, which tempts the uncritical to accept extrapolations at high flows. However, as the flow rate becomes large, the rate of increase of the suspended load lessens, and therefore a straight line extrapolation at high flows grossly exaggerates the sediment load. As is shown later, for even a short time interval (much less than a day) the straight line extrapolated load will yield unreasonably large quantities of sediment.

The data for Maunawili and Kamooalii streams as given by the U.S. Geological Survey (1970, pp. 274, 275) are plotted in Figures 2.7 and 2.8. Flow rates are given in cfs/sq mi, and sediment loads in tons/day/sq mi. For Maunawili the relationship is

$$S = 0.0169\ Q^{2.22}$$

and for Kamooalii it is

$$S = 0.0367\ Q^{2.19}$$

These empirical expressions appear to be applicable to flow rates up to 100 cfs/sq mi (65.7 m^3/min/km^2).

For Kahana computations, the mean of the above expressions is used:

$$S = 0.0268\ Q^{2.2}$$

It should be evident that the application to Kahana of an expression derived as the average of empirical relationships for other basins will yield, at best, relatively rough approximations of sediment discharge to the bay.

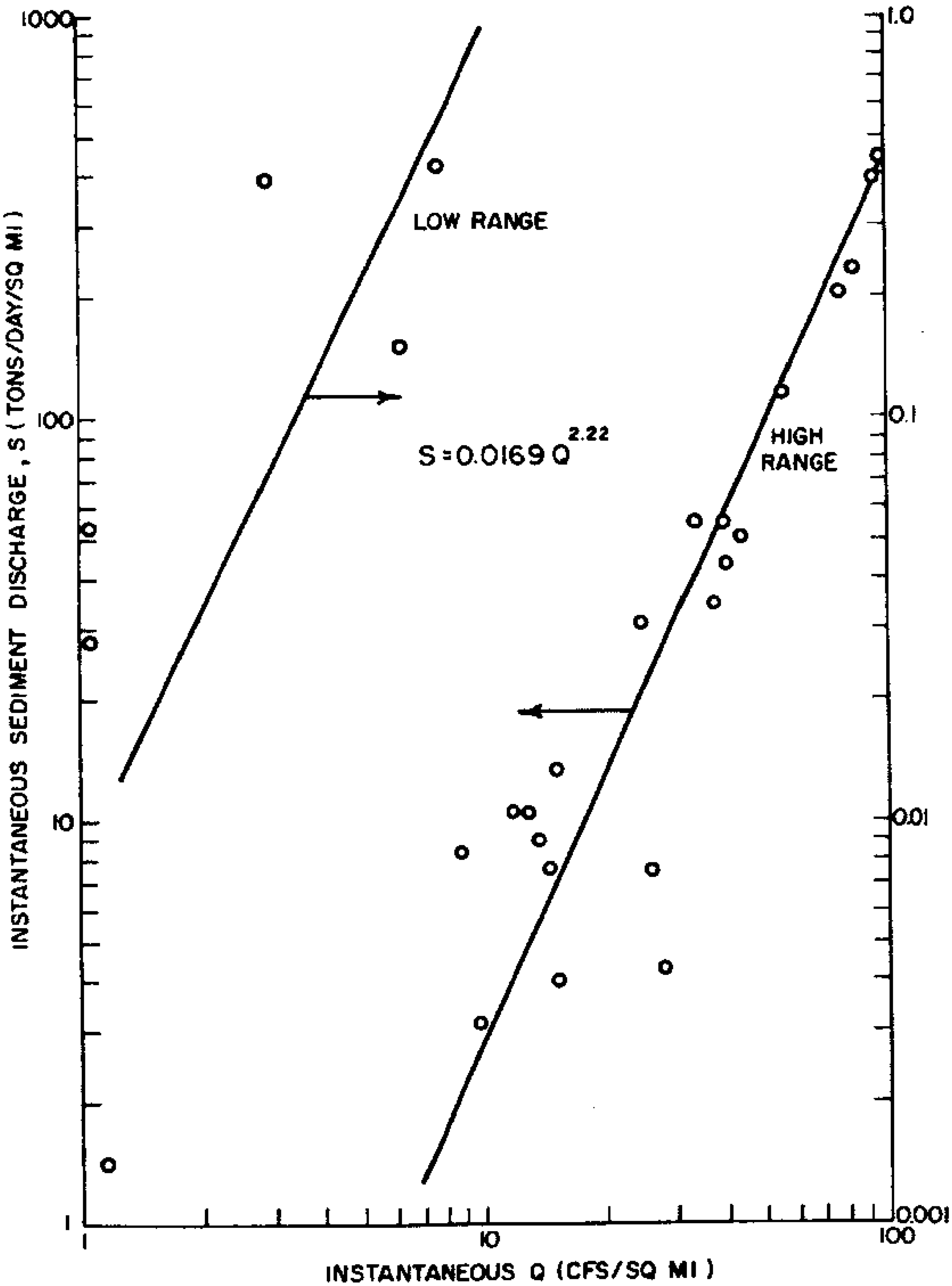
The sediment load which moves to Kahana Bay may be calculated as a sediment-duration curve by using the flow-duration curve of Kahana Stream in conjunction with the empirical suspended sediment output equation. Because the flow duration curve is derived for the USGS gage at the 30-foot (9.14 m) contour elevation, the computations specifically refer to the Mid Valley but are converted to units per square mile so that the mass output of the entire portion of the valley that drains to the bay may be computed by linear proportionation.

The first and simplest approach is to treat the empirical suspended load equation as applicable to all flow rates. The sediment-duration values for this assumption are given in Table 2.14. The technique employed in the computations is basically the same as that explained in Circular C-33, p. 22 (USGS and State of Hawaii 1971).

A sediment-duration curve based on Table 2.14 is given in Figure 2.9, with the log of sediment discharge plotted as the ordinate.

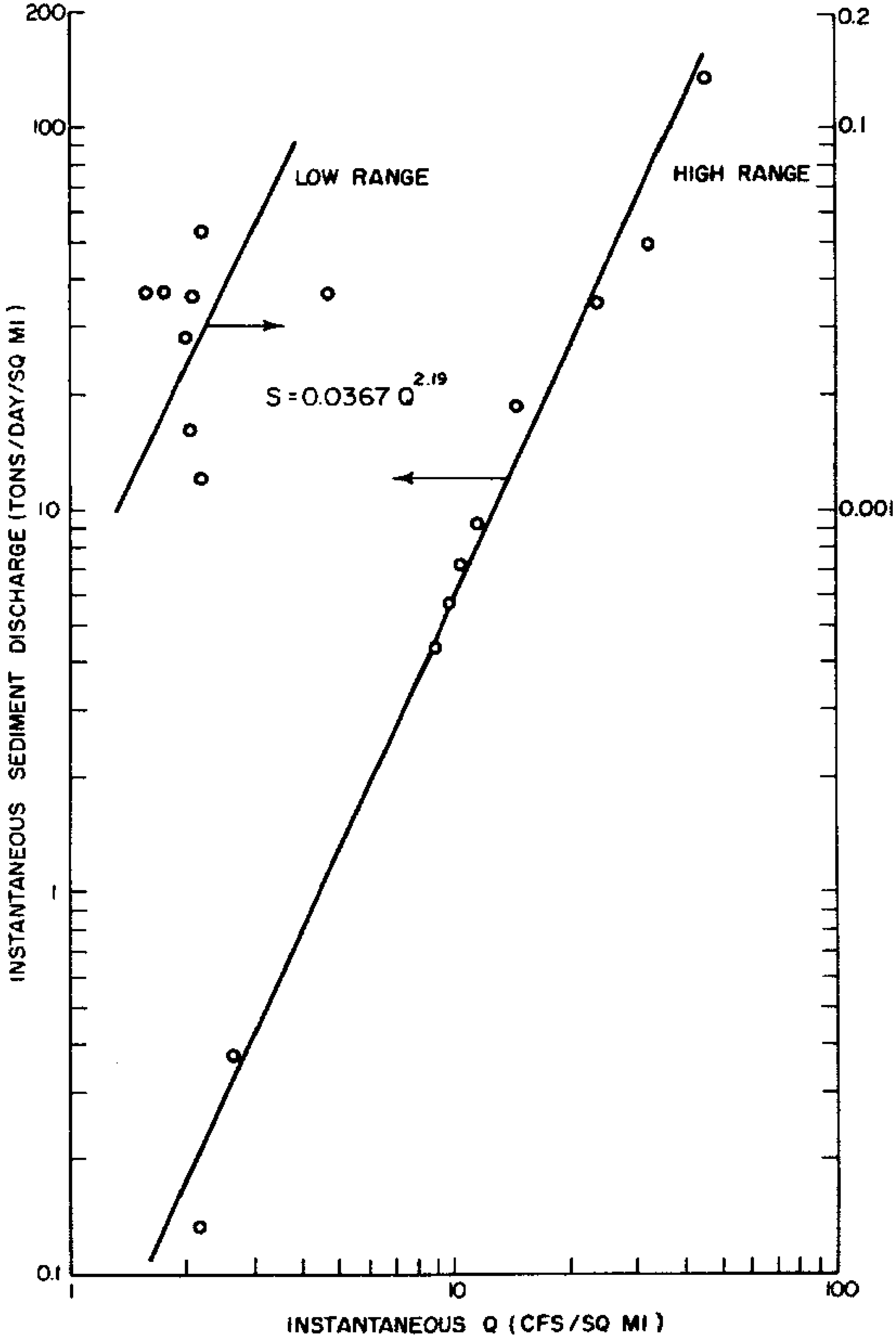
The computed value of 13,490 tons/yr/sq mi (47,250 kg/yr/ha) for Kahana far exceeds the maximum yields computed for windward valleys in Circular C-33. For Maunawili C-33 gives a value of 710 tons/yr/sq mi (2487 kg/yr/ha); for Kamooalii (gage 16273900, downstream from the gage used to obtain the empirical formular noted earlier) 910 tons/yr/sq mi (3187 kg/yr/ha); for Kahuluu, 1300 tons/yr/sq mi (4553 kg/yr/ha); and for Waihee, 1400 tons/yr/sq mi (4904 kg/yr/ha). It is evident that the average yield of sediment is very sensitive to high flows and to the use of the extrapolated power expression at these high flows.

To eliminate the exaggerated sediment loads computed at very high flow rates, the empirical expression can be limited to flows of less than about 100 cfs/sq mi (65.7 m^3/min/km^2). If in Table 2.14 only those flows equal to or less than 107 cfs/sq mi (70.30 m^3/min/km^2) are considered, the averaged daily output to the bay is 12.92 tons/day/sq mi (0.12 kg/day/ha).



DATA FROM WATER RESOURCES DATA FOR HAWAII, USGS 1970
GAGING STATION 16260500

FIGURE 2.7. SEDIMENT DISCHARGE VS. FLOW OF MAUNAWILI STREAM.



DATA FROM WATER RESOURCES DATA FOR HAWAII, USGS 1970
GAGING STATION 16270500

FIGURE 2.8. SEDIMENT DISCHARGE VS. FLOW OF KAMOOALII STREAM.

TABLE 2.14. SEDIMENT-DURATION VALUES, KAHANA STREAM FLOW DURATION CURVE FOR USGS GAGE.

TIME INTERVAL (PERCENT)	MEAN OF INTERVAL (PERCENT)	Q cfs/ sq mi	S TONS/DAY/ sq mi	S X TIME INTERVAL
.02	.01	987	103665	20.73
.03	.035	214	3590	1.08
.05	.075	160	1893	.95
.10	.15	134	1282	1.28
.30	.35	107	781	2.34
.50	.75	80	412	2.06
1.00	1.50	54	174	1.74
3.00	3.50	37	75.5	2.27
5.00	7.50	21	21.7	1.09
10.00	15.00	16	12.0	1.20
10.00	25.00	12	6.34	.63
10.00	35.00	10	4.25	.43
10.00	45.00	9	3.37	.34
10.00	55.00	8	2.60	.26
10.00	65.00	7	1.94	.19
10.00	75.00	6	1.38	.14
10.00	85.00	6	1.38	.14
10.00	95.00	5	.92	.09

TOTAL S X TIME INTERVAL = 36.96 TONS/DAY/sq mi = 13490 TONS/yr/sq mi.

NOTE: $S = 0.02680Q^{2.22}$

Only 2.74 days of the year were eliminated for this calculation, which shows the enormous effect that approximations at high flows have upon the sediment yield.

The sediment-duration curve for the valley exclusive of the 0.86 sq mi (2.23 km^2) that drain the Waiahole System is given in Figure 2.10. The curve is a linear extrapolation of the one computed for the USGS gage. The curve describes sediment output to the bay reasonably well for moderate and low flows but may grossly exaggerate it at high flows.

The highest average sediment output for windward Oahu (Waihee Stream) given in C-33 is 1400 tons/yr/sq mi (4904 kg/yr/ha), or 3.8 tons/day/sq mi (13.4 kg/day/ha), which is only one tenth of the computed value for Kahana Stream. This great disparity illustrates the inexactness of estimates based on the power relationship between suspended load and flow rate. Infrequent events produce the greatest proportion of total sediment that enters the bay; a single flood may deposit more detritus than a full year of low to moderate flows.

The computations for dissolved solids load (mass output) as given in Table 2.10 are considerably more reliable than those for suspended sediment load. The average total dissolved solids entering the bay is 1.45 tons/day/sq mi (0.014 kg/day/ha), whereas the average suspended load may be as

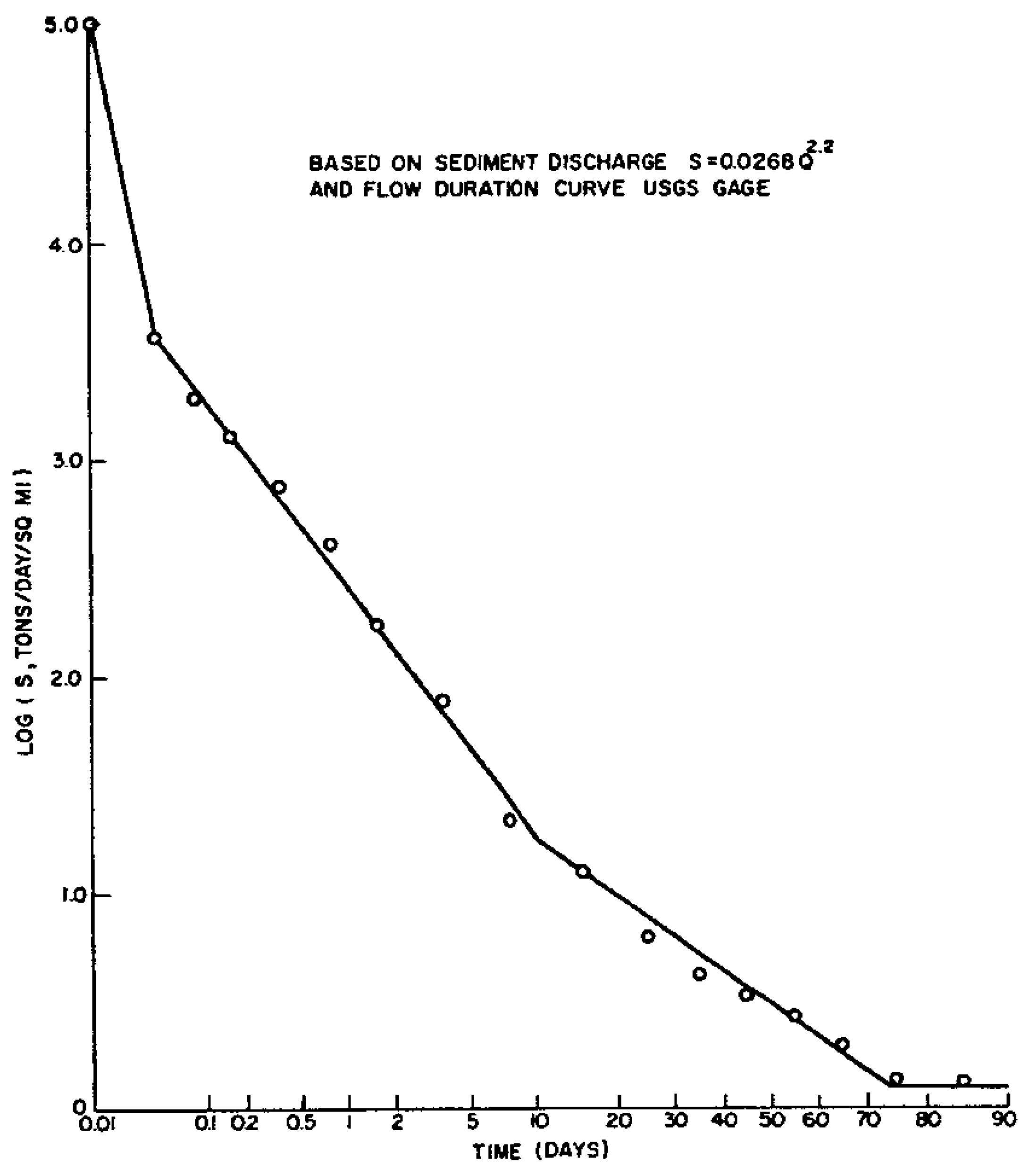


FIGURE 2.9. SEDIMENT DISCHARGE VS. DURATION CURVE OF KAHANA STREAM.

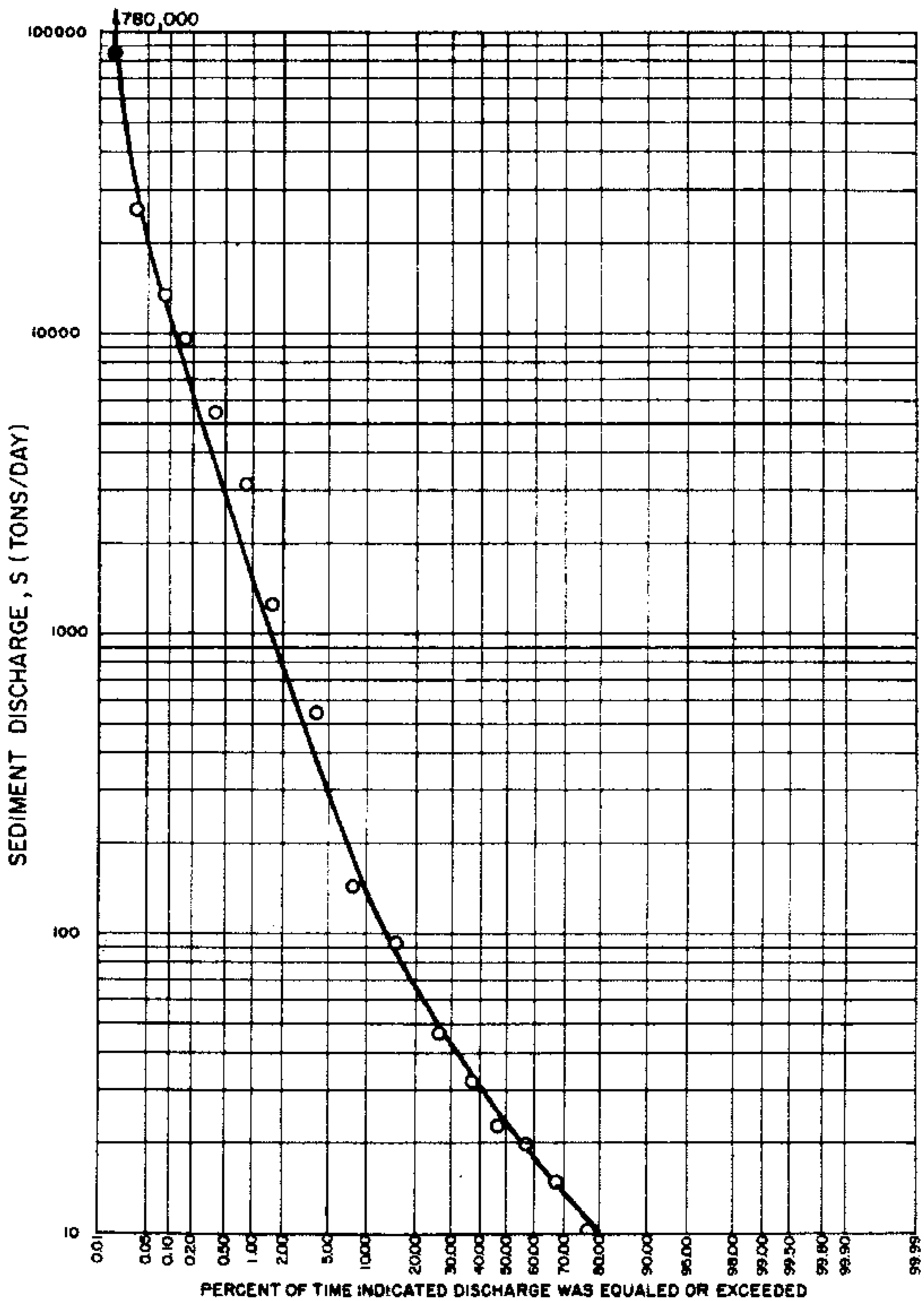


FIGURE 2.10. SEDIMENT DISCHARGE - DURATION CURVE OF KAHANA STREAM, KAHANA VALLEY BELOW WAIAHOLE SYSTEM.

high as 37 tons/day/sq mi (0.36 kg/day/ha), although more likely it is appreciably less than this. On the basis of the available sediment data for windward Oahu; it is apparent that detrital output to Kahana Bay exceeds dissolved solids output by a factor of at least 3 and perhaps as much as 25. The dissolved load is, however, very high compared to the average stream in most other regions of the world. According to Leopold et al. (1964 , p. 77) the average dissolved load for rivers in the United States with annual runoff greater than 10 in. (25.40 cm) is 125 tons/yr/sq mi (437 kg/yr/ha); the Kahana Stream dissolved solid load is 531 tons/yr/sq mi (1860 kg/yr/ha). The same authors note that from a sample of 70 U.S. rivers it was determined that 20 percent of the total load is accounted for by dissolved solids, and that for rivers which have an average flow greater than 0.7 cfs/sq mi (0.46 $m^3/min/km^2$) the proportion is 37 percent. Evidently both the dissolved and detrital loads of Kahana and other Hawaiian streams are unusually large, although the detrital load is small compared to world averages.

HEAVY METALS IN KAHANA STREAM SEDIMENTS. The results of analysis of sediments for heavy metal content made by the QCW project on samples collected at the USGS stream gage (Station 6, Fig. 2.11) are summarized in Table 2.15 from data presented in Table 2.23. For the purpose of the study herein reported, these values are considered representative of the territorially derived sediments, relatively uncontaminated by human activity, that are carried to Kahana Bay. In general, the values shown in the table are appreciably less than those reported in Table 2.5 for parent material from which the sediments were derived, but are at least three orders of magnitude greater than the concentrations found in Kahana Stream water (Table 2.12).

PESTICIDES IN KAHANA STREAM SEDIMENTS. The concentration of several common pesticides found in the sediment samples at the USGS gage in Kahana Valley are included with the heavy metals data in Table 2.15. Although the significance of the values reported are best evaluated in the context of Kahana Bay sediments, it is noteworthy that the ubiquitous DDT appeared in the highest concentration. To a significant degree the values shown must be taken as general background values for even relatively pristine land and water environments. The presence of small amounts of pesticides, particularly DDT, was observed and reported (*First Progress Report*) in the runoff from sugarcane plantations which had been under cultivation for nearly a century and which had never been treated with DDT.

Biota of Kahana Stream

There is little information available on the biota of Kahana Stream, most attention having been directed to coastal situations where pollution was evident or might be expected. Maciolek (1972) did make a careful study of the diadromus microflora of the Kahana Stream - estuary as distinct from Kahana Bay proper. He found eleven species of diadromus microflora in the juvenile or adult stages. As noted in Table 2.16, these were most abundant at sampling stations in the estuarine and Lower Valley sectors. Maciolek interpreted his results as indicating that larval and postlarval stages of the same fauna must be migrating to and from the ocean.

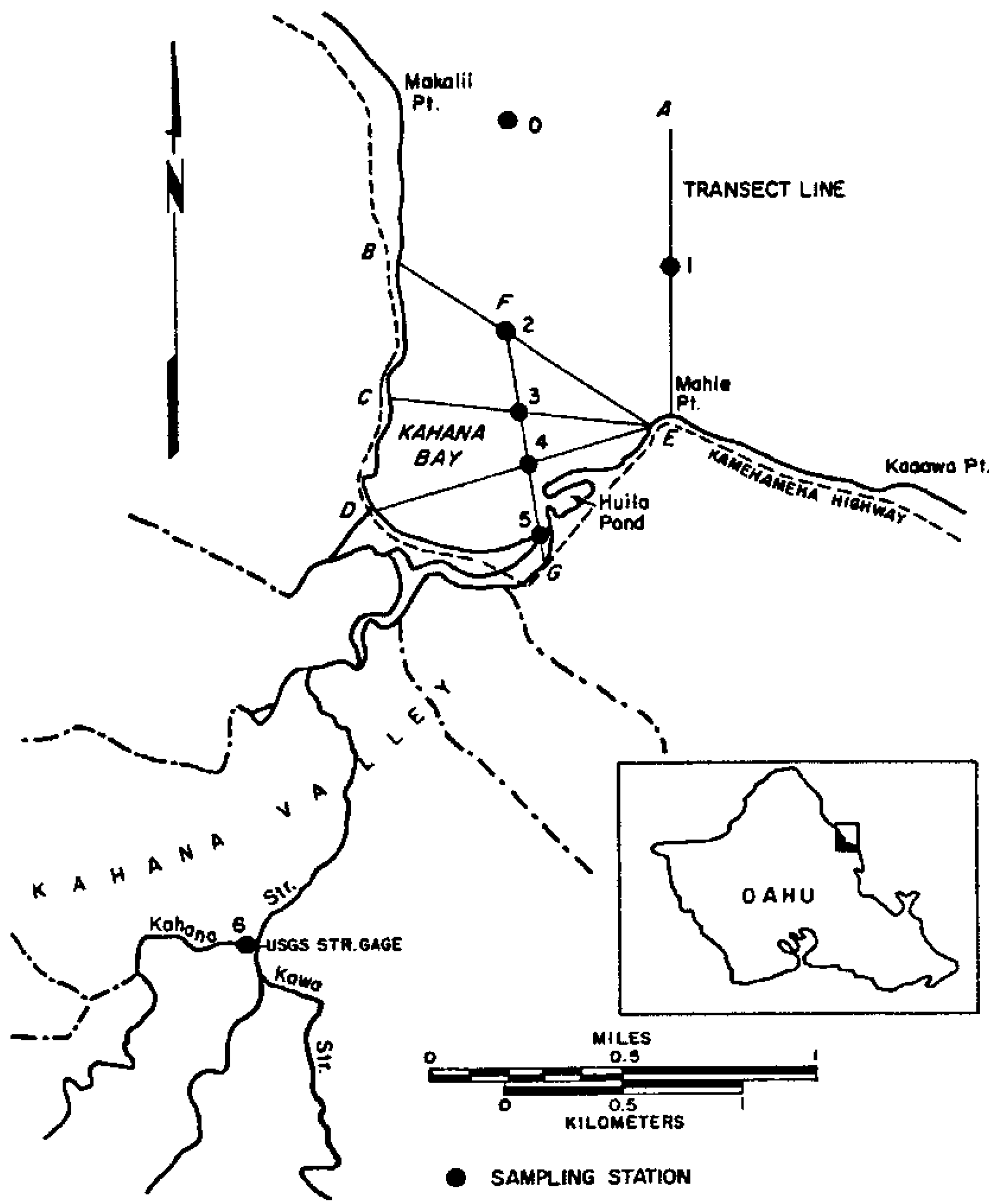


FIGURE 2.11. LOCATIONS OF TRANSECT LINES AND SAMPLING STATIONS, KAHANA BAY

TABLE 2.15. SUMMARY OF HEAVY METALS, PESTICIDES, AND NUTRIENTS IN KAHANA STREAM SEDIMENTS, MAR.-DEC. 1972 TO JAN.-FEB. 1973.

PARAMETER	SAMPLING DATE 03/18/72	05/14/72	10/31/72	11/22/72	12/20/72	01/17/73	02/28/73
Pb	29.3	5.0	--	15.5	13.6	22.2	33.6
Cu	160.1	98.0	--	56.4	47.4	55.6	78.8
Zn	94.5	62.8	--	45.7	41.0	50.4	51.6
Cd	ND	ND	--	1.1	ND	1.4	1.7
Hg	0.21	0.04	--	-.09	0.05	ND	0.05
Cr	147.1	47.4	--	109.1	79.8	121.8	112.3
Ni	349.8	298.0	--	108.5	174.8	213.5	156.9
As	--	--		--	--	12.0	3.2
DIELDRIN	--	4	12	13	46	11	ND
DDE	--	ND	8	8	15	6	ND
DDT	--	48	74	111	147	57	565
α CHLORDANE	--	11	16	ND	12	18	ND
γ CHLORDANE	—	12	18	ND	14	15	ND
TOTAL CHLORINATED HYDROCARBONS	—	75	128	132	240	101	565
TOTAL-N	1494	25	—	141	299	202	162
TOTAL-P	1009	702	--	775	776	1120	719
TOTAL-K	234	239	—	589	636	652	441

NOTE: ALL PESTICIDES REPORTED IN ppt; OTHER VALUES IN TABLE ARE ppm.

TABLE 2.16. DISTRIBUTION AND RELATIVE ABUNDANCE OF DIADROMOUS MACROFAUNA IN THE KAHANA STREAM-ESTUARY SYSTEM, OAHU, 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.

Physiography and Oceanography of Kahana Bay

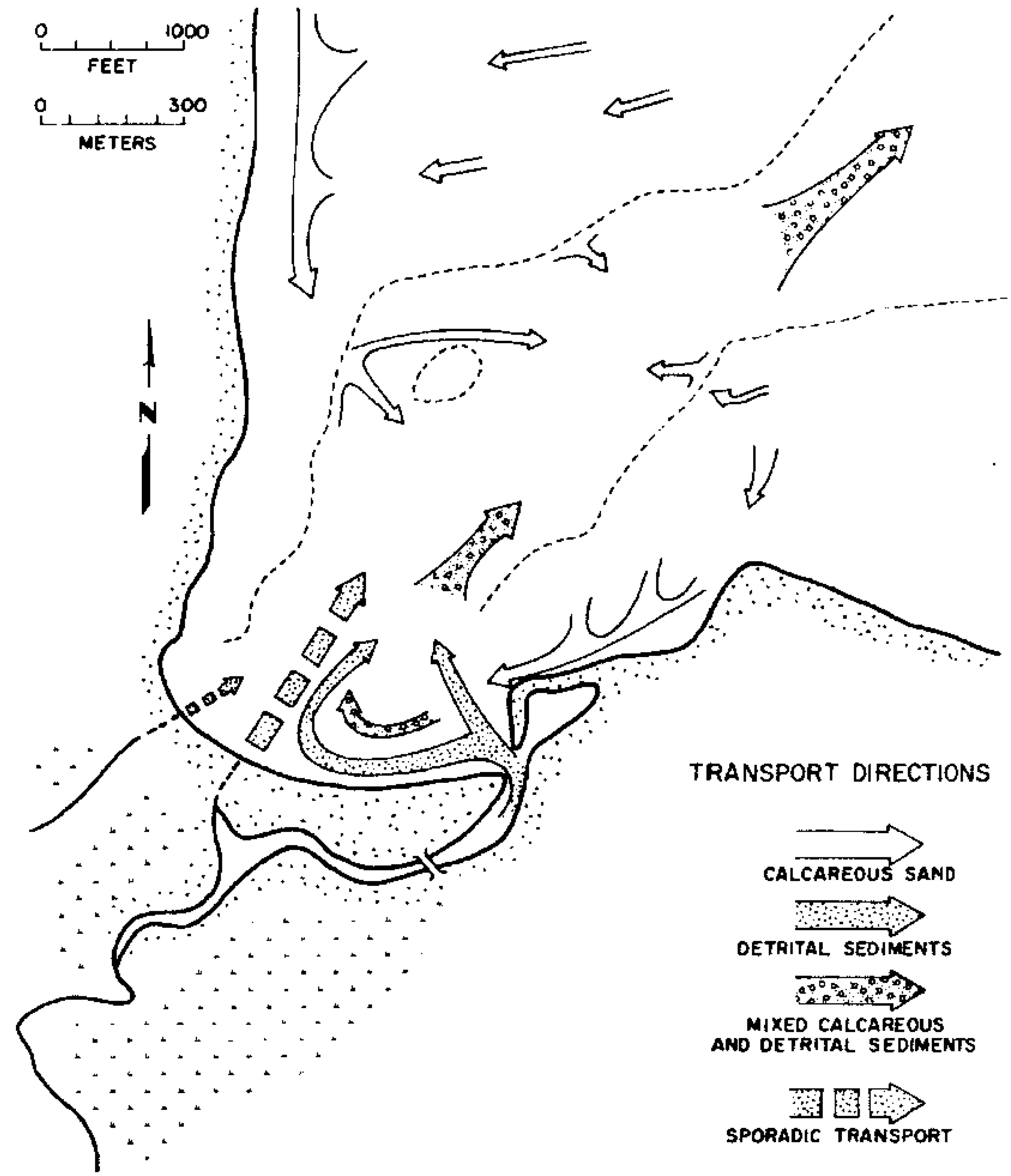
The geographical relationship of Kahana Bay to Kahana Stream, initially presented in Figure 2.1, is shown in greater detail in Figure 2.11. Included in the figure are transect lines and sampling stations (0 to 6) used in the QCW study herein reported. An extensive study of the physical and oceanographic features of the bay was reported by Coulbourn (1971). His findings, together with those of Maciolek, are the principal source of available information on the physiography and oceanography of Kahana Bay and its estuarine environs. These findings were summarized in the *First Annual Progress Report* of the QCW Project (1972), but are herein again summarized as necessary to an understanding of the QCW project's findings and evaluations.

The estuary of Kahana Stream, beyond which there is no tidal action or detectable salinity effects, extends landward about one mile from the bay shore line. Maciolek found this estuarine section to be a sinuous channel varying from 35- to 245-ft (10.67- to 74.68-m) wide and from 4- to 16-ft (1.22- to 4.88-m) deep at midchannel. Its volume, he reported as 84 acre-ft or 103,614.0 cu m, with a surface area of 14 acres (5.67 ha). Debris and sediments are scavenged from the estuary often enough by the winter and spring storms to limit their effect as an incubator of water quality factors. Salinity measurements showed the presence of density stratification, with a tendency of fresh water flowing over the surface of estuarine water during periods of low flow.

Coulbourn's report was concerned with the oceanographic characteristics of the bay itself. He notes that at the southeast corner of Kahana Bay is the remains of an old Hawaiian fishpond. By 1971 the pond had deteriorated into a saltwater marsh. Coulbourn noted that "a sand bar,...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" where it gradually merges into the deeper bay floor to the west. He also stated, in describing 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 ft (3.05 m) at the outer reef edges to sea level, where blocks of coral along the eastern margin are exposed at low tides...Except in nearshore areas, the reef edges are vertical cliffs, extending down to 30 ft (9.14 m) or more to the bottom of the bay."

Physiographically Kahana Bay is shown by the US Coast & Geodetic Survey map No. 3252 to be the head of a submarine canyon which is indistinguishable at 17 fathoms (30.6 m) and reappears again at 120 fathoms (216.0 m). Seismic reflections cited by Coulbourn (1971) reveal subbottoms characterized by smooth topography consisting of sediment overlying a more irregular basement. Of especial interest to the study herein reported is Coulbourn's 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.

Coulbourn made extensive observations of the oceanographic characteristics of Kahana Bay. Figure 2.12, reproduced from his report, shows graphically the sediment transport systems and circulation pattern within



SOURCE: COULBOURN 1971

FIGURE 2.12. CIRCULATION AND SEDIMENT TRANSPORT PATTERN, KAHANA BAY.

the bay. His studies of the physical oceanography of Kahana Bay reveal that it is exposed to prevailing northeast tradewinds and waves. Ocean swells lose their energy on entering the bay and generate but little wave heights on the beach.

Quality of Water in Kahana Bay

Although Coulbourn and Maciolek made extensive studies of some aspects of Kahana Bay, the quality of its water and sediments have been but little monitored. This situation exists because agencies, such as the Department of Health, concerned with water pollution have had more than enough situations where monitoring of pollutants is a problem great enough to command the full attention of their staff and the potential of their budgets. Consequently, there has been but limited specific study of waters in an unpolluted situation such as Kahana Bay.

Water Quality: Two sources of information on water quality are reported herein: 1) the Oahu Water Quality Project (OWQP) of the City and County of Honolulu (1971), and 2) the sampling program of the Quality of Coastal Waters project (QCW). Results of analyses of water samples taken near Station 5, Figure 2.11, by the OWQP in 1970-71 are summarized in Table 2.17.

TABLE 2.17. MONTHLY ANALYSIS AND AVERAGE VALUE OF WATER QUALITY, KAHANA BAY, AUG.-DEC. 1970, JAN. 1971.

QUALITY FACTOR	1970 AUGUST	SEPTEMBER	OCTOBER	DECEMBER	1971 JANUARY	AVERAGE VALUE
	(mg/ℓ)[a]					
SALINITY °/oo	20.78	26.44	5.61	1.97	0.56	11.07
DO	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	—	1000	800	1000	680,000	170,820
TEMPERATURE (°C)	25.53	26.55	22.32	21.48	21.84	23.54

SOURCE: OWQP 1971

[a] UNLESS OTHERWISE NOTED

Water quality observations made by the QCW project staff during the period 3/18/72 through 6/30/73 are reported in Table 2.18. In this table data are reported for each of the 6 sampling stations shown in Figure 2.11. The selection of the stations shown was intended to provide a baseline assay for Kahana Stream, Kahana estuary, Kahana Bay, and the near shore ocean. Therefore Stations 0 and 1 reflect quality characteristics of the ocean; Stations 2, 3, and 4 provide characteristics of Kahana Bay water; Station 5 represents the estuarine reach of Kahana Stream, and Station 6 represents

Kahana Stream itself. Thus, Station 5 data essentially extend those of Table 2.17 (OWQP) for Total-N and Total-P. Otherwise the two tables (2.17 and 2.18) are concerned with different parameters of water quality.

In Table 2.17 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 (1.83 m) depth of Kahana Stream to an average of 6.8 mg/ℓ through a 10-foot (3.05 m) 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.

Comparison of the water quality throughout the Kahana Bay system is best made by reference to Table 2.19. In this table are plotted the monthly water quality values for all waters of the area, calculated on the basis of the station averages. Seasonal effects are evident in the data. For example, seasonal effects with respect to dilution in Kahana Bay are described to some degree by total solids concentration and conductivity measurements. Of some interest is the fact that the dilution effects are most evident during what is not normally considered the rainy season--July through December. However, the effect of dilution in Kahana Bay is quite evident when the quality of water in the bay is compared with that in the ocean. In general, the levels of chlorides, conductivity, and total solids observed in bay samples were lower than those observed in ocean water samples.

To better describe the water quality of Kahana Stream, Kahana estuary, Kahana Bay, and the ocean, the monthly means for each were averaged and are tabulated in Table 2.20.

The quality of water discharged by Kahana Stream is significantly altered at the mouth of the stream. Most evident, of course, is the increase in concentration of solids as well as in nutrient levels. The solids increase can be attributed to both tidal flux and the accumulation of solids from overland flow, although the former is undoubtedly the most significant cause. Several factors may account for the increase in nitrogen and phosphorus, including: 1) accumulation from overland flows, 2) release through sediment desorption, and 3) products of biological decay of organic matter. Flow velocities at the mouth of the stream are quite low, thus solids with sorbed nutrients are allowed to settle, giving rise to periods of near-equilibrium conditions where desorption can occur. The rate of desorption, especially when biodegradation occurs, can account for some of the observed changes in nutrient concentration even though the estuary is scavenged of sediments seasonally by the extremes of discharge of Kahana Stream cited in a preceding section.

TABLE 2.18. WATER QUALITY ANALYSIS OF SIX SAMPLING STATIONS: KAHANA DRAINAGE SYSTEM (MAR.-DEC. 1972, JAN.-JUNE 1973).

PARAMETER	DATE	STATION 0[a]	1[a]	2[b]	3[b]	4[b]	5[c]	6[d]
		mg/ℓ						
pH (UNITS)	03-18-72	--	8.1	8.1	8.1	8.1	7.9	7.4
	05-14-72	--	8.1	8.1	8.1	8.1	7.5	--
	07-17-72	--	8.1	8.1	8.1	8.1	7.2	7.2
	09-14-72	8.0	8.0	8.0	8.0	8.0	8.0	7.3
	10-31-72	8.1	8.1	8.0	8.1	8.1	7.9	6.8
	11-22-72	8.2	8.1	8.1	8.1	--	7.8	7.7
	04-24-73	--	--	--	--	--	--	--
	06-20-73	--	--	--	--	--	--	--
TOTAL SOLIDS	03-18-72	--	37020	35820	35700	36050	--	78
	05-14-72	--	39630	30150	34900	39900	5240	85
	07-17-72	--	36396	36373	28545	24330	2529	90
	09-14-72	34807	39709	35536	35449	34791	7244	--
	10-31-72	38892	39255	38769	37546	38520	38006	131
	11-22-72	39883	37842	38065	36701	37022	9056	86
	12-20-72	41072	30954	39550	38960	39756	6766	210
	01-17-73	38730	38140	37100	37230	38000	18200	308
	02-28-73	40370	42000	42000	40620	35680	1650	242
	04-24-73	38150	38550	37840	36970	37920	4508	208
	06-20-73	40440	35885	35385	40070	33750	15900	148
SUSPENDED SOLIDS	05-14-72	--	12.0	6.0	10.0	12.0	7.0	--
	07-17-72	--	17.0	7.2	14.8	14.5	8.5	4.8
	09-14-72	35.8	34.8	33.4	35.6	32.2	18.6	--
	10-31-72	30.5	25.1	24.6	40.1	23.2	20.4	0.6
	11-22-72	39.0	30.0	30.0	29.0	27.0	9.4	46.0
	12 20-72	33.0	15.0	32.0	37.0	31.0	9.0	3.0
	01-17-73	42.0	47.0	35.0	43.0	44.0	38.0	5.2
	02-28-73	36.0	41.0	36.0	31.0	39.0	6.0	--
	04-24-73	39.0	43.0	42.0	40.0	37.0	8.0	2.0
	06-20-73	32.0	34.0	30.0	32.0	29.0	23.0	2.5
TOTAL VOLATILE SOLIDS	05-14-72	--	6030	3565	4450	5480	800	20
	07-17-72	--	4639	4673	3501	3314	477	45
	09-14-72	5373	6051	6665	5342	5091	1005	--
	10-31-72	4510	5350	3404	3291	4108	4056	33
	11-22-72	5267	3372	4152	3518	3852	1284	86
	12-20-72	6586	6472	6378	6854	6732	1126	82
	01-17-73	4716	5228	4842	4726	4960	2828	36
	02-28-73	6662	4716	5150	4770	4850	254	18
	04-24-73	4400	4968	4570	4502	4640	604	8
	06-20-73	6670	6665	5945	6200	5040	2580	84

TABLE 2.18. WATER QUALITY ANALYSIS OF SIX SAMPLING STATIONS: KAHANA DRAINAGE SYSTEM (MAR.-DEC. 1972, JAN.-JUNE 1973) (CONTD).

PARAMETER	DATE	STATION 0^a	1^a	2^b	3^b (mg/ℓ)	4^c	5^c	6^d
VOLATILE SUSPENDED SOLIDS	05-14-72	--	2.0	2.0	4.0	2.0	2.0	--
	07-17-72	--	7.0	5.2	5.0	4.8	4.0	2.5
	09-14-72	8.6	7.6	8.6	10.4	7.0	5.2	--
	10-31-72	7.4	4.6	6.0	3.6	5.6	4.2	1.7
	11-22-72	7.0	6.0	5.0	5.5	4.4	1.4	1.0
	12-20-72	7.0	8.0	8.0	9.0	7.0	4.0	3.0
	01-17-73	9.5	9.3	5.0	7.7	10.0	7.7	3.0
	02-28-73	8.4	8.8	8.6	6.6	9.0	4.0	--
	04-24-73	6.4	7.6	8.2	8.0	7.0	2.0	1.0
	06-20-73	4.0	5.8	3.6	4.2	4.0	3.2	0.4
TURBIDITY (FTU)	05-14-72	--	2.0	5.0	2.7	6.5	4.2	25.0
	07-17-72	--	1.2	1.4	4.1	4.3	7.6	1.7
	09-14-72	0.5	0.8	1.8	2.4	1.7	5.8	--
	10-31-72	1.3	0.9	1.0	1.6	1.0	4.2	1.7
	11-22-72	1.5	2.0	0.9	3.2	2.5	2.2	1.4
	12-20-72	0.1	1.4	0.9	1.2	1.3	2.6	1.7
	01-17-73	1.7	1.7	2.4	2.7	2.7	5.5	2.7
	02-28-73	2.0	0.8	0.7	1.5	3.0	2.5	1.6
	04-24-73	1.5	1.5	1.5	2.8	2.2	2.0	1.3
	06-20-73	1.8	1.0	1.5	2.0	1.6	3.9	1.4
CONDUCTIVITY (μmhos)	05-14-72	--	42000	35000	40000	44000	5800	160
	07-17-72	--	42400	39800	32000	28800	3540	111
	09-14-72	34600	34000	30000	30000	32000	7220	--
	10-31-72	32000	29200	30000	34000	29200	28000	88
	11-22-72	32000	32000	32000	31000	31000	8000	490
	12-20-72	32800	33000	32800	32000	31400	7000	320
	01-17-73	37000	37600	36000	37000	37200	20800	440
	02-28-73	40000	38800	38000	38600	38600	2400	188
	04-24-73	39000	39000	38000	37000	39000	5820	250
	06-20-73	39800	39800	35000	32600	34000	17600	198
CHLORIDES	03-18-72	--	18380	17710	17710	17800	--	25
	05-14-72	--	19094	14996	17496	19694	4899	4399
	07-17-72	--	19350	16200	13100	13200	1800	180
	09-14-72	18094	17894	15294	15894	15494	3399	--
	10-31-72	18000	19300	18200	19200	18150	15300	197
	11-22-72	18200	18150	18000	17600	17600	4141	148
	12-20-72	18250	17550	17650	17750	17750	3250	25
	01-17-73	18240	18840	17700	17900	17850	8970	30
	02-28-73	20480	20077	19770	18000	19060	7500	20
	04-24-73	18720	18720	18720	17900	18350	990	10
	06-20-73	18540	18540	15950	16410	15675	7375	15

TABLE 2.18. WATER QUALITY ANALYSIS OF SIX SAMPLING STATIONS: KAHANA DRAINAGE SYSTEM (MAR.-DEC. 1972, JAN.-JUNE 1973) (CONTD).

PARAMETER	DATE	STATION 0^a	1^a	2^b	3^b mg/ℓ	4^b	5^c	6^d
TOTAL NITROGEN	03-18-72	--	0.073	0.047	0.041	0.046	--	0.073
	05-14-72	--	0.081	0.110	0.189	0.163	0.046	0.040
	07-17-72	--	0.296	0.121	0.113	0.136	0.144	0.069
	09-14-72	0.133	0.115	0.114	0.181	0.171	0.180	--
	10-31-72	0.144	0.112	0.146	0.120	0.126	0.230	0.063
	11-22-72	0.129	0.155	0.152	0.145	0.148	0.109	0.073
	12-20-72	0.054	0.096	0.098	0.084	0.082	0.082	0.066
	01-17-73	0.077	0.074	0.163	0.076	0.083	0.128	0.067
	02-28-73	0.096	0.062	0.077	0.083	0.080	0.098	0.073
	04-24-73	0.041	0.032	0.028	0.065	0.060	0.064	0.070
	06-20-73	0.131	0.157	0.164	0.126	0.104	0.222	0.206
TOTAL PHOSPHORUS	03-18-72	--	0.028	0.031	0.030	0.025	0.030	0.016
	05-14-72	--	0.015	0.013	0.021	0.021	0.013	0.012
	07-17-72	--	0.047	0.040	0.060	0.028	0.053	0.002
	09-14-72	0.022	0.021	0.022	0.025	0.026	0.063	--
	10-31-72	0.019	0.016	0.017	0.018	0.018	0.090	0.008
	11-22-72	0.006	0.005	0.006	0.015	0.017	0.011	--
	12-20-72	0.022	0.025	0.020	0.026	0.024	0.012	0.014
	01-17-73	0.014	0.009	0.011	0.005	0.012	0.025	0.003
	02-28-73	0.034	0.026	0.026	0.028	0.028	0.002	--
	04-24-73	0.025	0.022	0.022	0.026	0.022	0.003	0.002
	06-20-73	0.040	0.045	0.035	0.025	0.029	0.023	0.016
ORGANIC CARBON	05-14-72	--	13.1	12.7	11.1	13.7	9.4	11.7
	07-17-72	--	5.5	5.0	5.5	6.0	3.5	2.5
	09-14-72	4.0	8.0	9.5	10.0	11.3	7.5	--
	10-31-72	41.5	13.0	9.0	8.5	4.5	6.8	6.0
	11-22-72	3.8	3.5	4.5	4.8	4.5	4.5	2.5
	12-20-72	3.0	3.8	1.6	4.5	4.5	4.5	2.0
	01-17-73	4.3	2.5	3.1	4.6	4.6	4.0	1.5
	02-28-73	4.0	3.0	3.0	2.2	3.0	2.7	4.6
	04-24-73	3.3	3.0	2.2	2.3	1.9	1.9	1.9
	06-20-73	3.6	3.6	3.2	3.2	2.3	2.0	2.3

NOTE: VALUES IN mg/ℓ UNLESS NOTED OTHERWISE.

[a] OCEAN
[b] KAHANA BAY
[c] KAHANA ESTUARY
[d] KAHANA STREAM

TABLE 2.19. SEASONAL VARIATION OF WATER QUALITY OF KAHANA STREAM DRAINAGE BASIN, MAR.-DEC. 1972, JAN.-FEB. 1973.

ANALYSIS	DATE	KAHANA STREAM	KAHANA ESTUARY	KAHANA BAY	OCEAN
pH (UNITS)	03-18-72	7.4	7.9	8.1	8.1
	05-14-72	--	7.5	8.1	8.1
	07-17-72	7.2	7.2	8.1	8.1
	09-14-72	7.3	8.0	8.0	8.0
	10-31-72	6.8	7.9	8.1	8.1
	11-22-72	7.7	7.8	8.1	8.1
TOTAL SOLIDS	03-18-72	78	--	35857	37020
	05-14-72	85	5240	34983	39630
	07-17-72	90	2529	29749	36396
	09-14-72	--	7244	35257	37258
	10-31-72	131	38006	38278	39074
	11-22-72	86	9056	37263	38863
	12-20-72	210	6766	39422	36013
	01-17-73	308	18200	37443	38435
	02-28-73	242	1650	39443	41185
	04-24-73	208	4508	37577	38350
	06-20-73	148	15900	36402	38163
TOTAL VOLATILE SOLIDS	05-14-72	20	800	4498	6030
	07-17-72	45	477	3829	4639
	09-14-72	--	1005	5699	5712
	10-31-72	33	4056	3601	4930
	11-22-72	86	1284	3841	4320
	12-20-72	82	1126	6655	6529
	01-17-73	36	2828	4843	4972
	02-28-73	18	254	4923	5689
	04-24-73	8	604	4571	4684
	06-20-73	84	2580	5728	6668
SUSPENDED SOLIDS	05-14-72	--	7.0	9.3	12.0
	07-17-72	4.8	8.5	12.2	17.0
	09-14-72	--	18.6	33.7	35.3
	10-31-72	0.6	20.4	29.3	27.8
	11-22-72	46.0	9.4	28.7	34.5
	12-20-72	3.0	9.0	33.3	24.0
	01-17-73	5.2	38.0	40.7	44.5
	02-28-73	--	6.0	35.3	38.5
	04-24-73	2.0	8.0	39.7	41.0
	06-20-73	2.5	23.0	30.3	33.0

TABLE 2.19. SEASONAL VARIATION OF WATER QUALITY OF KAHANA STREAM DRAINAGE BASIN, MAR.-DEC. 1972, JAN.-FEB. 1973 (CONTD)

ANALYSIS	DATE	KAHANA STREAM	KAHANA ESTUARY	KAHANA BAY	OCEAN
VOLATILE SUSPENDED SOLIDS	05-14-72	--	2.0	2.7	2.0
	07-17-72	2.5	4.0	5.0	7.0
	09-14-72	--	5.2	8.7	8.1
	10-31-72	1.7	4.2	5.1	6.0
	11-22-72	1.0	1.4	5.0	6.5
	12-20-72	3.0	4.0	8.0	7.5
	01-17-73	3.0	7.7	7.6	9.4
	02-28-73	--	4.0	8.1	8.6
	04-24-73	1.0	2.0	7.7	7.0
	06-24-73	0.4	3.2	3.9	4.9
TURBIDITY (FTU)	05-14-72	25.0	4.2	4.7	2.0
	07-17-72	1.7	7.6	3.3	1.2
	09-14-72	--	5.8	2.0	0.7
	10-31-72	1.7	4.2	1.2	1.1
	11-22-72	1.4	2.2	2.2	1.7
	12-20-72	1.7	2.6	1.1	0.8
	01-17-73	2.7	5.5	2.6	1.7
	02-28-73	1.6	2.5	1.7	1.4
	04-24-73	1.3	2.0	2.2	1.5
	06-24-73	1.4	3.9	1.7	1.4
CONDUCTIVITY (μmhos)	05-14-72	160	5800	39667	42000
	07-17-72	111	3540	33533	42400
	09-14-72	--	7220	30667	34300
	10-31-72	88	28000	31067	30600
	11-22-72	490	8000	31333	32000
	12-20-72	320	7000	32067	32900
	01-17-73	440	20800	36733	37300
	02-28-73	188	2400	38400	39400
	04-24-73	250	5820	38000	39000
	06-20-73	198	17600	33867	39800
CHLORIDES	03-18-72	25	--	17740	18380
	05-14-72	4399	4899	17395	19094
	07-17-72	180	1800	14167	19350
	09-14-72	--	3399	15561	17994
	10-31-72	197	15300	18517	18650
	11-22-72	148	4141	17733	18175
	12-20-72	25	3250	17717	17900
	01-17-73	30	8970	17817	18540
	02-28-73	20	7500	18943	20279
	04-24-73	10	990	18323	18720
	06-20-73	15	7375	16012	18540

TABLE 2.19. SEASONAL VARIATION OF WATER QUALITY OF KAHANA STREAM DRAINAGE BASIN, MAR.-DEC. 1972, JAN.-FEB. 1973 (CONTD).

ANALYSIS	DATE	KAHANA STREAM	KAHANA ESTUARY	KAHANA BAY	OCEAN
TOTAL NITROGEN	03-18-72	0.073	--	0.045	0.073
	05-14-72	0.040	0.046	0.154	0.081
	07-17-72	0.069	0.144	0.123	0.296
	09-14-72	--	0.180	0.155	0.124
	10-31-72	0.063	0.230	0.131	0.128
	11-22-72	0.073	0.109	0.148	0.142
	12-20-72	0.066	0.082	0.088	0.075
	01-17-73	0.067	0.128	0.107	0.076
	02-28-73	0.073	0.098	0.080	0.079
	04-24-73	0.070	0.064	0.051	0.037
	06-20-73	0.206	0.222	0.131	0.144
TOTAL PHOSPHORUS	03-18-72	0.016	--	0.029	0.025
	05-14-72	0.012	0.013	0.018	0.015
	07-17-72	0.002	0.053	0.043	0.047
	09-14-72	--	0.063	0.024	0.022
	10-31-72	0.008	0.090	0.018	0.018
	11-22-72	--	0.011	0.013	0.006
	12-20-72	0.014	0.012	0.023	0.024
	01-17-73	0.003	0.025	0.009	0.012
	02-28-73	--	0.002	0.027	0.030
	04-24-73	0.002	0.003	0.023	0.024
	06-20-73	0.016	0.023	0.030	0.043
ORGANIC CARBON	05-14-72	11.7	9.4	12.5	13.1
	07-17-72	2.5	3.5	5.5	5.5
	09-14-72	--	7.5	10.3	6.0
	10-31-72	6.0	6.8	7.3	27.3
	11-22-72	2.5	4.5	4.6	3.7
	12-20-72	2.0	4.5	3.5	3.4
	01-17-73	1.5	4.0	4.1	3.4
	02-28-73	4.6	2.7	2.7	3.5
	04-24-73	1.9	1.9	2.1	3.2
	06-20-73	2.3	2.0	2.9	3.6

NOTE: VALUES IN mg/ℓ UNLESS NOTED OTHERWISE.

TABLE 2.20. SUMMARY OF WATER QUALITY AVERAGES, KAHANA VALLEY DRAINAGE BASIN, MAR. 1972- JUNE 1973.

	KAHANA STREAM[a]	KAHANA ESTUARY[b]	KAHANA BAY[c]	OCEAN[d]
HYDROGEN ION CONCENTRATION, pH (UNITS)	7.3	7.7	8.1	8.1
TOTAL SOLIDS	158.6	10909.9	36515.8	38217
SUSPENDED SOLIDS	9.2	14.79	23.25	30.76
TOTAL VOLATILE SOLIDS	56.9	1431.4	4818.8	5417.3
VOLATILE SUSPENDED SOLIDS	1.8	3.77	6.18	6.7
TURBIDITY (FTU)	4.3	4.05	2.27	1.35
CONDUCTIVITY (μmhos)	249.4	10618.0	34533	36970
CHLORIDES	504.9	5762.4	17265.9	18692.9
TOTAL NITROGEN	0.08	0.13	0.11	0.11
TOTAL PHOSPHORUS	0.01	0.03	0.02	0.02
ORGANIC CARBON	3.89	4.68	5.55	7.27

NOTE: ALL UNITS IN mg/ℓ UNLESS NOTED OTHERWISE.

[a] STATION 6.
[b] STATION 5.
[c] STATIONS 2, 3, 4.
[d] STATIONS 0 AND 1.

As might be expected, the difference in the quality of water in Kahana Bay and in the ocean is only slight. The data confirmation indicates that the diluting effect of stream discharge on Kahana Bay is but small. The data (Table 2.20) can be considered as a fairly good representation of the water quality at various points in the system because the sampling program on which they are based has extended through one full year.

NUTRIENTS IN KAHANA BAY. The subject of nutrients in Kahana Bay is singled out from other matters of water quality both because of the emphasis placed upon nutrient concentrations in the control of the aesthetic and recreational value of water, and because of the value of data on nutrient concentration in establishing and in revising baseline water quality standards for receiving waters (e.g. Dept. of Health Chap. 37A, Water Quality Standards). In the case of Kahana Bay, which is designated as Class AA water by the state, the findings of the QCW and related studies are particularly significant.

Values of Total-P reported in Tables 2.17 and 2.18 for Station 5 show that of the 14 samples reported, 6 had a concentration of phosphorus in excess of the 0.02 mg/ℓ standard specified by the State of Hawaii for Class AA waters. In January 1971 (Table 2.17), at a time of maximum stream discharge, the excess of Total-P over the standard was nearly 2.5 times the 0.02 mg/ℓ value. More significant, perhaps, is the fact that of the 15 ocean samples reported in Table 2.18 for the open ocean (Stations 0 and 1), 7 exceeded the Total-P Standard.

Total nitrogen (Total-N) concentrations reported for Station 5 in the two tables (2.17 and 2.18) show that 10 of 14 samples exceeded the 0.1 mg/ℓ level of the state standards for Class AA waters. However, there is considerably greater variation in the magnitude of values presented in Table 2.17 than in Table 2.18. Again, as in the case of phosphorus, 7 of the 15 samples from the ocean (Stations 0 and 1) exceeded the standard for Kahana Bay. Within the bay itself (Stations 2, 3, and 4), the same pattern of 50 percent of the samples showing excess Total-N appears, although the percentage of samples with excess Total-P was even higher--16 of 27 samples, or nearly 60 percent.

To further evaluate the relationship of experimental data and state standards, Tables 2.21 and 2.22 have been prepared. From Table 2.21 it may be seen that the arithmetic mean of all samples assayed for total nitrogen over a one year period is 0.115 mg/ℓ (standard = 0.10 mg/ℓ). Inasmuch as the range of values measured is great (0.041 to 0.189), the geometric mean, another measure of central tendency, was determined also by frequency analysis. For Kahana Bay this geometric mean was found to be 0.117 mg/ℓ. Therefore, by any method of determining representative baseline levels, the data thus far collected clearly demonstrate that baseline nitrogen in this undeveloped area exceeds the Hawaii State standards for nitrogen in Class AA waters.

TABLE 2.21. SUMMARY OF NUTRIENT ANALYSES, KAHANA BAY AND OCEAN 1972-1973.

NUTRIENT	CLASS AA STANDARD	KAHANA BAY HIGH	KAHANA BAY LOW	KAHANA BAY MEAN	KAHANA BAY SD	OCEAN HIGH	OCEAN LOW	OCEAN MEAN	OCEAN SD
TOTAL-N	0.10	0.189	0.041	0.115	0.041	0.296	0.054	0.113	0.057
TOTAL-P	0.020	0.060	0.005	0.023	0.011	0.047	0.005	0.020	0.010

NOTE: UNITS IN mg/ℓ;

TABLE 2.22. SUMMARY OF FREQUENCY ANALYSES FOR NUTRIENTS, KAHANA BAY AND OCEAN, 1972-1973.

NUTRIENT	CLASS AA STANDARD	% OF TIME < AA STD. KAHANA BAY	% OF TIME < AA STD. OCEAN
TOTAL NITROGEN	0.10	36	50
TOTAL PHOSPHORUS	0.020	44	50

In the case of total phosphorus, both geometric and arithmetic means are nearly the same, and as with total nitrogen, baseline phosphorus levels in Kahana Bay also exceed the Hawaii state standards. Table 2.21 also includes the arithmetic means for both total nitrogen and total phosphorus in the near shore ocean. It is seen that the value for total nitrogen exceeds the Class AA standard whereas baseline phosphorus barely meets the

Class AA standard. However, based on geometric means, the ocean samples would conform to a Class AA standard for both constituents, as indicated by Table 2.22.

Inasmuch as the Kahana Bay coastal area is unaffected by urban development, these waters can serve as a baseline for setting water quality standards, and in light of the above discussion, it may well be advisable to redefine the standards for Class AA waters in terms of geometric means, as well as to reconsider the numerical values themselves.

HEAVY METALS AND PESTICIDES. From the data on heavy metals reported for Kahana Stream, together with the vast dilution of fresh water in Kahana Bay waters, it would not be expected that any influence on the heavy metal content by discharge from the drainage basin would be detectable. The same might be expected to be true of pesticides. Several examinations of Kahana Bay water showed no detectable amounts of these parameters, hence such analyses were abandoned for all bay samples except sediments.

SEDIMENTS IN KAHANA BAY. Sediment samples obtained at stations 1 through 6, Figure 2.11, were analyzed for heavy metals, pesticides, and nutrients. The results of these analyses are summarized in Table 2.23. Attention has previously been directed to the presence of heavy metals in Kahana Stream sediments and to their probable sources in the native rock and soils of the drainage basin. Migration of these sediments to Kahana Bay during flushout of the stream is undoubtedly a source of heavy metals in the sediments of Kahana Bay. In any event, heavy metals appeared in most bay sediment samples. Most evident were lead, copper, zinc, chromium, and nickel. However, cadmium and mercury were detected in most samples, albeit at lower concentrations than other heavy metals. Considerable nationwide research has been conducted which demonstrates the sorption kinetics of heavy metals on solids, both biological and sedimentary, and it is not unusual to observe high levels of heavy metals associated with these solids, especially in areas affected by man's activity. However, in the Kahana drainage basin, no significant activity that might contribute these heavy metals is present.

Pesticides analysis yielded the presence of DDT in all sediment samples whereas dieldrin, DDE, alpha chlordane, and gamma chlordane were only detectable periodically at very low levels. The levels of DDT measured were significantly greater than the other chlorinated hydrocarbons, however they were still several orders of magnitude lower than that reported for typical lake sediments from Green Bay and Southern Lake Michigan, where intense human activity is present.

Table 2.23 also includes the nutrient content in the sediments and it is interesting to note that the total phosphorus content in the Kahana Stream sediments was greater than that found in the sediments from the estuary. This tends to support the theory that phosphorus is being released into the water by desorption.

Biology and Biota of Kahana Bay

The data presented in Table 2.17 (OWQP study) includes some observations of BOD and coliform organisms in Kahana Bay water in 1970-71. BOD

TABLE 2.23. SEDIMENT ANALYSIS, KAHANA BAY. MAR.-DEC. 1972 TO JAN.-JUNE 1973.

STATION NO.	Pb ppm	Cu ppm	Zn ppm	Cd ppm	Hg ppm	Cr ppm	Ni ppm	DIELDRIN ppt	DDE ppt	DDT ppt	α CHLORDANE ppt	γ CHLORDANE ppt	TOTAL ORGANOCHLORINES ppt	T-N ppm	T-P ppm	T-K ppm	As ppm
SAMPLING DATE 03/18/72																	
1	30.7	16.6	23.0	ND	0.11	22.8	46.1	--	--	--	--	--		268	511	641	
2	24.4	3.0	2.3	ND	0.06	6.8	10.2	--	--	--	--	--		291	423	215	
3	29.0	8.1	11.7	ND	0.03	24.5	29.4	--	--	--	--	--		347	437	399	
4	26.2	2.4	1.3	ND	0.04	5.9	16.0	--	--	--	--	--		329	383	287	
5	24.9	9.6	12.6	ND	0.04	15.0	31.4	--	--	--	--	--		414	430	515	
6	29.3	160.1	94.5	ND	0.21	147.1	349.8	--	--	--	--	--		1494	1009	234	
SAMPLING DATE 05/14/72																	
1	16.5	1.0	ND	1.3	0.09	7.6	18.1	7	ND	43	5	9	64	364	372	252	
2	4.6	136.4	75.8	ND	0.18	94.3	205.8	ND	ND	119	16	8	143	3003	830	1813	
3	19.2	25.1	33.1	ND	0.04	50.6	45.3	ND	ND	60	4	6	70	302	377	449	
4	21.6	ND	3.6	1.8	0.01	12.2	29.9	11	ND	102	10	13	136	269	342	603	
5	29.6	17.9	20.0	0.7	0.01	22.7	45.8	9	ND	64	9	15	97	298	475	723	
6	5.0	98.0	62.8	ND	0.04	47.4	298.0	4	ND	48	11	12	75	25	702	239	
SAMPLING DATE 07/17/72																	
1	26.7	2.3	4.3	ND	0.05	10.0	12.3	ND	ND	43	ND	ND	43	274	388	313	
2	28.6	5.4	6.7	ND	ND	17.9	13.2	ND	ND	57	ND	ND	57	295	385	401	
3	27.5	21.2	40.1	ND	ND	50.4	43.1	ND	ND	45	ND	ND	45	236	374	435	
4	27.2	12.0	25.3	ND	ND	27.2	34.1	ND	ND	55	6	15	76	218	437	602	
5	20.7	14.9	21.0	ND	ND	30.6	35.1	ND	ND	45	ND	ND	45	168	476	492	
6	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
SAMPLING DATE 09/23/72																	
1	26.3	1.6	7.3	1.7	0.03	3.6	11.5	13	23	204	22	17	279	400	371	405	
2	31.7	2.2	8.1	1.9	0.03	4.1	13.8	6	19	81	10	12	128	359	336	410	
3	34.2	4.3	13.4	2.7	0.04	9.4	25.6	10	3	95	12	10	130	324	463	451	
4	32.7	18.7	44.3	1.8	0.04	29.6	40.1	8	12	91	14	14	139	313	501	722	
5	27.9	16.4	27.0	0.4	0.04	41.8	5.4	12	10	73	18	16	129	270	537	589	
6	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
SAMPLING DATE 10/31/72																	
1	30.4	4.7	3.9	1.0	0.30	6.2	19.5	10	37	82	ND	ND	129	376	372	488	
2	28.5	3.6	2.9	0.9	0.60	4.0	14.6	ND	ND	121	ND	ND	121	318	308	319	
3	36.1	35.1	45.1	0.6	0.20	51.2	63.4	ND	ND	ND	ND	ND	ND	1410	658	878	
4	30.8	13.7	37.2	1.4	0.40	22.0	36.5	10	12	53	ND	ND	75	332	460	542	
5	32.6	21.7	35.4	0.7	0.60	28.8	43.0	15	13	117	20	18	183	364	595	605	
6	--	--	--	--	--	--	--	12	8	74	16	18	128	--	--	--	
SAMPLING DATE 11/22/72																	
1	16.1	3.4	7.1	1.3	0.15	3.8	19.1	ND	ND	ND	ND	ND	ND	404	372	440	
2	10.0	3.0	5.7	1.3	0.05	1.0	16.3	ND	ND	132	ND	ND	132	205	240	350	
3	13.0	4.0	7.7	1.8	0.39	8.3	18.1	ND	ND	132	ND	ND	132	273	417	435	
4	17.6	9.9	17.9	1.6	0.05	18.0	36.0	13	9	52	14	13	101	221	417	608	
5	13.6	16.3	24.9	1.2	0.06	27.1	36.8	13	9	75	22	13	132	201	492	644	
6	15.5	56.4	45.7	1.1	0.09	109.1	108.5	13	8	111	ND	ND	132	141	775	589	
SAMPLING DATE 12/20/72																	
1	35.9	ND	8.6	1.8	1.01	6.3	44.4	27	22	160	ND	ND	209	357	352	344	
2	40.9	3.0	5.0	0.6	0.06	7.4	48.1	18	ND	187	ND	ND	205	419	419	421	
3	36.9	2.8	4.6	1.1	ND	6.3	41.8	9	ND	45	ND	ND	54	341	372	403	
4	36.0	10.3	35.5	1.0	ND	20.6	56.6	12	7	64	22	15	120	363	476	549	
5	23.4	17.2	25.2	ND	ND	28.5	56.9	29	21	164	41	43	297	286	461	583	
6	13.6	47.4	41.0	ND	0.05	79.8	174.8	46	15	147	18	14	240	299	776	636	
SAMPLING DATE 01/17/73																	
1	34.2	5.1	6.2	2.6	ND	9.4	51.3	15	9	91	17	15	147	310	520	429	4.1
2	30.9	4.0	4.4	2.8	ND	7.3	43.7	19	9	174	39	15	236	481	424	333	2.9
3	40.8	5.9	7.6	3.1	ND	10.0	51.9	13	12	130	12	12	179	278	544	422	10.4
4	28.2	25.6	42.4	2.3	ND	36.7	80.5	14	13	66	ND	ND	93	303	615	605	21.2
5	34.4	21.3	29.8	3.0	ND	28.3	75.0	9	ND	38	13	12	72	260	598	582	14.4
6	22.2	55.6	50.4	1.4	ND	121.8	213.5	11	6	57	12	15	101	202	1120	652	2.0

TABLE 2.23. SEDIMENT ANALYSES, KAHANA BAY (CONTD).

STATION NO.	Pb ppm	Cu ppm	Zn ppm	Cd ppm	Hg ppm	Cr ppm	Ni ppm	DIELDRIN ppt	DDE ppt	DDT ppt	α CHLORDANE ppt	γ CHLORDANE ppt	TOTAL ORGANOCHLORINES ppt	T-N ppm	T-P ppm	T-K ppm	As ppm
SAMPLING DATE 02/28/73																	
1	31.6	4.5	6.8	3.5	0.06	14.9	52.0	ND	ND	188	ND	ND	188	209	413	372	5.2
2	36.8	4.4	4.2	2.6	0.03	18.4	44.1	ND	ND	113	ND	ND	113	192	315	375	4.0
3	33.3	8.3	3.5	2.6	0.03	17.0	39.8	ND	ND	139	ND	ND	139	217	348	369	13.8
4	35.5	18.9	20.2	3.4	0.02	23.1	57.9	12	17	128	ND	ND	157	114	420	429	28.5
5	37.1	22.3	23.8	3.0	0.03	28.7	54.8	ND	ND	209	ND	ND	209	93	540	523	19.6
6	33.6	78.8	51.6	1.7	0.05	112.3	156.9	ND	ND	565	ND	ND	565	162	719	441	3.2
SAMPLING DATE 03/29/73																	
1	22.1	5.4	8.3	1.3	0.18	8.9	40.2	ND	ND	58	ND	ND	58	340	425	253	6.7
2	20.4	6.8	6.3	2.0	0.28	6.0	34.0	ND	ND	54	ND	ND	54	286	464	457	5.4
3	29.1	7.8	10.6	1.8	0.19	9.7	50.4	ND	ND	57	ND	ND	57	363	422	337	25.0
4	29.0	10.6	12.3	1.6	0.15	17.6	66.2	ND	ND	53	ND	ND	53	231	437	397	14.9
5	31.7	22.8	35.3	1.8	0.16	42.2	84.5	ND	ND	85	ND	ND	85	334	655	696	4.7
6	--	--	--	--	--	--	--	ND	ND	73	ND	ND	73	--	--	--	--
SAMPLING DATE 06/20/73																	
1	15.2	4.1	4.9	2.1	0.12	13.0	47.8	ND	ND	ND	ND	ND	ND	669	374	489	4.2
2	26.6	3.4	2.5	2.6	0.04	9.9	45.6	ND	ND	305	ND	ND	305	345	298	399	3.0
3	19.9	3.6	5.5	2.6	0.02	16.7	43.7	ND	ND	241	ND	ND	241	502	446	477	3.9
4	23.0	12.6	20.9	2.1	0.02	36.9	70.8	ND	ND	121	ND	ND	121	302	425	698	17.4
5	19.7	11.3	16.4	2.1	0.03	39.7	71.5	ND	ND	155	ND	ND	155	156	435	358	10.4
6	24.0	59.2	41.8	1.9	ND	171.3	144.3	ND	ND	137	ND	ND	137	297	754	453	1.9

values reported are generally low--2 mg/ℓ or less--but there was enough increase as the rainy season brought in greater dilution to suggest that organic matter brought in from the land was the principal source of observed BOD. Surface runoff is also the logical source of coliform organisms, the very dense concentration 680,000/100 mℓ (Table 2.17), being obviously associated with a flood flow capable of diluting the bay water. That such a dilution did occur is evidenced by the exceptionally low value of salinity at the time (January 1971).

Data on coliform organisms and on nutrients, 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 bimonthly samples taken along the shoreline just off the beach park, Figure 2.10, are summarized in Table 2.24. The data in themselves are not particularly revealing, except as they indicate relatively clean water, and establish a minimum baseline for comparison of the Kahana Bay findings with those of other situations where man's activities enter as a factor.

In terms of water quality standards, the data in Table 2.24 show that Kahana Bay tends to satisfy Class A standards rather than the Class AA for which the bay is classified by the state.

BIOTA OF KAHANA BAY. Observations of the biota and the biology of Kahana Bay were made by an intensive study of the area during the summer of 1972. Most of the findings were published in the *First Annual Progress Report* (Lau 1972) but are herein included in order that the necessary evaluation of the Kahana Bay situation may be documented. Figure 2.13, which shows greater detail of the Bay area shown in Figure 2.11, shows the transect lines along which biological observations were made. Surveys of benthic

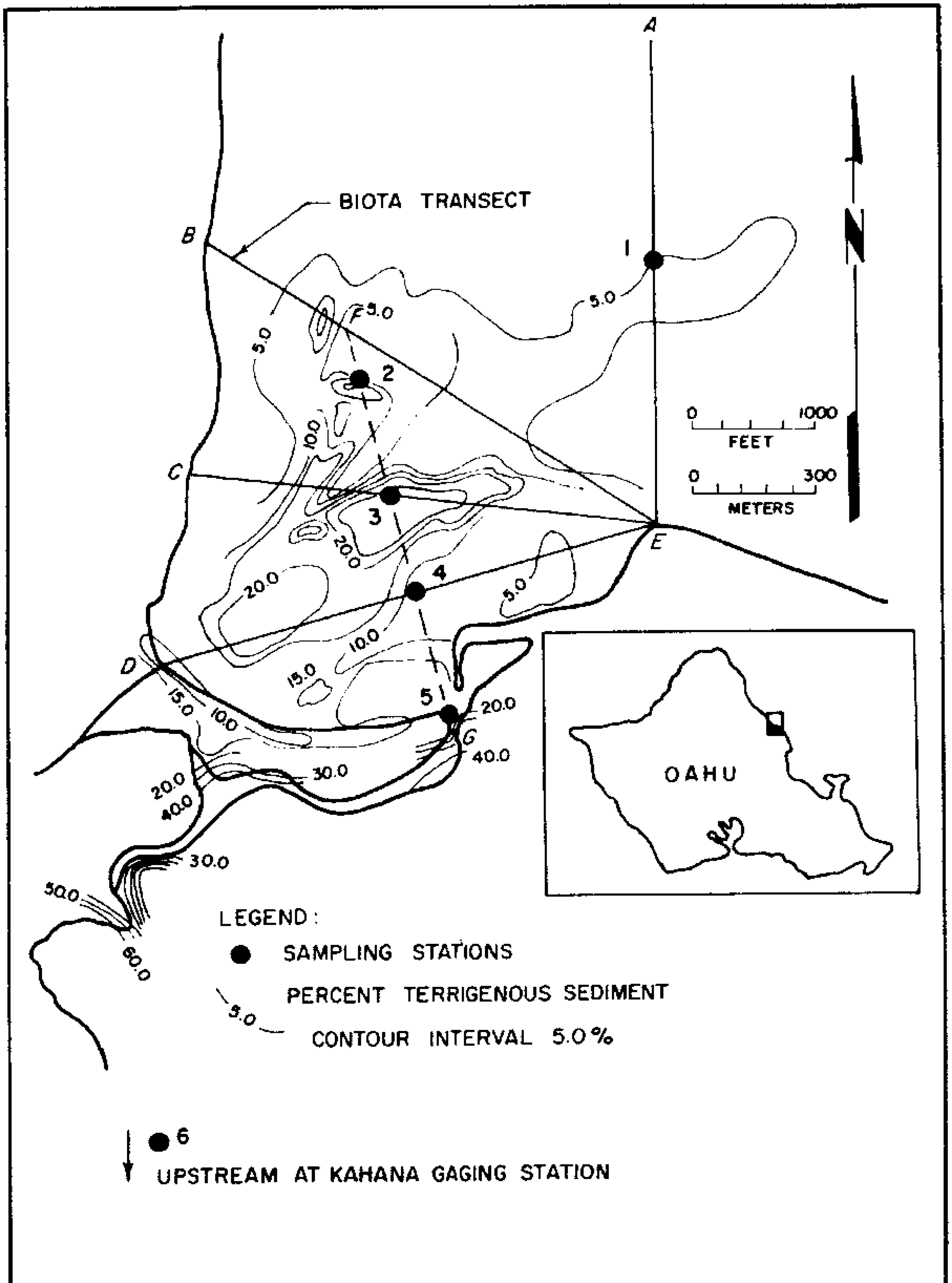


FIGURE 2.13. SAMPLING STATIONS FOR KAHANA BAY AND STREAM.

TABLE 2.24. BIMONTHLY DETERMINATION OF COLIFORM ORGANISMS, KAHANA BAY, 1970-1973.

	TOTAL COLIFORMS (MPN/100 mℓ)							
	1970		1971		1972		1973	
JANUARY	7	--	2400	240	43	93	240	240
FEBRUARY	43	--	43	43	460	93	460	23
MARCH	93	--	240	1100	240	0	240	93
APRIL	240	93	93	1100	≥2400	46000	1100	240
MAY	93	240	93	43	23	240	460	93
JUNE	--	--	43	0	240	240	1100	9
JULY	240	43	1100	240	93	93	460	1100
AUGUST	1100	240	240	43	460	43	93	460
SEPTEMBER	240	4	--	--	460	240	240	460
OCTOBER	240	--	--	--	4300	93	240	240
NOVEMBER	460	--	--	--	240	93	≥2400	460
DECEMBER	460	460	--	--	9	430	--	--

biota were made at the same sampling sites (Stations 1 to 5) utilized in the analyses of water and sediments reported in preceding sections. Onshore features described in the First Report were used to orient the transect lines to bisect a coral knoll which is an important feature of the bottom of Kahana Bay. This knoll was selected as the major station for a benthic and fish population survey. It is a well-defined small patch of coral rock completely surrounded by a sandy bottom. Thus it is effectively isolated 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. Benthic measurements were also made on the seaward facing reef slope along transect line A-E (Fig. 2.13). At all survey sites the percent cover of the substrate was determined and the density of abundant benthic invertebrates was measured. In this, use was made of underwater photography and special techniques which yielded information necessary for scale measurements and abundance counts.

The location, depth, clarity, and bottom type at the 5 sampling stations were observed. The results are summarized in Table 2.25. Values shown in the table agree with those of Coulbourn (1971) at similar locations. Turbid water in the inner bay is probably the result of suspension of fines of terrigenous origin and brought in by Kahana Stream. This sediment is continuously resuspended by wave action in the shallower regions of the Bay and is carried seaward by tidal currents. Turbidity increases after periods of heavy rain and persists for several days, but is less noticeable further seaward where dilution with cleaner ocean water flowing into the deep channel is a major factor. Turbidity at Station 1 is much greater than at offshore locations along the windward coast at similar depths, where the bottom can often be seen at 50 to 60 ft (15.24 to 18.288 m).

In order to study systematically the coral knoll it was divided into four quadrants along the north-south and east-west directions. In each quadrant the density of three species of sea urchins--*Tripneustes gratilla Pseudoboletia indiana*, and *Echinometra mathaei*--was measured by the method

TABLE 2.25. LOCATION, DESCRIPTION, AND PHYSICAL MEASUREMENTS AT SAMPLING STATIONS.

STATION	DEPTH (m)	DEPTH OF CLARITY (m) 06/06/72	EXTINCTION COEFFICIENT	BOTTOM TYPE	LOCATION
1	15.0	9	.2	CLEAN CALCAREOUS SAND	100 m NORTH OF REEF SLOPE ALONG TRANSECT LINE A-E[a]
2	7.0	5.5	.3	MIXED SAND AND TERRIGENOUS MATERIAL	JUNCTION OF TRANSECT B-E AND F-G, JUST SHOREWARD OF CORAL KNOLL
3	3.5	3.5	.5	MIXED SAND AND TERRIGENOUS MATERIAL	JUNCTION OF TRANSECT C-E AND F-G
4	3.0	3.0	.6	MIXED SAND AND TERRIGENOUS MATERIAL	JUNCTION OF TRANSECT D-E AND F-G
5	1.0	---	---	MIXED SAND AND TERRIGENOUS MATERIAL	MOUTH OF KAHANA STREAM AT EAST END OF SAND BEACH
6	---	---	---	---	AT GAGING STATION IN KAHANA STREAM

[a] REFER TO FIGURES 2.11 AND 2.13 FOR LOCATION OF TRANSECT LINES.

of Batchelor (1971) which corrects for pattern as well as indicates whether organisms are evenly distributed, aggregated, or randomly placed. Results of the study of the coral knoll are summarized in Table 2.26, which presents a species list of all invertebrates observed in that area.

Density of the three species of sea urchins in the four quadrants of the coral knoll was measured in detail. The southwest quadrant, which encompasses a tongue of loose coral rubble, showed a strikingly different pattern than that which characterized the rest of the knoll. *Psuedoboletia indiana* was the dominant urchin in this quadrant, but was too sparse for measurement in the other three quadrants. *Echinometra mathaei*, which was the dominant urchin in three quadrants, was completely absent on the coral rubble tongue.

Observations of the species of coral and their distribution by depth and orientation to the knoll are shown in Tables 2.25 and 2.26. The results are in themselves difficult to relate to the quality of water discharged from undeveloped land. Fresh water entering the bay during periods of heavy rainfall may be a growth limiting factor to some species living in shallow water where the effect of fresh water is greatest. The zonal dominance or absence of coral within the bay is most likely governed by oceanographic

TABLE 2.26. 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 Sp.	OCTOPUS	KNOLL FLAT	VERY RARE (1)* (BUT REPORT COMMON)
ARTHROPODA	*Stenopus hispidis*	BANDED SHRIMP	KNOLL SLOPES	VERY RARE (1)
	Dardanus Sp.	HERMIT CRAB	KNOLL FLAT	VERY RARE (1)
	Panulirus marginatus	SPINY LOBSTER	KNOLL SLOPES	COMMON
ECHINODERMATA	*Tripneustes gratilla*	SEA URCHIN	KNOLL FLAT	VERY COMMON
	Echometra 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 FLAT	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) = NUMBER SIGHTED.

phenomena rather than land use. The data, however, are useful as a baseline against which to measure the findings of coral crop in coastal waters subject do discharges from industry or other activity.

Micromolluscan assemblages from Stations 1, 2, 3, and 5, and two samples from the coral knoll were analyzed for species composition, diversity and standing crop during the study period herein reported. Three assemblages are distinguished: Stations 1 and 3 with high proportions of the archaeogastropod *Tricolia* and low species diversity values calculated in terms of the Shannon-Weaver index; Station 2 and the samples from the coral knoll substrate, with a high proportion of rissoids, high species diversity, and low standing crop; and Station 5 with a high proportion of Cerithiidae, high diversity, and high standing crop. (Fig. 2.14). The

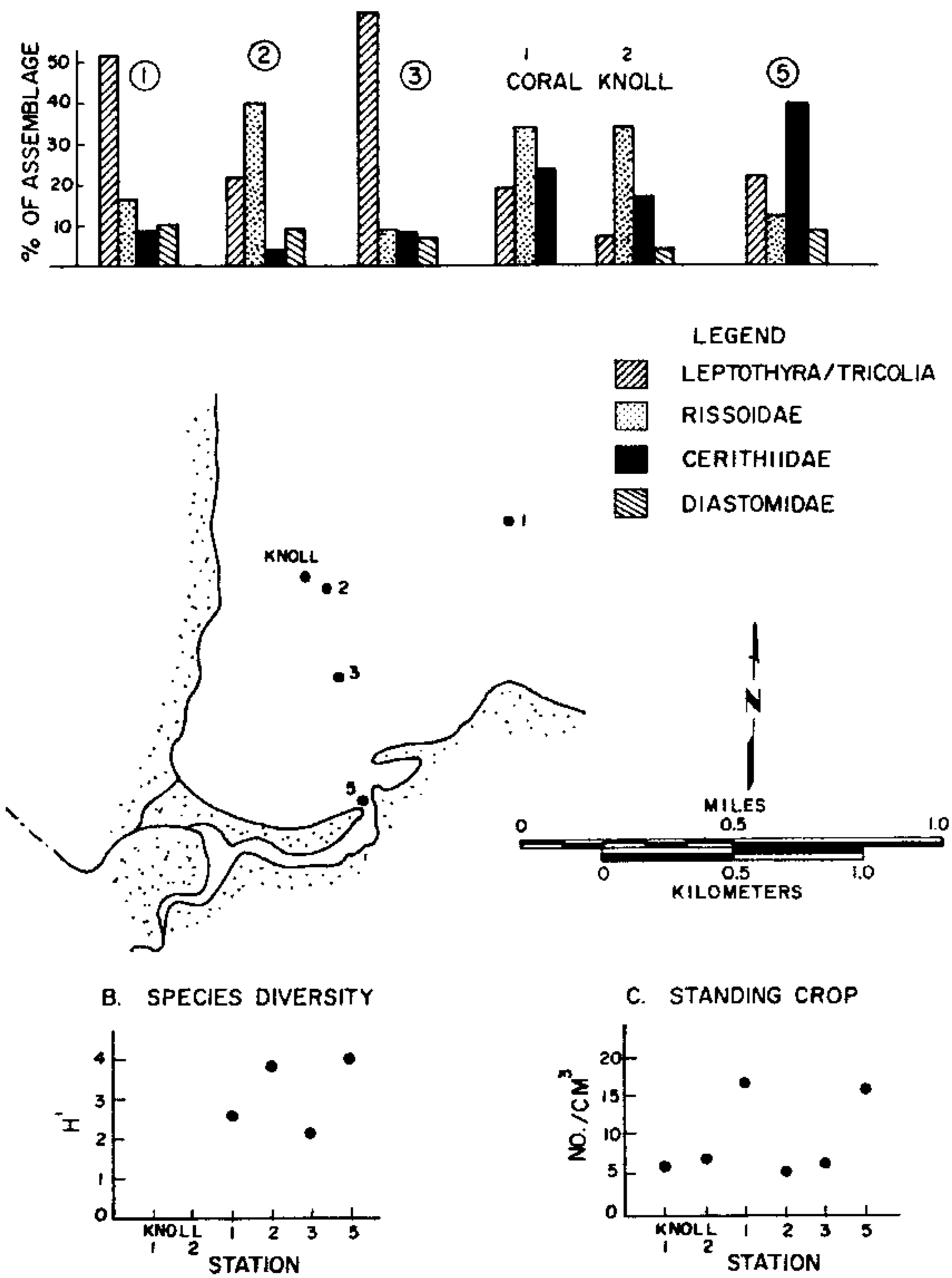


FIGURE 2.14. MICROMOLLUSCAN SPECIES COMPOSITION FOR KAHANA BAY STATIONS 1, 2, 3, AND 5.

species composition and low diversity values of Stations 1 and 3 are somewhat anomalous when compared with stations elsewhere in the islands at similar depths. Station 2 and the knoll samples, however, are comparable both in terms of composition and diversity with, for example, the subtidal stations at Kilauea and McBryde, on Kauai. The assemblage at Station 5 does not represent an *in situ* assemblage and except for the occurrence of the Cerithiidae, other aspects of the sample must be treated cautiously. A considerable number of shells of freshwater molluscs in the sample contribute both to standing crop and diversity in the assmeblage, and they indicate the mixed nature of the assemblage. The Cerithiidae, however, are characteristic of shallow water areas and characteristic of the sampling station area.

SUMMARY: KAHANA BAY

Kahana Bay was selected as a representative situation in which the influence of land use on the quality of coastal water is that of an uncontrolled natural discharge from an essentially pristine area. It was recognized at the outset that when coastal water quality is measured by the response of aquatic biota, no truly typical example of any type of situation may exist because of the overriding influence of uncontrollable oceanographic factors. Nevertheless, without some baseline against which to evaluate situations involving urban, industrial, or agricultural land development, it is impossible to make intelligent decisions concerning measures for effective pollution control systems.

To establish such a baseline, the Quality of Coastal Water Project of the Sea Grant Program, University of Hawaii, initiated a program of data collection and evaluation at Kahana Bay concurrent with similar studies of the influence of land development on other coastal waters in Hawaii. From the results made available by other investigators and agencies, together with experimental observations by the Project staff, a thorough analysis was made of the hydrology, physiography, and related aspects of the drainage area of Kahana Stream, the quality factors discharged into Kahana Bay via fresh water and stream sediments, the quality of water and sediments within the bay, and the biota of the bay.

It was found that the total dissolved material which discharges into Kahana Bay via Kahana Stream is quite small. Of the chemical constituents, only N, P, and SiO_2 could be said to enrich the waters of the bay, the remaining elements being those that already exist in greater concentrations. The average flow of Kahana Stream was computed to be about 36 cfs (61.2 m^3/min), with variations from 25 cfs (42.5 m^3/min) as the lowest daily average, and 1750 cfs (2975.0 m^3/min) as the average maximum discharge. The largest instantaneous maximum of record is 5430 cfs (9231.0 m^3/min).

At the average flow of 36 cfs (61.2 m^3/min) the total dissolved solids load is estimated at 1.45 tons/day/sq mi (5.08 kg/day/ha), whereas the average suspended sediment load may be as great as 37 tons/day/sq mi (129.6 kg/day/ha).

Heavy metals, particularly Cr, Cu, Pb, and Ni, occur in quite heavy concentrations in the volcanic rock of Kahana Stream drainage area. However, their solubility under prevailing environmental conditions in Kahana Stream is very low, hence only minute traces appear in the fresh water. However, as might be expected expected, heavy metals do appear in appreciable concentrations in the stream sediments. Pesticides in the stream waters and sediments were principally DDT, with occasional lesser concentrations of chlordane. Nutrient analyses ranged from about 140 to 1500 ppm, Total-N; 719 to 1009 ppm Total-P; and 234 to 652 ppm Total-K.

Once within the bay, the concentration of heavy metals and pesticides in the water was impossible to measure because of the great dilution with sea water. Heavy metals and small amounts of pesticides, however, appeared in the bay sediments brought in by the stream.

Concentrations of both Total-N and Total-P in Kahana Bay waters were generally greater than the standards set for Class AA waters prescribed by the state for Kahana Bay. The open ocean likewise did not consistently meet the standards for Class AA. Coliform organisms observed in samples of bay water taken by the Department of Health at a small beach area entrance to Kahana Bay also indicated that the bay meets Class A standards rather than the more exacting Class AA requirements.

The study produced evidence that during times of heavy rainfall the turbidity of the nearshore water of the bay increases and a measurable loss of clarity occurs. A lowering of the salinity of this water at such times also indicates that dilution with fresh water is sometimes appreciable, perhaps sufficient to make the nearshore waters marginal for some types of coral found there.

The estuarine sector of the Kahana Stream-Bay system acts as a temporary settling basin, and evidence was found that desorption of phosphorus was occurring in this sector due to microbial degradation of organic matter. Seasonal flushout of the estuary by flood waters, however, prevents any appreciable buildup of sediments in the estuarine sector.

Studies of biota in Kahana Bay--sea urchins, coral, and miscellaneous invertebrates as well as micromolluscs--show variations within the bay environment which are more related evidently to the oceanography and other characteristics of the bay than to the quality of water and sediments discharged from the stream. There was no evidence that the diversity of life in Kahana Bay was limited by quality factors originating on the land. The biological data presented are therefore subject to little interpretation in terms of response of living organisms to discharges from Kahana Stream. They do, however, give some baseline data, as do the results of chemical analyses, against which to compare the results of similar observations in other land use situations--urban, industrial, and agricultural.

Chapter 3

COASTAL WATER QUALITY AND URBAN LAND DEVELOPMENT

INTRODUCTION

Scope of the Urban Situation

Of the several types of land development situations which may have significant effects upon the quality of abutting coastal waters, urbanization is by far the most complex. In fact, it is not feasible to relate coastal water quality categorically to urban activities in the same sense that it may be related to sugarcane culture, general agriculture, specific industries, or to the natural phenomena that distinguish undeveloped land. This is true even though urbanization of land may readily be identified as the overwhelming source of water quality factors in a particular case. The reasons are not hard to discover. They include:

- The variety of waste-generating and unregulatable activities of man.
- The nature and disposal of wastes generated in urban situations.
- The fluctuations in scale and continuity of any individual activity.
- The degree of attention given to management of water quality factors in wastewater treatment.
- The technology used in waste control and the objectives of such use.

More specifically, it might be noted that domestic sewage is generally separated from other runoff from urbanized land. It is continuously produced within the community. In an untreated condition, human bodily discharges differ from the organic plant and animal residues produced by nature only by a lowered energy level and in the concentration and continuity of discharge from the originating land area. In Hawaii, particularly, sewage effluents are discharged into coastal waters at points other than the natural channels of surface drainage.

The condition and concentration of domestic sewage makes for a high demand for oxygen by microbes seeking to exploit the energy not extracted from food by man's digestive processes. Thus, the objective of sewage treatment has traditionally been that of reducing the BOD (biochemical oxygen demand) of sewage before releasing it into an environment where aquatic life may be suffocated for lack of oxygen or buried by sediments. To achieve this objective, as well as the secondary objectives of aesthetics and protecting the health of men using coastal waters and the food harvested from them, solids reduction and chlorination have been instituted along with biostabilization in the sewage treatment plant.

In a modern urban environment, however, sewage is not comprised strictly of human bodily wastes and residues from the preparation of food. Some industry, and most of the commerce and the citizens of the community also discharge assorted wastes to the sewer. Regardless of regulations intended to eliminate or to limit the discharge of certain materials, it is impossible to control what every small electroplater, storage battery reclaimer, service station operator, and individual householder does with chromium, lead, used cylinder oil, paint thinner, surplus pesticides, unwanted prescription drugs, and miscellaneous materials from time to time. Thus, sewage is one aspect of urbanization of land which may affect the quality of coastal waters in zones and in ways quite distinct from other sources of quality factors from urban land development.

Runoff from the surface of land structures is a second major class of coastal water pollutant. Understandably, it has been given far less attention than has sewage. Generally such runoff is seasonal and discharges via natural, or man-altered natural, channels. It transports a wide variety of debris from streets, roofs, and paved areas, as well as from raw or vegetated land. Among such materials are oil and grease dropped on pavements by automobiles, dust from tire wear on streets, animal and bird droppings, and residues from natural vegetation either with or without pesticide residues. It also carries the natural residues of weathering of rock and, more important, sediments eroded from land under development or from highway cuts and fills. Sometimes it also carries overflow from sanitary sewers. Draining of swamps, paving of land surfaces, and straightening and lining of channels increases the velocity and the total volume of surface runoff from the intensity of any given storm. As a factor in coastal water quality, surface runoff involves problems distinct from those of domestic sewage and often in a different sector of coastal water.

Although suitability for recreational use of coastal waters may be one of the parameters of water quality and also one of the objectives of water quality management, recreation in an urban setting may be a quality determinant of a particular body of coastal water. For example, the heavy recreational load on the inshore water at Waikiki may represent one effect of urbanization of land, essentially independent of sewerage and surface runoff phenomena. Similarly, pleasure boating and recreation-oriented structures such as marinas represent activities which are urban in significance but which have effects on coastal water quality not apparent in any data intended to relate quality to urbanization as one broad category of land use.

There are other aspects of urbanization that defy the investigator who would seek a typical norm against which to compare other urban developments. One is the tendency of man to concentrate his coastal communities around some special, rather than typical, geographical feature. Thus, Pearl Harbor is utilized as it is because of man's need for harbor facilities. Similarly, Kaneohe Bay is utilized because it is suited to man's other urban needs. It may be said in truth that embayments represent coastal waters which are of special concern to man, because of their beauty their role as a habitat of living things, their utility as food sources, their safety for watercraft, their recreational potential, and so on. No two are exactly alike except in their ability, perhaps, to attract men to the site and so become associated with urbanization.

Finally, although the design of ocean outfalls for sewage disposal can be accomplished with considerably confidence on the basis of certain engineering and oceanographic information, there is yet need to monitor coastal waters of the area to make certain that predicted results are attained. Therefore, in the interest of both basic design knowledge and protection of the quality of coastal waters, it is often necessary to observe coastal water quality in urban areas as a long-term precautionary measure rather than as a procedure for evaluating the immediate effects of urbanization on coastal water quality.

Fractionating the Urban Situation

Factors, such as those outlined in the preceding section, underscore the impossibility of developing a basis for managing coastal water quality in urban situations in general by observing the components of adjacent inshore waters and the abundance and diversity of life within them in a particular situation, then relating the findings to the overall activity of an urban community. The most compelling reasons are:

- Although the aquatic situation may be revealed empirically, the variety of urban activities is too complex to determine which activities are secondary and which are critical to the observed results. The complexity of man's activities in an urban situation is matched by the variability of situations, hence there is no such thing as a typical urban situation in the categorical sense.
- The coastal water of a bay affected by an urban community may involve several sectors or zones, rather than the entire bay, with each zone affected by different aspects of urban land use.

One need only to compare the quality of water off Waikiki with that of Ewa Judicial District to document the fact that the two sites have almost nothing in common except that they are adjacent to Mamala Bay.

The obvious answer to the dilemma posed by the diversity of effects associated with urban land development as a type of situation is to break down the overall situation into component parts -- into subsituations in which the quality of water in a specific sector of coastal water can be related to some identifiable element, or elements, or urbanization. In Hawaii such an approach has considerable feasibility because the topography and the physiography of the islands generally force urban growth to expand laterally along a narrow coastal zone, rather than landward into the mountain areas. Thus, land development for urban use tends to spill over a series of ridges which extend seaward from the mountains, dividing the land area into a series of valleys fronting on the ocean. Because beaches and bays tend to characterize the natural mouth of a valley, the coastal waters of the overall urban community tend to differ from bay to bay, reflecting man's activity within the separate valleys as well as his subsequent attempts to develop the ridge land between them. This means that, for example in one case, land development for housing of people plus ongoing further subdivision of land, may be identifiable as the principal contributor of water quality factors to an adjacent beach area or bay. In another coastal water zone the urban factor may be sewage effluents. In yet another, recreational activity may be the dominant factor.

The foregoing circumstance means that to a significant degree it is feasible to fractionate the cause-effect relationship between urban land development and coastal water quality. Such a fractionation is doubly fortunate because:

- By isolating the effect of individual types of urban activity on coastal water quality, the knowledge gained from a specific situation may serve to identify and minimize the urban activity principally responsible for any observed degradation of water quality in some other general situation of urban land development. Thus, from an inability to find a typical urban situation, may yet come information applicable to a considerable spectrum of atypical situations, and so make it possible to identify appropriate measures for reducing or eliminating the consequences of past decisions and developments.

- Many urban land use problems involve planning decisions concerning proposed extensions of urban communities into land areas presently characterized by low population density. In such situations the proposed development is of some definite nature and will give rise to only certain types of water quality factors, rather than to the entire spectrum of factors characteristic of an all-urban community. Consequently, far more useful results can be obtained by fragmenting the situation in the study of urban land development, than by observing an overall situation. For example, it would be much easier to judge what institutional and regulatory measures are needed to protect Kaneohe Bay if the effects of sewage effluents, surface runoff from urbanized land, recreational use, etc., could be sorted out individually, even though there may be synergistic effects of the mixture not identified by the fragmented approach to separate sources of pollution.

Pursuant to the foregoing rationale, several urban subsituations are identified in the sections of this chapter which follow, and the results of studies of varying degrees of intensity are reported.

MAUNALUA BAY

Nature of the Situation

In developing coastal valleys for urban purposes, natural swampy areas are often drained and filled in to maximize the land area which may be occupied by houses. However, if the swampy area is extensive and low lying, especially if it is within the tidal zone, construction of housing around marinas made by dredging and filling of swampland is an attractive alternative. The result is an 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. Disturbing swampland by dredging has the effect of abruptly releasing organic matter which may have accumulated over centuries.

Such an effect is, however, transient and hence not as serious as two other factors: 1) the confining of water under circumstances of poor circulation and 2) the continuous presence of people and their urban activities on the shoreline. The first often serves as an incubator for organisms under eutrophic conditions and as a settling basin 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 aesthetically objectionable between flushouts and may discharge periodically an appreciable volume of unsatisfactory waste into adjacent coastal waters. An opportune area to isolate and study this facet of urbanization exists at Maunalua Bay where the residential development of Hawaii Kai is a prominent feature.

Although the name Maunalua Bay applies to the reach of coastal water extending from Kupikipikio Point to Koko Head, the greatest degree of embayment is adjacent to Koko Head. This sector of the bay, which is the study area herein reported, is located on the island of Oahu approximately 10 mi(16 km) 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 3.1. The projected land drainage area is slightly greater than 4000 acres (1620.0 ha) and is characterized by steep ridges and mildly sloping valleys. The study area extends from an elevation of over 2000 ft (609.6 m) on the Koolau Mountain Range at the northern boundary of the watershed areas to sea level at the 258 acre (104.49 ha) Hawaii Kai Marina which constitutes 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 remnants of accumulations of lava flows. There is an abundance of koa-haole 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 landslides are common where the gradient is steep and near the mountain crests.

According to the *Atlas of Hawaii* (1973), the study area receives an average of 30 to 40 in. (76.2 to 101.6 m) of annual rainfall. 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 (1012 ha) Kuapa Pond, an old Hawaiian fish pond, into a series of channels separated by fingers of land and islands. The completed 258-acre (104.49 ha) marina is reported to have 12 mi (19 km) of shoreline and an average depth of 6 ft (1.83 m) (Kaiser Aetna Corporation, n.d.). The marina has two openings into Maunalua Bay beneath bridges on Kalanianiole Highway that traverse the narrow strip of land between the marina and the bay. The openings into the main body of the marina is large enough to permit boats with superstructures up to 13 ft (3.96 m) above the waterline to pass through at high tide.

Prior to the dredging of the Hawaii Kai Marina and of the deep channel outlet for boats, a survey was undertaken in 1961 by marine advisers to assess the tidal flushing action and the effects of sediments on water quality (Marine Advisers 1961). Turbidity and current measurements were made at 5 stations at low and high tides and 15 stations were surveyed for depth and sediment characteristics. The stations extended from Paiko Peninsula to Portlock. The survey showed that the turbidity in Maunalua

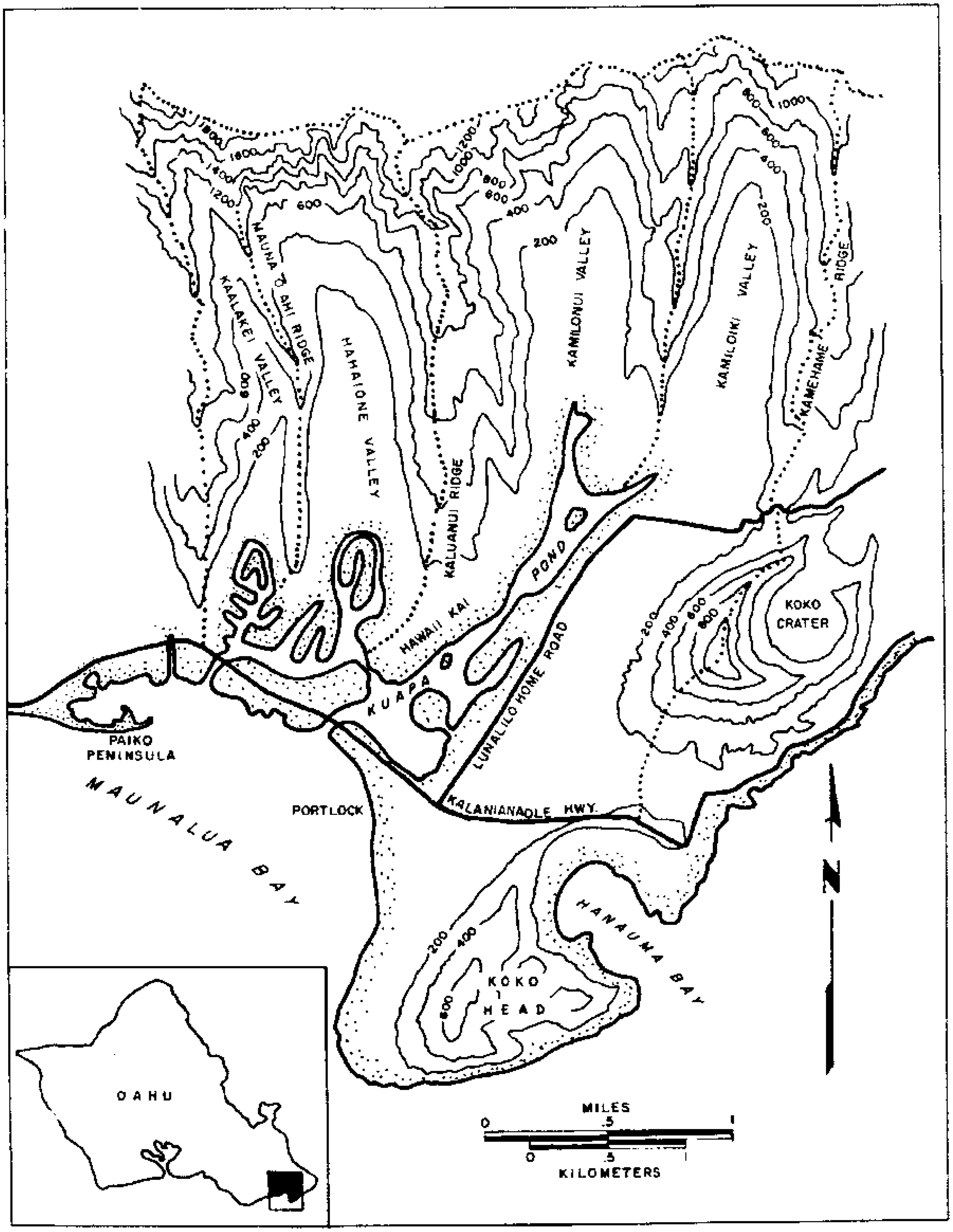


FIGURE 3.1. MAUNALUA BAY AREA

Bay was caused by the exit of turbid water from Kuapa Pond and the resuspension of sediments from the reef flats caused by tidal currents.

The pattern of water flow into Kuapa Pond has changed since the opening of a new channel, with the major volume of flow entering through this channel. The distribution of sediment and water turbidity has also changed and a new survey similar to the 1961 survey would furnish comparative data on the water and sediment movement patterns before and after the dredging of the new channel.

The Hawaii Kai area, currently in a fairly rapid state of development, has a population of 17,000 to 18,000, including the area representing 20 to 25 percent of the land southeast of Kalanianiole Highway at the western base of Koko Head, outside the defined study area. Ultimately, the projection of population growth 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 shelters one of Hawaii's shallowest reef. 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 the 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. An extensive reef area 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.

Studies of Water Quality

Data on the quality of water within the study area come primarily from limited monitoring by the State Department of Health, and from a program of sampling and analysis initiated by the QCW project. Data on the bacteriological quality of water have been collected by the Health Department since 1970. The present (1973) program involves sampling water on a twice per month schedule at each of 6 shoreline stations within the marina (see Figure 3.2). Results of coliform analyses of water from these stations show that the maximum concentration of coliform organisms occurs at the Koko Isle sampling site (Station 2) where over a 12-month period the monthly average concentration of coliforms was 567 per 100 mℓ; and of fecal coliforms 185 per 100 mℓ. Similarly, a station located at the Frigate Boating landing off of Hawaii Kai Drive (Station 6) had an average of 269 total coliforms per 100 mℓ and 114 fecal coliforms per 100 mℓ, over a 14-month period. The other four sampling stations all yielded results within the State Department microbiological requirements for Class A waters.

TABLE 3.0 MONTHLY AVERAGE COLIFORM CONCENTRATIONS IN HAWAII KAI MARINA WATERS, DEPT. OF HEALTH OCT. 1969-AUG. 1971.

	STATION 1 MPN/100 ML		STATION 2 MPN/100 ML		STATION 3 MPN/100 ML		STATION 4 MPN/100 ML		STATION 5 MPN/100 ML		STATION 6 MPN/100 ML	
DATE	TOTAL	FECAL	TOTAL	FECAL	TOTAL	FECAL	TOTAL	FECAL	TOTAL	FECAL	TOTAL	FECAL
OCT. 1969	4	0	-	-	0	0	43	4	-	-	-	-
MAR. 1970	0	0	-	-	3	0	4	0	-	-	-	-
APR. 1970	0	0	-	-	3	0	23	4	-	-	-	-
JULY 1970	-	-	-	-	-	-	-	-	-	-	689	635
AUG. 1970	-	-	252	47	-	-	-	-	-	-	281	12
SEPT 1970	-	-	166	25	-	-	-	-	-	-	625	84
OCT. 1970	6	6	1100	1100	151	1	23	9	-	-	43	13
NOV. 1970	23	4	460	93	0	0	43	43	-	-	198	189
DEC. 1970	4	4	-	-	-	-	9	4	-	-	521	31
JAN. 1971	240	15	1100	240	15	9	23	9	43	43	93	9
FEB. 1971	4	0	460	9	4	0	0	0	7	0	21	0
MAR. 1971	23	9	1100	93	7	0	23	23	43	7	93	93
APR. 1971	1100	93	1100	1100	21	4	240	93	1100	1100	43	3
MAY 1971	11	0	43	2	2	2	22	0	2	0	7	0
JUNE 1971	2	0	166	26	2	0	4	4	2	0	49	5
JULY 1971	2	0	68	15	4	2	4	0	122	49	5	5
AUG. 1971	2	0	1750	230	12	0	2	0	6	2	47	47

DEPARTMENT OF HEALTH DATA.

In order to evaluate the various parameters of the older portion of the marina, four stations were established by the QCW Project within the marina: two in Maunalua Bay proper, and one in the nearshore ocean waters at the southern base of Koko Head (Fig. 3.2). Station 1 should evaluate the effects of urbanization, as well as serve as a baseline for the effects of construction and development leading ultimately to approximately double the present housing units in its drainage area. This portion of the marina is small enough so that rapid environmental changes to the input of the marina will be reflected in the water samples and not be dissipated as might be the case in larger portions of the marina. Station 2 is intended to reflect possible effects of the interconnecting channel

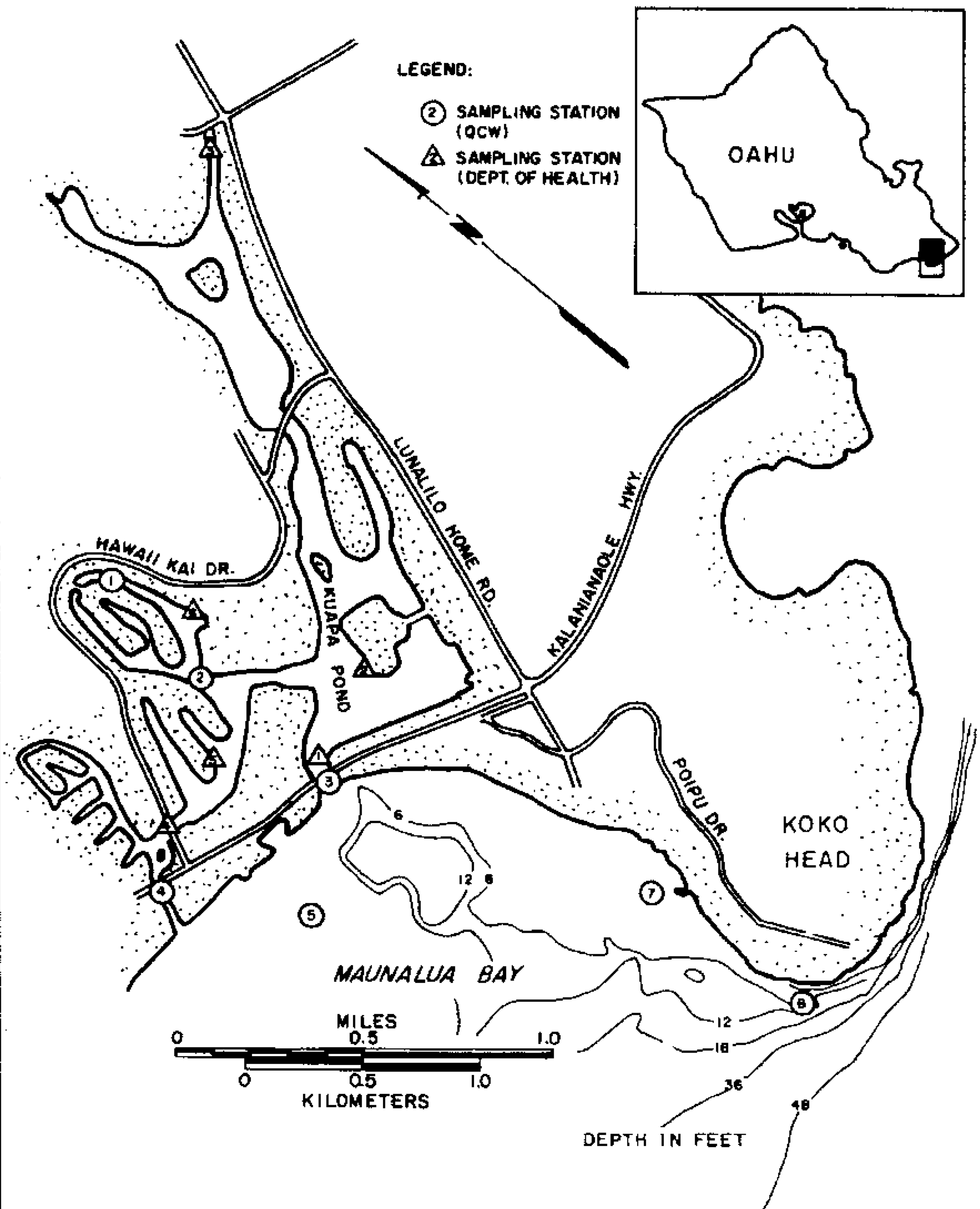


FIGURE 3.2. HAWAII KAI MARINA SAMPLING STATIONS USED IN THE COASTAL WATER QUALITY STUDY.

and Stations 3 and 4 are intended to measure the effects of the interchange of marina and bay waters. Stations 5 and 7 should indicate the baseline quality of Maunalua Bay as well as the effects of marina discharge, while Station 6 is intended to demonstrate the effects of marina discharge on near-shore coastal waters.

The water quality analyses for the seven stations are tabulated in Tables 3.1, 3.2, and 3.3. From the data given in Table 3.1 seasonal variations of the measured parameters over a 10-month period are not readily apparent; however, there is some indication that the Maunalua Bay and near-shore ocean waters are directly influenced by the marina discharge, as was expected. A plot of the monthly averages of suspended solids, volatile suspended solids, turbidity, total nitrogen, total phosphorus, and organic carbon for each station shows corresponding changes in concentration throughout the 10- to 13-month study period.

Table 3.4 summarizes the arithmetic means for each of the standard quality parameters, excluding heavy metals and pesticides. It is evident from this table that suspended solids, volatile suspended solids, turbidity, total nitrogen, total phosphorus, and organic carbon all decrease from the most inland station to the ocean station below Koko Head. Comparing the quality of water observed at Stations 1 and 6, there are significant differences in suspended solids (46 and 28 mg/ℓ), turbidity (14 and 2 FTU), total nitrogen (0.264 and 0.127 mg/ℓ), and total phosphorus (0.046 and 0.027 mg/ℓ). The effect of tidal interchange and dilution between Maunalua Bay waters and marina waters are also shown by the gradual decrease in these parameters at Stations 2, 3, 4, and 5. If the mean averages for Stations 1, 2, 3, and 4 are taken as representative of marina waters, Stations 5 and 7 as representative of Maunalua Bay waters, and Stations 6 as near-shore ocean waters, the general quality of these waters is as shown in Table 3.5.

Although there is some indication that urban development in Hawaii Kai has affected Maunalua Bay and near-shore ocean waters, the extent to which this development has affected these waters can be demonstrated by comparing nutrient levels measured at this location with that observed at Kahana Bay, a relatively undeveloped coastal zone. At Kahana Bay, both bay and ocean waters demonstrated lower levels of total nitrogen and phosphorus (0.115 and 0.023 mg/ℓ, respectively, for bay waters, and 0.113 and 0.020 mg/ℓ, respectively, for ocean waters) than measured at Maunalua Bay (0.138 and 0.033 mg/ℓ, respectively, for bay waters, and 0.127 and 0.027 mg/ℓ respectively, for ocean samples).

Based on the mean average for total nitrogen, the waters of both Maunalua Bay and the near-shore ocean meet the Class A standard of 0.15 mg/ℓ total nitrogen set by the State of Hawaii. The means of the values measured at these two locations were 0.138 and 0.127 mg/ℓ, respectively. On the other hand, the waters of both Maunalua Bay and the near-shore ocean do not meet the Class A standard of 0.025 mg/ℓ total phosphorus, also based on the mean of the values measured. The total-P levels at the two locations were 0.033 and 0.027 mg/ℓ, respectively.

Water samples from all stations were also subjected to analysis for

TABLE 3.1. WATER QUALITY ANALYSES OF SEVEN SAMPLING STATIONS, MAUNALUA BAY JAN.-DEC. 1972 AND JAN.-MAY 1973.

PARAMETER	DATE	STATION NO. 1	2	3	4	5	6	7
pH (UNITS)	01-27-72	7.6	--	--	--	--	--	--
	04-29-72	7.6	--	7.8	7.8	--	--	--
	05-06-72	—	--	--	—	8.0	8.1	—
	07-15-72	8.1	8.1	8.1	8.1	8.1	8.2	8.2
	09-14-72	8.0	8.0	8.1	8.0	7.9	8.0	8.0
	10-25-72	7.9	8.1	8.0	8.1	8.1	8.1	8.1
	11-17-72	8.0	8.0	8.1	8.0	8.0	7.9	8.0
SUSPENDED SOLIDS	06-10-72	68.0	83.0	75.0	63.0	69.0	23.0	—
	07-15-72	19.2	24.2	12.4	13.4	20.2	3.5	--
	09-14-72	27.0	25.4	28.6	15.8	35.2	16.2	19.6
	10-25-72	50.2	49.8	52.1	44.5	46.8	29.2	31.6
	11-17-72	50.5	45.0	43.0	37.0	38.0	30.0	31.0
	12-07-72	18.2	16.8	21.6	19.4	37.0	17.4	10.6
	01-19-73	47.0	44.0	51.0	47.0	46.0	39.0	40.0
	02-20-73	50.0	44.0	53.0	51.0	50.0	40.0	39.0
	03-27-73	59.0	56.0	56.0	52.0	40.0	40.0	40.0
	05-29-73	68.0	50.0	52.0	49.0	51.0	40.0	41.0
VOLATILE SUSPENDED SOLIDS	06-10-72	18.0	28.0	25.0	27.0	21.0	20.0	—
	07-15-72	6.2	7.6	4.8	3.8	7.2	3.2	--
	09-14-72	7.8	7.6	15.6	5.0	8.6	5.0	6.6
	10-25-72	8.0	7.4	9.6	7.8	8.8	4.0	4.2
	11-17-72	10.2	9.6	7.8	6.2	6.6	5.0	5.0
	12-07-72	3.2	4.0	5.0	2.7	22.6	3.6	2.4
	01-19-73	10.6	11.2	12.4	12.6	11.2	10.4	10.0
	02-20-73	9.0	8.0	10.0	8.0	9.0	7.5	7.0
	03-27-73	12.0	12.0	10.0	9.6	8.0	7.4	8.0
	05-29-73	14.2	11.0	9.6	9.2	11.0	8.0	8.4

PARAMETER	DATE	STATION NO. 1	2	3	4	5	6	7
TURBIDITY (FTU)	06-10-72	20.0	14.0	12.0	17.0	5.5	4.0	—
	07-15-72	8.7	17.0	6.8	5.4	8.6	0.2	1.2
	09-14-72	4.3	7.4	5.2	1.8	2.5	1.7	1.8
	10-25-72	14.0	14.0	11.0	13.0	10.0	5.0	2.0
	11-17-72	15.0	12.0	8.8	8.0	5.7	0.3	0.8
	12-07-72	9.8	9.2	12.0	9.1	7.5	0.5	1.5
	01-19-73	12.0	8.8	17.0	8.2	6.9	2.5	3.7
	02-20-73	8.4	9.0	15.0	11.0	9.0	2.7	3.0
	03-27-73	25.0	22.0	14.0	15.0	8.2	0.4	2.4
	05-29-73	27.0	20.0	13.0	11.0	11.0	1.6	2.5
ORGANIC CARBON	04-29-72	12.0	--	9.0	10.0	—	--	—
	05-06-72	--	--	—	—	9.0	9.0	—
	06-10-72	8.5	6.8	8.1	8.5	4.0	5.8	--
	07-15-72	5.2	4.2	4.0	6.8	--	5.2	--
	09-14-72	10.5	5.0	4.0	4.0	5.0	4.5	4.5
	10-25-72	4.8	5.5	6.0	4.5	3.5	3.5	2.1
	11-17-72	6.5	5.0	5.5	5.5	4.0	4.5	4.5
	12-07-72	7.0	5.5	4.5	6.0	6.0	4.5	3.5
	01-19-73	5.3	6.7	5.0	2.3	4.0	5.1	8.9
	02-20-73	3.7	3.2	4.3	3.2	4.3	4.6	2.0
	03-27-73	4.8	3.0	3.8	3.5	3.0	3.5	3.8
	04-24-73	6.2	3.0	5.0	3.2	5.0	3.2	3.8

NOTE: ALL UNITS IN mg/ℓ UNLESS OTHERWISE STATED.

TABLE 3.1. WATER QUALITY ANALYSES OF SEVEN SAMPLING STATIONS, MAUNALUA BAY JAN.-DEC. 1972 AND JAN.-MAY 1973 (CONTD).

PARAMETER	DATE	STATION NO. 1	2	3	4	5	6	7
TOTAL SOLIDS	06-10-72	--	43090	38418	38865	38040	38663	--
	07-15-72	37906	38289	38502	37291	38552	41416	38560
	09-14-72	36543	39382	39811	37929	37808	38900	39908
	10-25-72	39198	38728	38710	39142	39224	39918	39730
	11-17-72	38237	37924	38636	38794	38097	37551	38265
	12-07-72	38864	39204	39345	38286	38442	40400	38563
	01-19-73	37700	37850	38800	37600	38740	38120	37900
	02-20-73	39365	37300	37200	37200	37575	36930	38000
	03-27-73	37250	37150	37740	37600	38035	37470	38250
	05-29-73	39450	39405	40300	39660	39740	39620	39675
TOTAL VOLATILE SOLIDS	06-10-72	--	9445	4550	4995	4300	4725	--
	07-15-72	4768	4624	4693	4459	4985	4711	4957
	09-14-72	3127	4838	4629	4070	3858	4281	4901
	10-25-72	4768	4742	4560	4974	5164	5802	5146
	11-17-72	4243	4907	3960	3963	3915	4051	3851
	12-07-72	5443	4564	4671	3715	4270	5656	4119
	01-19-73	4650	4100	4660	3860	4740	4030	4000
	02-20-73	3060	3200	3025	3000	3540	3050	3950
	03-27-73	3840	3820	3530	3900	3990	3700	3975
	05-29-73	5940	5680	6324	6065	5675	5820	5550
CHLORIDES	04-29-72	18798	--	19421	19076	--	--	--
	05-06-72	--	--	--	--	19421	19421	--
	06-10-72	18894	19094	19094	18994	18994	19094	--
	07-15-72	19494	19394	19494	18894	19294	19394	19494
	09-14-72	19994	20494	20594	20294	20594	20494	--
	10-25-72	17994	17994	18194	18294	18094	18094	18094
	11-17-72	18200	18100	18280	18300	18300	18280	18300
	12-07-72	18150	17950	18250	18050	17750	18350	18250
	01-19-73	19250	19500	19600	19600	19800	19800	19800
	02-20-73	18500	18500	18500	18500	18300	18300	18900
	03-27-73	18530	18720	18625	18625	18625	18720	18720
	05-29-73	18530	18530	18530	18810	18620	18720	19270

PARAMETER	DATE	STATION NO. 1	2	3	4	5	6	7
TOTAL NITROGEN	04-29-72	0.055	—	0.127	0.184	--	—	--
	05-06-72	—	—	—	—	0.142	0.058	--
	06-10-72	0.279	0.224	0.204	0.155	0.203	0.077	—
	07-15-72	0.405	0.268	0.179	0.208	0.159	0.268	—
	09-14-72	0.145	0.059	0.081	0.094	0.095	0.102	0.071
	10-25-72	0.291	0.213	0.219	0.259	0.218	0.112	0.317
	11-17-72	0.258	0.172	0.152	0.117	0.146	0.097	0.101
	12-07-72	0.232	0.218	0.146	0.197	0.204	0.157	0.097
	01-19-73	0.221	0.213	0.170	0.167	0.167	0.101	0.124
	02-20-73	0.181	0.156	0.138	0.172	0.144	0.164	0.127
	03-27-73	0.195	0.159	0.111	0.157	0.100	0.188	0.104
	05-29-73	0.287	0.155	0.124	0.120	0.107	0.070	0.036
TOTAL PHOSPHORUS	04-29-72	0.084	--	0.043	0.058	—	--	—
	05-06-72	--	—	--	--	0.035	0.023	--
	06-10-72	0.047	0.040	0.030	0.041	0.031	0.023	--
	07-15-72	0.080	0.091	0.061	0.056	0.057	0.039	0.057
	09-14-72	0.039	0.041	0.044	0.037	0.035	0.033	0.031
	10-25-72	0.035	0.032	0.034	0.034	0.025	0.024	0.020
	11-17-72	0.026	0.022	0.028	0.016	0.021	0.010	0.010
	12-07-72	0.038	0.034	0.035	0.035	0.034	0.029	0.028
	01-19-73	0.033	0.037	0.048	0.011	0.056	0.025	0.025
	02-20-73	0.036	0.035	0.043	0.046	0.043	0.044	0.043
	03-27-73	0.053	0.049	0.045	0.045	0.036	0.028	0.028
	05-29-73	0.057	0.046	0.040	0.037	0.033	0.022	0.025
CONDUCTIVITY (μmho/cm)	06-10-72	41000	41000	40000	41600	40600	41400	—
	07-15-72	42000	42000	40000	41200	43800	43000	--
	09-14-72	33200	34000	33000	33000	33000	33000	34000
	10-25-72	40000	39000	39000	39000	38400	38500	39500
	11-17-72	40800	41000	41000	41200	41000	41000	41000
	12-07-72	40000	39200	40000	39600	39200	40200	40000
	01-19-73	40500	39200	40000	40500	40000	43000	43000
	02-20-73	37000	37000	37000	37000	36000	30000	37000
	03-27-73	38000	38000	38000	37600	38000	37000	38000
	05-29-73	39000	36600	36000	40000	38800	39400	39600

NOTE: ALL UNITS IN mg/ℓ UNLESS OTHERWISE STATED.

TABLE 3.2. ANALYSES FOR HEAVY METALS IN WATER SAMPLES, MAUNALUA BAY APR.-NOV. 1972 TO JAN.-MAR. 1973.

METAL	DATE	STATION NO. 1	2	3	4	5	6	7
LEAD	04-29-72	ND	--	ND	ND	--	--	--
	05-06-72	--	--	--	--	ND	ND	--
	07-15-72	ND	ND	ND	ND	ND	ND	ND
	09-14-72	ND	ND	ND	ND	ND	ND	ND
	10-25-72	ND	ND	1	4	ND	ND	4
	11-17-72	3	6	6	6	5	5	6
	01-19-73	ND	ND	ND	5	ND	4	1
	02-20-73	2	ND	ND	4	ND	ND	ND
	03-27-73	4	4	5	3	1	2	ND
COPPER	04-29-72	ND	--	ND	ND	--	--	--
	05-06-72	--	--	--	--	ND	ND	--
	07-15-72	5	7	3	10	3	4	4
	09-14-72	1	2	1	1	1	ND	2
	10-25-72	2	3	4	13	2	14	ND
	11-17-72	5	4	1	2	ND	ND	ND
	01-19-73	2	3	6	ND	ND	5	2
	02-20-73	5	1	1	2	1	1	3
	03-27-73	2	2	2	2	4	1	2
ZINC	04-29-72	ND	--	ND	ND	--	--	--
	05-06-72	--	--	--	--	ND	ND	--
	07-15-72	6	4	ND	8	4	6	3
	09-14-72	2	ND	ND	1	ND	ND	ND
	10-25-72	84	3	98	3	12	ND	2
	11-17-72	ND	ND	ND	ND	ND	ND	ND
	01-19-73	6	5	4	3	2	3	3
	02-20-73	4	3	1	2	2	ND	1
	03-27-73	ND	ND	ND	ND	2	ND	ND

METAL	DATE	STATION NO. 1	2	3	4	5	6	7
CADMIUM	04-29-72	ND	--	ND	ND	--	--	--
	05-06-72	--	--	--	--	ND	ND	--
	07-15-72	ND	ND	ND	ND	ND	ND	ND
	09-14-72	ND	3.3	ND	ND	2.7	1.3	ND
	10-25-72	ND	ND	ND	ND	ND	ND	ND
	11-17-72	ND	ND	ND	ND	ND	ND	ND
	01-19-73	ND	ND	ND	ND	ND	ND	ND
	02-20-73	ND	ND	ND	ND	ND	ND	ND
	03-27-73	ND	ND	ND	ND	ND	ND	ND
CHROMIUM	07-15-72	ND	ND	13	68	4	ND	ND
	09-14-72	ND	ND	ND	ND	ND	ND	ND
	10-25-72	ND	ND	3	2	3	ND	ND
	11-17-72	ND	4	4	3	ND	ND	3
	01-19-73	2	ND	2	4	2	4	ND
	02-20-73	ND	ND	ND	ND	ND	ND	ND
	03-27-73	ND	ND	ND	ND	ND	ND	ND
NICKEL	07-15-72	ND	ND	ND	ND	ND	ND	ND
	09-14-72	ND	ND	ND	ND	ND	ND	ND
	10-25-72	ND	ND	2	ND	ND	ND	1
	11-07-72	4	4	ND	ND	4	ND	ND
	01-19-73	ND	ND	ND	ND	ND	ND	ND
	02-20-73	ND	ND	ND	ND	ND	ND	ND
	03-27-73	4	ND	ND	ND	ND	ND	ND

NOTE: ALL UNITS IN μg/ℓ; MERCURY NOT DETECTED.

TABLE 3.3. PESTICIDES ANALYSES OF SEVEN SAMPLING STATIONS, MAUNALUA BAY, APR.-NOV. 1972.

PESTICIDE	DATE	STATION NO. 1	2	3	4	5	6	7
DIELDRIN	04-29-72	1	--	1	2	--	--	--
	05-06-72	--	--	--	--	<1	<1	--
	07-15-72	ND	ND	ND	ND	ND	ND	ND
	09-14-72	1	<1	<1	1	<1	<1	<1
	10-25-72	3	2	2	2	ND	<1	<1
	11-17-72	3	3	<1	<1	<1	ND	<1
DDT	04-29-72	0.5	--	2	2	--	--	--
	05-06-72	--	--	--	--	4	4	--
	07-15-72	1	1	1	1	1	2	2
	09-14-72	<1	<1	2	4	4	1	<1
	10-25-72	1	2	1	1	1	1	1
	11-17-72	<1	<1	1	1	1	1	1
α CHLORDANE	04-29-72	ND	--	ND	ND	--	--	--
	05-06-72	--	--	--	--	ND	ND	--
	07-15-72	<1	1	ND	ND	ND	ND	ND
	09-14-72	1	2	2	ND	ND	ND	ND
	10-25-72	2	2	1	ND	ND	ND	ND
	11-17-72	<1	2	ND	ND	ND	<1	ND
γ CHLORDANE	04-29-72	ND	--	ND	ND	--	--	--
	05-06-72	--	--	--	--	ND	ND	--
	07-15-72	<1	<1	ND	1	ND	ND	ND
	09-14-72	<1	1	2	ND	ND	ND	ND
	10-25-72	1	1	1	ND	ND	ND	ND
	11-17-72	<1	<1	ND	ND	ND	<1	ND
PCP	04-29-72	ND	--	ND	ND	--	--	--
	05-06-72	--	--	--	--	ND	ND	--
	07-15-72	6	ND	15	3	8	4	3
	09-14-72	10	5	5	9	ND	8	14
	10-25-72	16	5	5	5	3	7	3
	11-17-72	41	19	14	9	19	9	7
LINDANE	04-29-72	0.4	--	0.4	0.7	--	--	--
	05-06-72	--	--	--	--	<1	<1	--
	07-15-72	<1	1	<1	ND	ND	ND	ND
	09-14-72	<1	<1	ND	ND	ND	ND	ND
	10-25-72	2	1	1	1	ND	ND	ND
	11-17-72	1	1	ND	ND	ND	1	ND

NOTE: ALL UNITS IN ng/ℓ; DDE ANALYSED BUT NOT DETECTED.

TABLE 3.4. SUMMARY OF MEAN VALUES FOR WATER QUALITY ANALYSES, MAUNALUA BAY, JAN. 1972 TO MAR. 1973.

ANALYSIS	STATION NO. 1	2	3	4	5	6	7
pH	7.9	8.1	8.0	8.0	8.0	8.1	8.1
TOTAL SOLIDS	38279	38832	38746	38237	38425	38899	38761
TOTAL VOLATILE SOLIDS	4427	4992	4460	4300	4444	4583	4045
SUSPENDED SOLIDS	46	44	45	9	43	28	33
VOLATILE SUSPENDED SOLIDS	10	11	11	9	12	7	6
TURBIDITY; FTU	14	13	11	10	6	2	2
CONDUCTIVITY, umhos/cm	39150	38700	38400	39070	38880	38650	39012
CHLORIDES	18758	18828	18962	18858	18890	18970	18854
TOTAL NITROGEN	0.264	0.184	0.150	0.166	0.153	0.127	0.122
TOTAL PHOSPHORUS	0.046	0.043	0.041	0.038	0.037	0.027	0.030
ORGANIC CARBON	7.0	5.0	5.5	5.4	5.0	5.0	4.2

NOTE: ALL UNITS IN mg/ℓ UNLESS NOTED.

TABLE 3.5. SUMMARY OF WATER QUALITY, HAWAII-KAI MARINA, MAUNALUA BAY, AND OCEAN.

ANALYSIS	MARINA	MAUNALUA BAY	OCEAN
pH	8.0	8.1	8.1
TOTAL SOLIDS	38524	38593	38899
TOTAL VOLATILE SOLIDS	4545	4245	4583
SUSPENDED SOLIDS	44	38	28
VOLATILE SUSPENDED SOLIDS	10	8	7
TURBIDITY, FTU	12	4	2
CONDUCTIVITY, µmhos/cm	38830	38946	38650
CHLORIDES	18852	18872	18970
TOTAL NITROGEN	0.191	0.138	0.127
TOTAL PHOSPHORUS	0.042	0.033	0.027
ORGANIC CARBON	5.7	4.6	5.0

NOTE: ALL UNITS IN mg/ℓ UNLESS NOTED.

pesticides. The results are summarized in Table 3.3. Despite their minute concentration, DDT, dieldrin, and PCP are ubiquitous, whereas α-chlordane, γ-chlordane, and lindane were only infrequently detected. DDE was also analyzed for but was not detected.

Heavy metals in the water samples were measured. As shown in Table 3.6, copper appeared to be the only metal consistently present, although at very low concentrations. Analyses for mercury were made but not detected.

Studies of Sediments

Studies were made of both the type of sediments eroded from the land in the study area and of their content of heavy metals, nutrients, and pesticides. The dominant clay mineral in the four valleys of the Hawaii Kai area is montmorillonite. Kaolinite is present along the hill slopes and a mixture of both minerals is found on the valley floor. The combination of low rainfall and poor drainage typical of the area is favorable for the formation of montmorillonite. Kaolinite is found where rainfall is higher and drainage better. It is presumably transported onto the valley floor by erosional processes and surface runoff. Tuff along the western slopes of Koko Head crater consists mostly of amorphous materials and some nonclay materials, such as augite, zeolites, and calcite. Most of the fill land areas consist of montmorillonite. The mud samples from Kuapa Pond (Fig. 3.1) and Maunalua Bay are also mostly montmorillonite. Calcareous sand is the major sediment type in the bay, where patches of mud are also present.

Results of the analyses of sediment samples secured at all seven sampling stations and assayed for nutrients, heavy metals, and pesticides are tabulated in Table 3.6. Lead, copper, zinc, chromium, and nickel were all found in significant quantities, while cadmium and mercury were present at fairly low levels. Although these metals, as well as nutrients, were of the same order of magnitude as that observed at Kahana Bay, in every case the concentrations found in Maunalua Bay sediments were greater by at least a factor of 1.2 (Table 3.7).

Of special interest are the pesticide levels found in Maunalua Bay, also shown in Table 3.7, which were at least an order of magnitude greater than the Kahana Bay sediments. This readily reflects the effects of urban development in a coastal area.

Studies of Biota

To explore the biota of Maunalua Bay, a biological survey was made for QCW project in 1972. Two sites were selected at Station 6 (Fig. 3.2). One, designated as Station 6a, was located in about 8 meters of water and about 100 meters from the shoreline within a fairly persistent plume of turbid water extending from within the east end of Maunalua Bay and along the shoreline around Koko Head out to Station 6. The second site, designated as Station 6b, was located about 200 meters from the shoreline cliff

TABLE 3.6. SEDIMENT ANALYSES, HAWAII KAI, MAUNALUA BAY JULY 1972 TO MAR. 1973.

STATION NO.	Pb ppm	Cu ppm	Zn ppm	Cd ppm	Hg ppm	Cr ppm	Ni ppm	DIELDRIN ppt	DDE ppt	DDT ppt	α CHLORDANE ppt	γ CHLORDANE ppt	DDD ppt	TOTAL ORGANOCHLORINES ppt	T-N ppm	T-P ppm	T-K ppm
SAMPLING DATE 07/15/72																	
1	20.1	85.3	74.2	ND	0.34	91.0	184.6	761	ND	ND	9570	8760	ND	19091	894	892	3060
2	26.0	62.5	64.4	ND	0.22	114.6	108.2	208	ND	205	544	315	ND	1070	2515	616	3762
3	29.3	9.8	17.5	ND	0.05	20.5	88.6	73	26.5	229	109	100	ND	464	516	582	1004
4	33.7	12.8	21.8	ND	0.04	22.9	77.2	1367	ND	1396	506	279	ND	3348	399	542	968
5	15.7	5.5	9.6	ND	0.03	12.4	21.5	93	ND	33	65	57	ND	248	745	451	543
7	22.5	2.7	2.8	ND	ND	13.0	22.6	30	ND	38	51	42	ND	161	680	697	497
SAMPLING DATE 09/14/72																	
1	23.0	78.3	75.6	0.3	0.05	56.5	121.8	860	ND	367	478	320	ND	1825	1451	320	4248
2	26.6	53.2	60.2	0.9	0.09	45.5	127.5	381	ND	364	529	296	ND	1170	1254	547	3719
3	25.5	7.8	15.7	1.2	ND	13.2	48.9	159	ND	683	243	197	ND	1282	261	514	846
4	34.4	46.2	59.7	ND	0.37	40.3	84.6	331	ND	645	253	191	ND	1420	1491	651	2805
5	20.5	3.2	21.8	0.2	0.02	4.9	20.5	50	ND	156	ND	ND	ND	206	414	472	493
7	17.1	--	48.0	ND	0.04	29.1	62.0	112	ND	264	424	382	ND	1182	910	680	3190
SAMPLING DATE 10/25/72																	
1	37.2	120.8	105.4	ND	2.04	75.0	167.2	1628	119	295	1500	1020	ND	4634	2121	353	4477
2	39.6	62.8	82.0	ND	0.83	52.5	87.3	359	93	599	3358	1090	ND	3471	1036	537	3974
3	37.4	11.4	31.3	5.6	0.08	14.6	72.7	55	204	628	182	175	ND	1244	219	503	1020
4	46.2	19.2	29.1	9.7	0.22	26.3	71.1	913	196	5550	1060	718	ND	8236	555	512	527
5	36.9	8.5	14.3	5.5	0.08	12.8	32.2	ND	ND	ND	ND	ND	ND	ND	424	511	497
7	32.9	39.0	62.5	5.5	0.57	28.3	93.6	55	30	107	395	324	ND	919	193	850	4733
SAMPLING DATE 11/17/72																	
1	38.5	104.1	108.8	ND	0.55	67.2	149.2	3160	580	5030	2660	1800	ND	13310	1146	354	4713
2	42.2	96.4	89.3	1.4	0.39	63.5	151.3	1230	395	ND	1550	1000	ND	3875	1254	598	4609
3	34.5	11.9	18.0	2.6	0.10	16.6	103.3	2280	90	212	473	316	ND	3371	167	517	765
4	35.2	12.4	23.1	2.5	0.07	22.1	89.2	91	18	265	104	74	ND	550	370	608	1249
5	58.2	69.5	72.2	1.6	0.20	85.2	110.4	710	256	3030	700	718	ND	7414	1408	698	3622
7	29.8	34.4	61.1	1.7	0.30	42.0	208.9	ND	ND	130	ND	ND	ND	150	866	680	4703
SAMPLING DATE 12/07/72																	
1	28.0	182.4	100.4	3.2	0.16	82.2	196.2	358	209	290	1580	1025	354	3496	955	415	4147
2	50.7	70.7	88.6	1.9	ND	74.9	137.0	ND	168	218	1050	760	278	2424	1058	596	4000
3	27.8	9.7	72.6	3.5	0.14	33.7	149.5	ND	238	410	335	587	128	1418	173	508	2159
4	58.3	38.8	104.0	2.5	0.14	92.0	98.3	ND	139	1260	1090	753	268	3510	1005	663	2711
5	32.7	29.3	34.9	3.4	ND	37.4	40.3	ND	292	1055	535	299	78	2055	673	474	1828
7	20.6	37.8	69.4	1.0	0.04	43.8	161.0	ND	ND	309	ND	ND	ND	309	228	1029	5769
SAMPLING DATE 01/19/73																	
1	31.1	101.7	94.4	0.4	0.5	87.8	145.7	2275	295	967	1250	1275	ND	5042	1077	436	4084
2	35.8	74.2	75.3	0.4	0.2	80.1	123.7	416	180	582	573	508	ND	2259	1067	669	4385
3	46.8	15.0	25.4	2.2	0.1	16.5	88.5	72	91	105	114	97	ND	559	169	648	484
4	45.7	8.4	23.7	0.5	0.1	27.2	149.2	1012	ND	155	ND	ND	ND	1167	293	590	761
5	48.4	58.1	70.4	1.1	0.2	79.6	94.6	272	183	959	257	235	ND	1906	1482	757	3107
7	33.5	31.7	56.3	ND	0.2	53.9	98.4	208	ND	3088	ND	ND	ND	1296	474	1040	4441
SAMPLING DATE 02/17/73																	
1	55.2	117.0	90.3	2.3	0.4	81.3	152.0	2750	960	1028	3720	2686	ND	11058	1120	595	4482
2	23.3	68.1	65.0	1.7	0.3	82.9	96.5	195	525	866	254	254	ND	2094	1110	218	2180
3	13.4	12.4	26.2	2.4	0.1	24.6	111.4	440	216	680	740	653	ND	2729	279	659	827
4	29.8	18.4	18.7	2.6	ND	20.9	89.4	166	ND	95	136	155	ND	556	214	610	726
5	55.0	53.5	53.6	2.0	0.1	69.0	100.0	184	ND	2280	ND	ND	ND	2464	1164	606	2275
7	28.4	35.5	59.5	1.8	2.2	56.4	203.9	39	42	232	232	216	ND	761	246	799	2485
SAMPLING DATE 03/27/73																	
1	21.9	90.7	91.6	2.7	0.14	101.1	79.8	3056	927	752	3611	2575	ND	10871	782	381	4255
2	53.6	76.2	78.8	3.1	0.06	112.6	115.4	1018	555	743	1628	1476	ND	5420	1179	701	4721
3	29.4	12.9	68.8	1.9	0.01	20.4	127.5	141	155	434	206	190	ND	1106	299	665	1102
4	36.6	15.0	20.6	2.3	0.01	17.8	64.4	4839	108	269	269	183	ND	5668	318	665	940
5	40.8	53.5	64.2	2.4	0.08	72.9	82.8	1743	625	7105	460	568	ND	10502	1262	754	2705
7	26.0	42.6	66.0	3.0	ND	36.7	170.7	ND	ND	ND	ND	ND	ND	ND	387	1135	5634

TABLE 3.7. HEAVY METALS, NUTRIENTS, AND PESTICIDES CONTENT OF SEDIMENTS, KAHANA STREAM, KAHANA BAY, HAWAII KAI MARINA, MAUNALUA BAY.

PARAMETERS	KAHANA STREAM	KAHANA BAY	HAWAII KAI MARINA	MAUNALUA BAY
Pb ppm	19.9	27.9	32.9	33.6
Cu ppm	82.7	13.1	52.2	33.8
Zn ppm	57.7	17.7	58.1	47.0
Cd ppm	0.7	1.3	1.8	1.8
Hg ppm	0.07	0.11	0.23	0.24
Cr ppm	103	20.5	52.9	41.1
Ni ppm	217	40.3	113.7	95.3
T-N ppm	356	379	801	722
T-P ppm	850	443	547	726
T-K ppm	465	506	2589	2908
DIELDRIN ppt	14	8	921	219
DDE ppt	6	6	200	90
DDT ppt	167	96	766	1174
α CHLORDANE ppt	10	8	1147	182
γ CHLORDANE ppt	10	8	922	178
DDD ppt	--	--	*	*
TOTAL ORGANO-CHLORINE ppt	207	126	3956	1843

* DETECTED ON ONLY ONE DAY

outside the turbid water plume at a depth of 12 meters.

At both locations percent substrate cover was estimated using a photographic transit technique. A rectangular metal frame supporting a Nikonos camera and a Honeywell 770 electronic flash unit in an Ikelite underwater housing was used. The frame positions the camera a fixed distance from the bottom so that a uniformly illuminated area of 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 color photo transparency is then projected onto a piece of white cardboard ruled off in decimeters. Percent substrate cover in each decimeter is estimated. These estimates are then summed and averaged. This technique also produces a permanent photographic record of the bottom.

At site 6b dry weight biomass of benthic algae was determined. All benthic algae was removed from four 0.25 m^2 quadrates, randomly selected along a 20 m transect line. Wet and dry weights for each sample were determined. Samples were dried in a 100° F oven for 24 hours.

Sea urchin density was estimated at each site, 6a and 6b, using the Batchelor method (1971). Horizontal visibility was measured along a transect line laid on the bottom. One diver observed the disappearance of a second diver as he swam away along the line.

Primary productivity at Station 6b was determined using a light-dark bottle technique. Two 1-liter capacity bottles, one clear and one painted black, were filled with sea water at a depth of 9 m, sealed and attached to anchors and floats to suspend them 1 m from the bottom. A third bottle was filled, brought to the surface where dissolved oxygen was fixed to be later measured by the Winkler technique. After 24 hours the light and dark bottles were removed and similarly treated.

The marine zone at station 6 was found to begin at a sheer rock cliff which drops immediately to a depth of about 5 meters to a rather flat bottom. Shallow, sand-filled canyons of 1- to 2-meters depth occasionally cut through the region. The coral covered bottom slopes gently seaward to a depth of about 8- to 10- meters and about 100 meters from shore. At greater distances and depths from shore, the bottom composition abruptly changes to coarse, clean white sand with occasional rock outcrops which are covered with the benthic alga, *Dictyopteris* sp.

In the vicinity of Station 6a, large mounds with sheer vertical faces and flat tops extend from 8-meters depth to within 3- to 4-meters of the surface. A large variety of invertebrate fauna were associated with the vertical faces of these mounds.

The bottom at Station 6a was abundantly covered with live coral, predominantly *Porites lobata*, and a few heads of live *Pocillopora meandrina*. A black encrusting sponge tentatively identified as *Haliclona melanadocia* was also common.

Station 6b was within the deeper zone of dense benthic algal growth. Results of the photographic transect to determine percent algal cover are shown in Table 3.8. Algal biomass determinations are shown in Table 3.9.

TABLE 3.8. PERCENT OF THE BENTHIC ALGA *Dictyopteris* sp. AT STATION 6b.

NUMBER PHOTOS	TOTAL AREA	MEAN % ALGA COVER	RANGE
8	5.33 m^2	63%	56% - 69%

NOTE: PHOTOGRAPHIC TRANSECT TECHNIQUE MEASUREMENT, AUGUST 9, 1972.

TABLE 3.9. BIOMASS OF THE BENTHIC ALGA *Dictyopteris* sp. REMOVED FROM FOUR 0.25 m^2 QUADRANTS.

QUADRANT	WET WEIGHT (g)	DRY WEIGHT (g)
1	184.0	35.0
2	83.2	29.5
3	282.5	39.5
4	218.6	36.0
AVERAGE	192.1	35.0

NOTE: RANDOM SELECTION ALONG A 20 m TRANSECT, JULY 26, 1972.

Horizontal visibility at Station 6a varied from as little as 5 m to over 20 m during the one month study period. Horizontal visibility at tation 6b was consistently 30 m or greater. These results reflect the variability in location of the turbid water plume in this region.

Sea urchin density at Station 6a and 6b are shown in Table 3.10.

TABLE 3.10. DENSITY OF SEA URCHINS AT STATION 6A AND 6B. 24 AND 26 AUGUST, 1972.

	STATION 6a		STATION 6b	
	DENSITY/m^2	$\frac{\Sigma r_1}{\Sigma r_2}$	DENSITY/m^2	$\frac{\Sigma r_1}{\Sigma r_2}$
Tripneustes gratilla	.47	.91	3.55	1.0
Echinothrix calamaris	.20	1.5	--	--

r_1 = DISTANCE FROM TRANSECT POINT TO NEAREST SEA URCHIN (a)

r_2 = DISTANCE FROM SEA URCHIN (a) TO ITS NEAREST NEIGHBOR

$N(r_1, r_2)$ = 25 FOR EACH DENSITY ESTIMATE

$\frac{\Sigma r_1}{\Sigma r_2}$ = .88 INDICATES RANDOM DISTRIBUTION

$\frac{\Sigma r_1}{\Sigma r_2}$ > .88 INDICATES AGGREGATION

$\frac{\Sigma r_1}{\Sigma r_2}$ < .88 INDICATES EVEN DISTRIBUTION

Tripneustes gratilla was common at both stations but more abundant in the algal flat. *Echinothrix calamaris* was less abundant in the region of coral flat and completely absent in the algal flat. These distributions possibly reflect differences in food preference.

The results of population studies of fish and invertebrates within the study area are being compiled. Other QCW studies of Maunalua Bay are still in progress. Consequently, it is too early to make a final evaluation of the effects of the Hawaii Kai type of urban development upon coastal water quality.

WAIKIKI BEACH

Nature of Situation

The Waikiki Beach area of Oahu is one in which recreation is the principal consideration in decisions involving constraints upon urban land use; its use is a major aspect of urbanization that in itself might degrade the quality of coastal water. The beach and the inshore waters which it fronts represent, perhaps, a unique situation in Hawaii, although in years to come similar situations may develop elsewhere in the state.

The situation at Waikiki Beach affords an 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 any other quality factors which may migrate into the area from elsewhere. Some urgency to conduct such a study derives from persistent evidence from the past that coliform counts at various sectors of the beach are occasionally above the limits set for bathing beach waters by the State Department of Health.

Originally, Waikiki Beach was a barrier beach between the Ala Wai-Moiliili duckponds and swamps and the ocean (Moberly and Chamberlain 1964). Interception of surface runoff from Manoa and Palolo streams and adjacent areas by the Ala Wai Canal, and drainage of the swamps into the canal, changed the character of the area significantly. The drainage of surface water into the coastal water at the beach was especially reduced. Thus, in recent years Waikiki Beach has become an artificial beach checked by groins and a seawall and augmented by imported sand. Typical artificial sections are Kuhio Beach, near the center of Waikiki, and a new eastward extension of this beach.

The central reef area off Kuhio Beach and adjacent hotels has been largely cleared of coral heads for the safety and convenience of beach users. 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 Gray's Beach and the Halekulani Hotel.

Figure 3.3 shows the general aspect of Waikiki Beach along with transect lines used by the Corps of Engineers in studies of the area. Of particular note is that the beach area is bound on the east by the relatively pristine waters off Diamond 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 runoff from a large urban land area

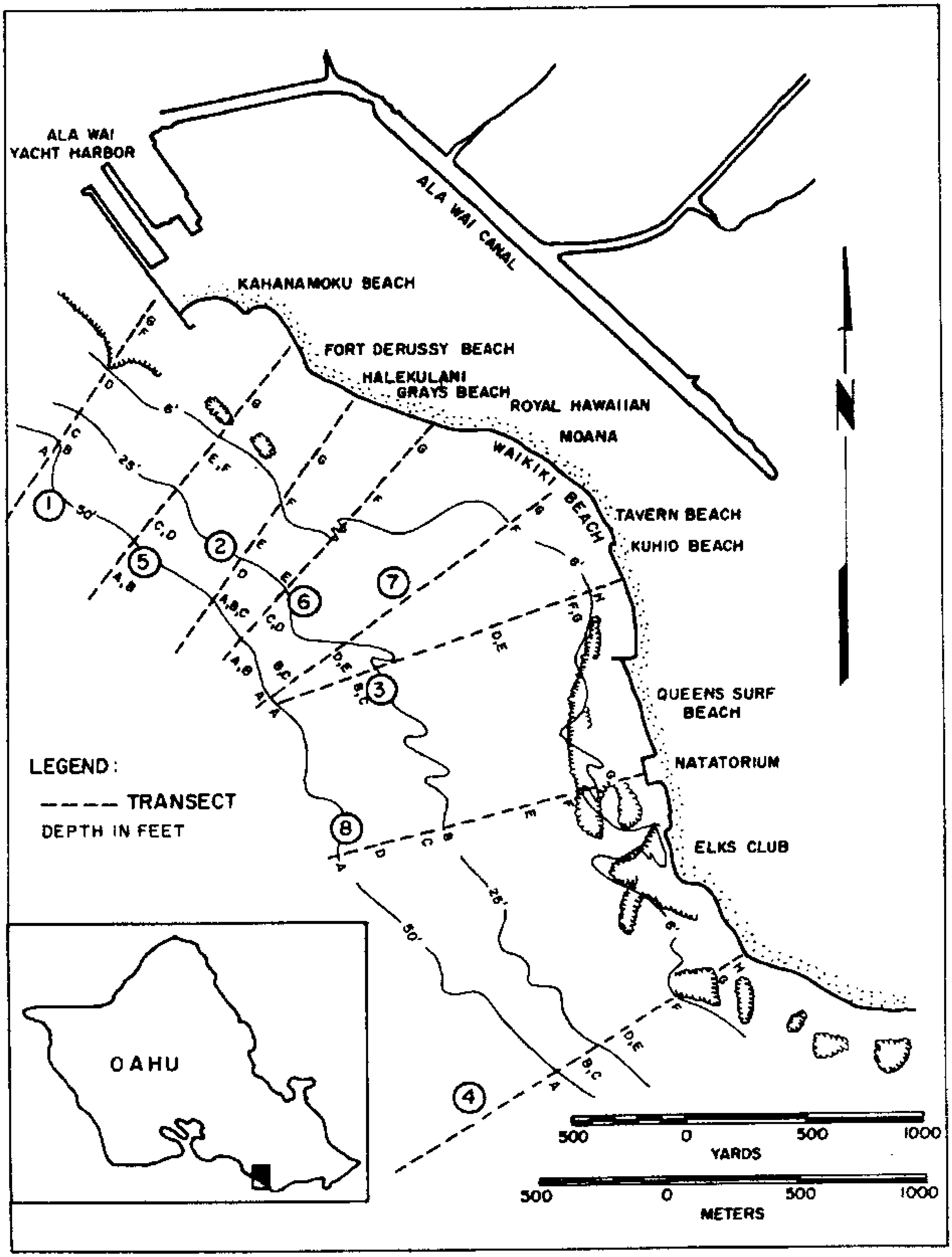


FIGURE 3.3. SAMPLING STATION TRANSECTS AT WAIKIKI BEACH.

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 the effects of increased use and density.

Water Quality at 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 from the Elks Club on the east to Kahanamoku Beach on the west (Fig. 3.3). Results of these analyses, summarized in Table 3.11, show that about 4.5 percent of

TABLE 3.11 ANALYSES OF COLIFORM DATA OF EIGHT STATIONS, WAIKIKI BEACH. 1969-1971.

STATION LOCATION	TOTAL NUMBER OF SAMPLES TAKEN 1969, 1970, 1971	NUMBER OF SAMPLES $\geq$ 1000 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
WAIKIKI NATATORIUM	92	2
ELKS CLUB	164	2

1285 samples taken at eight stations during the 3-year period between 1969 to 1971 exceeded the maximum coliform concentrations of 1000/100 $m\ell$ standard for Class A waters. Compilation of more recent data (for years 1972 and 1973) has not yet been completed.

An extensive study to determine the movement of water, shifting of sands, and wave front patterns off Waikiki Beach under various weather, wave, and tide conditions was conducted by Keith E. Chave of the University of Hawaii, Department of Oceanography, for the U.S. Army Corps of Engineers. Although the basic objective of the Chave project was concerned with the physical aspects of the environment, cooperation between the Chave project and the Coastal Water Quality group was arranged to obtain analytical data on the quality of ocean water and sediments. Tables 3.12 and 3.13 present the results of analyses of surface water and sediments samples taken along the transects (TR-1 to TR-8) of Figure 3.3.

From Table 3.12, total coliform densities were negligible when com-

TABLE 3.12. SURFACE WATER QUALITY ANALYSIS OF EIGHT STATIONS, WAIKIKI COASTAL WATER AREA.

TRAN-SECT	pH, UNITS									DISSOLVED OXYGEN, mg/ℓ								
	01/13/72			03/24/72			09/25/72			03/29/72			09/25/72			03/13/73		
	SOUNDING (FT)									SOUNDING (FT)								
	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	8.31	8.28	8.34	7.85	7.20	7.05	6.20	6.40	6.40	7.40	7.50	7.40
TR-2	8.40	8.35	8.40	8.19	8.20	8.19	8.24	8.28	8.30	7.30	7.20	7.35	6.80	6.10	6.50	7.40	7.40	7.50
TR-3	8.20	8.35	8.35	8.19	8.22	8.20	8.29	8.28	8.25	7.35	7.20	7.30	7.00	6.80	7.00	7.50	7.00	6.80
TR-4	8.35	8.30	8.35	8.24	8.20	8.20	8.28	8.30	8.34	8.19	7.62	7.82	7.80	8.20	8.70	8.00	7.80	8.60
TR-5	8.40	8.30	8.35	8.20	8.21	8.22	8.30	8.27	8.34	8.05	7.40	7.10	7.30	6.00	6.60	7.80	8.00	7.40
TR-6	8.40	8.40	8.40	8.19	8.21	8.21	8.24	8.29	8.30	8.20	7.10	7.25	5.80	6.60	6.60	8.10	8.40	8.40
TR-7	8.25	8.45	8.35	8.21	8.18	8.21	8.26	8.28	8.28	8.20	6.90	7.10	6.30	6.40	6.80	6.90	8.40	8.40
TR-8	8.30	8.30	8.30	8.21	8.19	8.21	8.29	8.29	8.31	7.78	7.65	7.40	7.20	7.60	8.20	8.40	8.80	8.30

TRAN-SECT	TURBIDITY, FTU												TOTAL COLIFORM, MPN/100 ML								
	01/13/72			03/29/72			09/25/72			03/13/73			03/29/72			09/25/72			03/13/73		
	SOUNDING (FT)												SOUNDING (FT)								
	6	25	50	6	25	50	6	25	50	6	25	50	6	25	50	6	25	50	6	25	50
TR-1	4.10	2.30	0.90	0.34	0.36	1.05	1.00	0.32	0.34	0.25	0.60	1.70	0	0	0	0	1	0	3	3	3
TR-2	1.30	2.40	1.00	0.75	0.49	0.86	1.00	0.32	0.34	0.50	0.45	1.00	2	2	24	0	2	3	1	1	1
TR-3	3.00	3.80	1.00	1.00	0.36	0.22	0.33	0.24	0.20	0.80	0.80	1.10	38	5	11	1	1	2	0	1	2
TR-4	3.00	2.80	4.00	1.05	0.95	0.46	0.32	0.25	0.15	0.80	2.20	0.90	9	15	0	0	0	1	0	0	2
TR-5	1.70	2.40	0.50	0.63	0.34	0.45	0.45	0.35	0.12	1.80	0.70	1.00	0	1	0	2	0	0	0	1	1
TR-6	2.80	3.00	1.00	0.46	0.49	0.63	0.56	0.38	0.33	1.30	0.60	1.50	14	1	0	0	0	0	2	2	0
TR-7	2.70	2.40	0.80	0.80	0.36	0.69	0.20	0.29	0.24	1.00	3.40	1.00	5	1	0	0	0	1	1	1	4
TR-8	3.20	1.20	0.50	0.83	0.40	0.40	0.25	0.57	0.17	1.10	0.70	0.70	0	17	0	1	0	3	0	2	2

TRAN-SECT	SALINITY, $^{o}/_{oo}$						CHLORIDES, mg/ℓ					
	01/03/72			03/29/72			09/25/72			03/13/73		
	SOUNDING (FT)						SOUNDING (FT)					
	6	25	50	6	25	50	6	25	50	6	25	50
TR-1	32.8	--	26.0	33.4	33.4	33.0	18394	18094	18394	18540	18540	18540
TR-2	36.6	31.2	--	32.8	33.0	32.8	18394	18194	18394	18140	18360	18240
TR-3	35.0	33.0	--	32.2	33.0	33.0	20494	20594	20594	18440	18360	18360
TR-4	32.0	32.8	--	32.4	32.0	31.9	20494	20594	20594	18360	18360	18240
TR-5	32.4	31.2	--	32.5	32.4	33.0	20494	20594	20594	18620	18530	18530
TR-6	33.2	31.2	--	32.4	33.0	33.2	20694	20594	20594	18620	18530	18620
TR-7	33.2	33.0	--	32.2	32.8	32.8	18494	19094	17194	18720	18620	18620
TR-8	--	33.0	--	33.0	32.8	33.0	18394	18294	18294	18800	18620	18720

TABLE 3.12. SURFACE WATER QUALITY ANALYSIS OF EIGHT STATIONS, WAIKIKI COASTAL WATER AREA (CONTD).

TRAN-SECT	TOTAL NITROGEN, mg/ℓ											
	01/13/72			03/29/72		09/25/72			03/13/73			
	SOUNDING (FT)											
	6	25	50	6	25	50	6	25	50	6	25	50
TR-1	0.254	--	0.091	--	--	0.085	0.132	0.104	0.087	0.169	0.093	0.126
TR-2	0.174	0.793	0.061	--	--	0.044	0.069	0.067	0.126	0.162	0.128	0.135
TR-3	0.267	0.181	0.115	--	--	0.057	0.071	0.061	0.083	0.112	0.105	0.097
TR-4	0.255	0.266	0.063	--	--	0.081	0.161	0.126	0.105	0.123	0.122	0.162
TR-5	0.594	0.546	0.041	--	--	0.048	0.201	0.102	0.053	0.100	0.097	0.110
TR-6	0.308	0.812	0.043	--	--	0.078	0.101	0.125	0.102	0.100	0.094	0.120
TR-7	0.078	0.704	0.045	--	--	0.084	0.072	0.186	0.129	0.153	0.154	0.135
TR-8	0.220	--	0.075	--	--	0.037	0.114	0.141	0.105	0.270	0.109	0.119
TRAN-SECT	TOTAL PHOSPHORUS, mg/ℓ											
	01/13/72			03/29/72		09/25/72			03/13/73			
	SOUNDING (FT)											
	6	25	50	6	25	50	6	25	50	6	25	50
TR-1	0.026	--	0.039	--	--	0.038	0.040	0.042	0.036	0.030	0.030	0.031
TR-2	0.032	0.031	0.042	--	--	0.025	0.042	0.037	0.039	0.030	0.030	0.030
TR-3	0.113	0.017	0.025	--	--	0.030	0.037	0.037	0.037	0.027	0.027	0.029
TR-4	0.032	0.041	0.028	--	--	0.032	0.040	0.037	0.036	0.026	0.026	0.034
TR-5	0.024	0.054	0.021	--	--	0.045	0.036	0.040	0.034	0.034	0.032	0.033
TR-6	0.014	0.026	0.017	--	--	0.029	0.034	0.038	0.034	0.029	0.032	0.033
TR-7	0.011	0.035	0.025	--	--	0.023	0.036	0.051	0.036	0.030	0.031	0.034
TR-8	0.029	0.048	0.018	--	--	0.030	0.040	0.074	0.035	0.034	0.033	0.032

pared to a standard permitting a maximum of 1000/100 mℓ. These counts ranged from 0 to 38 per 100 mℓ. However, the State Health Department reported MPN results ranging from 0 to 46,000 per 100 mℓ, with 4.5 percent of the 1285 samples having an MPN greater than 1000 per 100 mℓ, see Table 3.11. In either case, it appears that the Waikiki Beach waters generally conform to Class A bacteriological standards.

The water along all transects was clear, with greater than 85 percent of the samples analyzed having a turbidity of less than 2 FTU's. Dissolved oxygen concentrations ranged from 5.8 to 8.8 mg/ℓ with a mean of 7.4 mg/ℓ. Frequency analysis indicated dissolved oxygen concentrations to be greater than 6.0 mg/ℓ for more than 97 percent of the time, well above the minimum 5.0 mg/ℓ Class A Standards. Salinity and pH were observed to be well within normal limits, with a mean salinity of 32.8 percent and a mean pH of 8.3.

Nutrient analyses were limited to total nitrogen and total phosphorus and, in general, standards of 0.15 mg/ℓ total nitrogen were met whereas values of 0.025 mg/ℓ total phosphorus were not met. Total nitrogen was generally lower at lower depths and on every sampling day the arithmetic mean for the 50-ft (15.24 m) depth conformed with the Class A Standard of 0.15 mg/ℓ. However, total nitrogen at all depths ranged from 0.037 to 0.812 mg/ℓ with an arithemtic mean of 0.157 mg/ℓ, but distribution of these values was abnormal and values less than 0.15 mg/ℓ were observed over 74 percent of the time. This abnormality was due to the Jan. 13, 1972 samples in which nitrogen in the shallower depths was significantly higher than that observed for the three other sampling dates. Inasmuch as this difference cannot be rationally explained, it may well be valid to establish background water quality based on measurements of central tendencies such as geometric means, rather than arithmetic means. The geometric mean for total nitrogen at Waikiki Beach is 0.140 mg/ℓ which is well within the limits established by the Hawaii State Health Department for Class A waters. On the other hand, the arithmetic mean of 0.157 mg/ℓ exceeds this standard. This illustrates the need for specifying the method of establishing the general characteristics in water quality studies, especially when these assessments deal with water quality standards.

Levels of total phosphorus ranged from 0.011 to 0.074 mg/ℓ, with an arithmetic mean of 0.033 mg/ℓ and a geometric mean of 0.032 mg/ℓ, both exceeding the Class A Standards. Furthermore, the Class A Standard of 0.025 was met only 14 percent of the time. Inasmuch as no discernible effect on Waikiki Beach water quality by external factors (such as point discharges of pollutants) could be detected, the near-shore waters in this study area were considered to be affected solely by the intense recreational activity in Waikiki. On the other hand, the general characteristics of this water are such that no specific water quality effect could be attributed solely to the presence of large numbers of people in a relatively small area of coastal water. Therefore, it can be assumed that the observed levels of total phosphorus are natural levels and it would appear that for total phosphorus, the Class A Standard as set by the Hawaii State Health Department, is too stringent.

Quality of Sediments, Waikiki Beach

Analyses of sediments at Waikiki Beach are summarized in Table 3.13.

In nitrogen, phosphorus, and potassium the sediments at Waikiki are comparable to those observed previously in north Kauai (Lau 1972, Table 3.17). Of the heavy metals, lead content of the Waikiki samples is similar to that found in coastal sediments at north Kauai, but about 1.5 to 2 times that reported for the one observation at the assumed pristine area of Kahana Bay. On the other hand, the cadmium 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 chromium.

Biota at Waikiki Beach

Studies of biota at Waikiki Beach were made by the University of Hawaii (Chave et al. 1973) in cooperation with the QCW Project and as part of a Waikiki Beach Erosion Project supported by the U.S. Army Corps of Engineers. Data were taken along transect lines shown in Figure 3.3. Results presented in greater detail in the Chave report are summarized in the following paragraphs.

DISTRIBUTION AND ABUNDANCE OF ALGAE. Algal distribution and abundance were assessed by measuring the percent cover and the dry weight/unit area at each hard-bottom station. The cover was higher at the 12 hard-bottom stations inside the reef crest, 36.1 percent (avg.) than at the 27 hard-bottom stations outside the crest, 22 percent (avg.). Along the shore, percent cover was also almost twice as high on transects 3, 8, and 4 (southeast of Kuhio Beach) as on the other transects (Fig. 3.3).

The number of species of algae was also higher than inside the reef crest (avg. ~ 12.4) than outside (avg. ~ 7.2), but the values were not particularly higher on lines 3, 8, and 4. Values for diversity were highest on the reef flat, and one of the lowest values also was found on the reef flat at Station 3H near the Kapahulu storm drain. Diversity tended to be lower on lines 3, 4, and 5 than on other lines.

Algal dry weight varied greatly between stations. However, it was definitely greater inside the reef crest (avg. of 117.8 gm/m^2 for 12 stations) than outside (21.54 g/m^2, 30 stations) and greater on the slope than on the flat bottom. Along the shore (outside the reef crest), values tended to be low on transects 1, 5, 2, and 7 (the northwest end of the study area) and high on lines 6, 3, 8, and 4 (southeast end of the area).

DISTRIBUTION AND ABUNDANCE OF CORALS. One of the most striking patterns of distribution and abundance determined in this survey is that of corals. Coral abundance (percent cover) was generally greater on lines 1, 5, 2, and 6, the northwest lines, than on lines 7, 3, 8, and 4, the southeast lines. The abundance of species followed this same pattern.

TABLE 3.13. ANALYSIS OF SEDIMENTS, WAIKIKI BEACH 1972 .

NUTRIENTS AND HEAVY METALS	STATION NO.																					
	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

SOURCE: LAU 1972.
ND = NOT DETECTABLE

NUMBER OF INVERTEBRATE SPECIES. Due to the large range in size and abundance of invertebrates and the subsequent necessity of using three methods to assess their abundance, the total number of individuals per station was not calculated nor was the measure of species diversity based on information theory, H'; rather the total number of species at each station found by all methods was used as a measure of species diversity. Data on the number of species on line 1 can't be directly compared with data from the other seven lines of the original survey because only data for the point-quadrat method and some casual observations on presence and absence of species were made along line 1. So that some comparison of line 1 with other lines can be made, the number of species found by the point-quadrat method on line 1 has been tabulated.

Sand stations contained about a tenth as many species as did hard-bottom stations. Line 3 shows somewhat fewer species on hard substrate than do the other six comparable lines. The number of species on the reef flat, reef slope, and on the flat bottom at 50 ft (15.24 m) are approximately equal.

Since the total number of invertebrate species seemed very similar in all reef zones and on each line, the data were grouped into the major invertebrate phyla represented in the samples and the species distribution pattern in these phyla was examined. The number of species in each phylum at each station is the sum of the species found by sampling techniques 1.1, 2, 4 and 6, except in the case of line 1.

Species of the phylum Mollusca were most abundant at deep stations on hard substrates and were almost twice as abundant on line 8 as on other lines. Echinodermata species were equally abundant in all zones -- more abundant on hard surfaces than on sand bottoms -- and almost twice as abundant on lines 2 and 6 as on the other lines.

Corals predominated at the deep-water stations, especially near the Ala Wai Canal, sponges predominated at the deep stations off Diamond Head (although invertebrates were generally less abundant on line 4), and echinoderms tended to be dominant on reef-flat stations and on line 8.

DISTRIBUTION AND ABUNDANCE OF FISHES. The data can be summarized as follows:

Reef Zones	Number of Individuals	Number of Species	Diversity
Reef zones	19	17	21
Substrate types	20	18	18
Transect line	20	17	21

The number of species is roughly similar in the three reef zones. The mean number of species on each of the eight lines is also roughly similar, but values for the stations are highly variable. If the stations are classified by substrate types, it can be seen that only two to three species are found on sand bottoms at all depths, about 17 on flat limestone bottoms, and between 25 and 30 species on bottoms with live coral.

The average number of individuals per count was greater on the reef slope and deep flat than on the reef flat. There were approximately twice as many individuals per count (108 and 100 respectively) on bottoms with live coral as on any other substrates; the fewest (3.6) were on sandy bottoms. There were generally twice as many individuals near the Ala Wai Canal end of the survey area (lines 1, 5, 2, 6, and 7) as on the other three lines; presumably due to the greater incidence of coral on the former lines.

Species diversity measures summarize the information of both the number of species and the number of individuals in each sample. Diversity was highest in areas of live coral and lowest on sand, and increased progressively from the reef-flat habitat to the reef slope to the deep flat. Diversity on hard substrates did not show any particular pattern or gradient along the shore.

The wrasse *Stethojulis balteatus* and the surgeonfish *Naso unicornis* were most common on the reef flat. The reef slope lines 1, 5, 2, and 6 were dominated by the wrasse *Thalassoma duperreyi*, which is mainly associated with coral, or by the sand-dwelling form *Xyrichthys leclusei*. The other lines were dominated by various members of five fish families, mainly wrasses. The most abundant species on the flat bottom were mainly the deeper water, sand- and rubble-dwelling fishes: *Parapercis schauinslandi*, *Parapeneus pleurostigma*, *Cheilinus rhodocrous*, and *Pseudojuloides cerasinus*.

Analysis of data from the point-quadrat samples of algae (excluding sand stations) showed that stations fell into three fairly distinct groups, indicating the presence of three fairly distinct communities; these roughly correspond to the division of stations into three zones created at the beginning of the study: a reef-flat community, a reef-slope community, and a deep-water community.

Analysis of the data from the fish counts indicated the existence of two fairly distinct communities; one composed of stations from deep-water sites containing large amounts of coral, and one composed of stations on the reef flat.

SUMMARY. The most marked patterns of distribution and abundance observed in this study were revealed by the measures of coral cover, abundance of fishes and fish species, and algal cover. The first three of these measures show a high degree of correlation; the values are all high at the stations outside the reef crest on lines 1, 5, 2, and 6. This pattern is especially marked in the case of corals; all values of more than 10 percent cover occur outside the reef crest on lines 1, 5, 2, and 6.

Percent cover of algae showed almost the opposite pattern; values were high inside the reef crest and on lines 3, 8, and 4. Dry weights of algae showed high values on or near the reef flat on all lines.

Sponges, echinoderms, and molluscs were common on lines 8 and/or 4 and on the reef-flat stations of most lines. This pattern parallels that of algal distribution.

Values of every measure of abundance and diversity of each group of organisms were considerably lower at sand substrate stations than at other substrates, while values of fish species and individuals were greatest at areas containing live coral. The abundance of invertebrate species did not seem to be consistently related to the presence of live coral.

Analysis of the species composition at the different stations indicates that in the case of both fishes and algae, stations could be grouped into a reef-flat community and a reef-slope community. There was a distinct flat-bottom community of algae, and the extent of the reef-slope community of fishes closely approximated areas of high coral abundance.

Conclusion

The waters off Waikiki Beach have been examined for various quality parameters over a period of 12 months by the QCW project staff. From the findings there is little evidence which would attribute any specific water quality effect solely to the presence of intense recreational activity at Waikiki. In general, the waters are clear and, with the exception of phosphorus, meet the standards set by the Hawaii State Health Department for Class A waters.

SANDY BEACH

Nature of the Situation

Sandy Beach represents another situation in which recreation is the principal beneficial use of a coastal water to be protected by decisions related to urban zoned land. The factors which characterize the situation, however, are distinctly different than those existing at Waikiki.

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 (631.8 ha) 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.

Urban population pressure against a recreational area was the principal factor in selecting the Sandy Beach situation for study by the QCW Project. Such pressure is exerted in two ways: 1) persistent proposals for intensive urban development of adjacent land, and 2) the anticipated growth of the Hawaii Kai area, the treated domestic sewage of which is discharged through an ocean outfall offshore from the beach area into water designated as Class A by the State Department of Health.

The general beach area, treatment plant site, and outfall location are presented as Figure 3.4 and the beach shoreline and profile as Figure 3.5. Although the area mauka of the beach in Kalama Valley has been zoned as an Urban District since 1964, it has been relatively undeveloped prior to 1972. The area has historically been in agricultural use, such as truck crop farming and swine and poultry production on land leased from the B. F. Bishop Estate. Since control of the area has passed to the Hawaii Kai Development Corporation, all the lessees have been relocated from the Valley preparatory to the development of the area for residential use or resort, or both.

The sewage flow to the Hawaii Kai treatment plant presently comes from residential areas as far west as Kulionou Valley and includes the presently developed Hawaii Kai units in the Kuapa Pond marinas and Hahaione, Kamilonui, Kalama, and Kamiloiki Valleys. The treatment plant went on line in 1966 as a primary facility with chlorination, discharging through a 1400-foot (426.72 m) outfall at a depth of 46 ft (14.02 m), using only four of the ten 8-inch (20.32 cm) diffuser ports constructed. The plant was converted to the activated sludge process in early 1972 at a design flow 3.1 mgd (11,733.5 m^3/day). The estimated sewage discharge for Sandy Beach by the year 2020 is 8.6 mgd (32,551.0 m^3/day).

Water Quality at Sandy Beach

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 by the QCW Project in early Janaury 1972. Available data were found (First Progress Report, 1972) 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. August 1970, monthly data collection was extended to such other water quality parameters as fecal coliform, total nitrogen, 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 above the discharge end of the existing outfall sewer. Water quality parameters observed included such physical factors as temperature, salinity, dissolved oxygen, clariy 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 total coliform detection in shoreline water samples definitely increased between 1963 and 1972-73. For example, of the 6 samples reported in 1963 none were positive, whereas in 1972-73 the frequency of positives in 44 samples was 50 percent. Reported fecal coliform concentrations were at levels below that of total

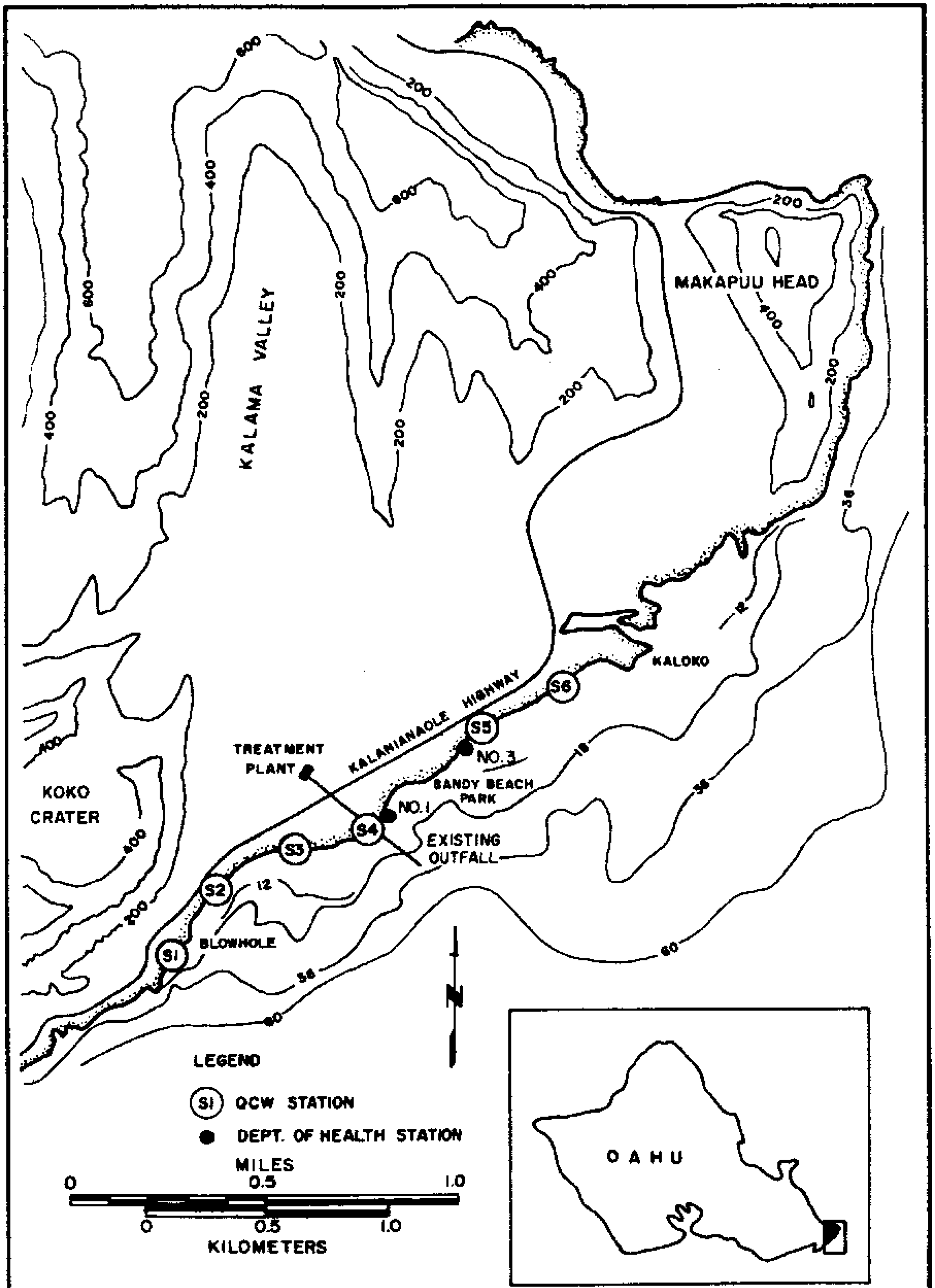
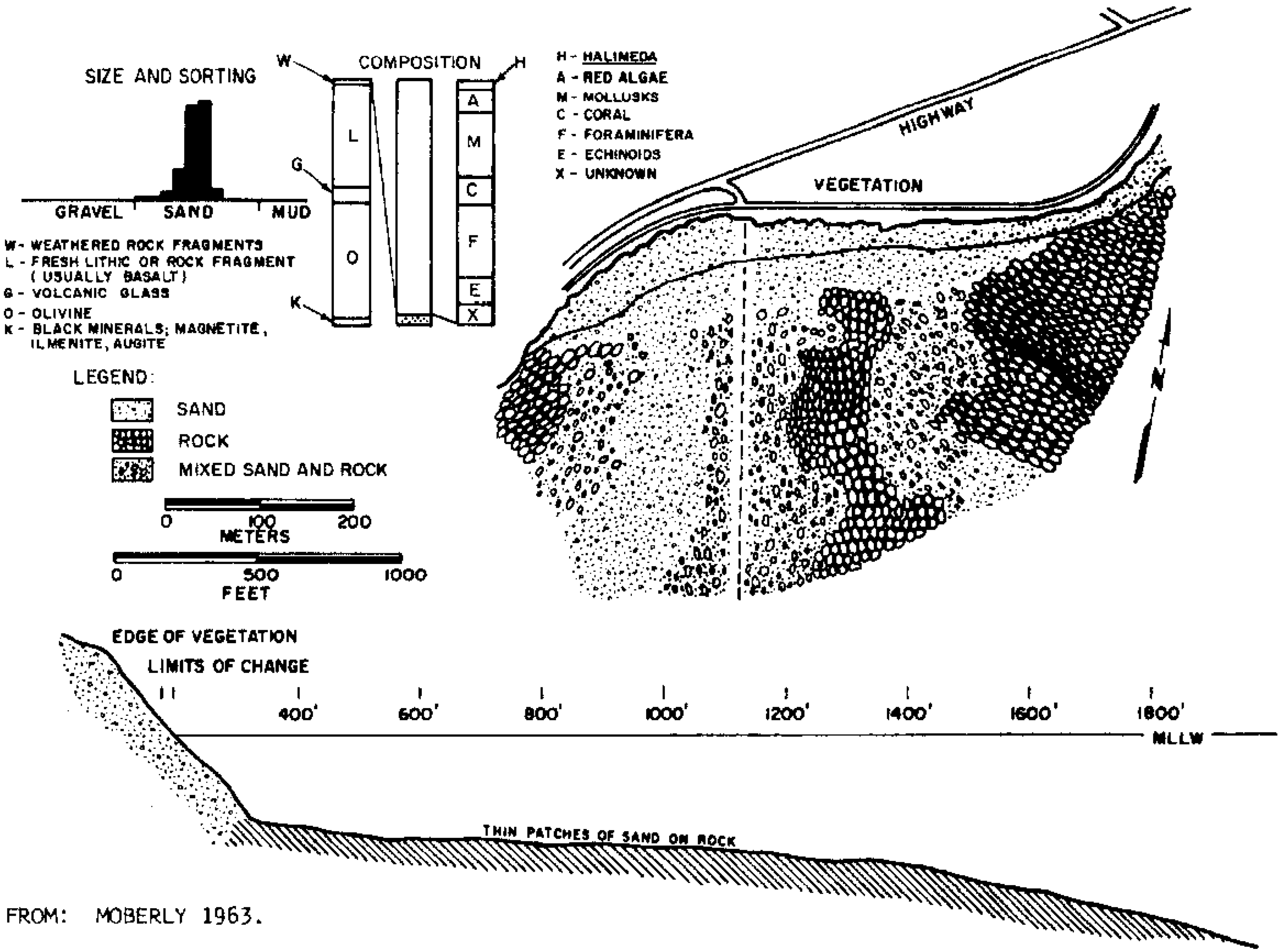


FIGURE 3.4. OUTFALL SEWER AND WATER SAMPLING STATIONS, SANDY BEACH.



FROM: MOBERLY 1963.

FIGURE 3.5. SHORELINE AND PROFILE, SANDY BEACH.

coliform.

b) In 5 of the 23 monthly samples taken in 1972-73, measured total nitrogen content in the shoreline samples exceeded state standards. One sample was equal to state standards (Fig. 3.6). Measured phosphorus in these same samples exceeded the standards only once (Fig. 3.7).

c) pH was above the state standard of 8.5 once in the 23 monthly samplings. (Fig. 3.8).

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. 3.9), none of the shoreline water quality parameters exceeded state standards. No similar current measurements for other months are available, but generalized probably current patterns are predominantly offshore.

The consulting firm of Sunn, Low, Tom & Hara, Inc. initiated a year-long 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 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.

With the availability of past WQPO and Health Department data, together with the Sandy Beach offshore study, the Coastal Water Quality Project control group decided 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 three shoreline 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 3.4 and designated as station numbers S1 to S6. The stations were selected to include the areas immediately adjacent to the outfall and also the areas north and south of the outfall. The photographic observations, begun in January 1972, were made on a monthly basis while the water quality observations were made on a quarterly basis for one year. The results of this one year survey are given in Tables 3.14, 3.15, and 3.16. The mean averages for each sampling day are given in Table 3.17, as well as the mean average of all samples analyzed.

In general, the waters off Sandy Beach are clear, with an average turbidity of 1 FTU. However, this parameter was observed to decrease from 0.8 to 0.4 FTU from July 1972 to January 1973. Average suspended solids was 26 mg/ℓ, and this parameter was observed to increase from 9 to 38 mg/ℓ during the same period. Volatile suspended solids likewise increased, as did total solids. One might associate an increase in these parameters to increased productivity. However, total volatile solids decreased during this same period and this might indicate something different. It might well be possible, therefore, that these increases in total and suspended solids were due to increased land clearing for domestic urban development in Kalama Valley during this period.

Associated with the decrease in total volatile solids was a similar decrease in organic carbon. These decreases might very well be the result

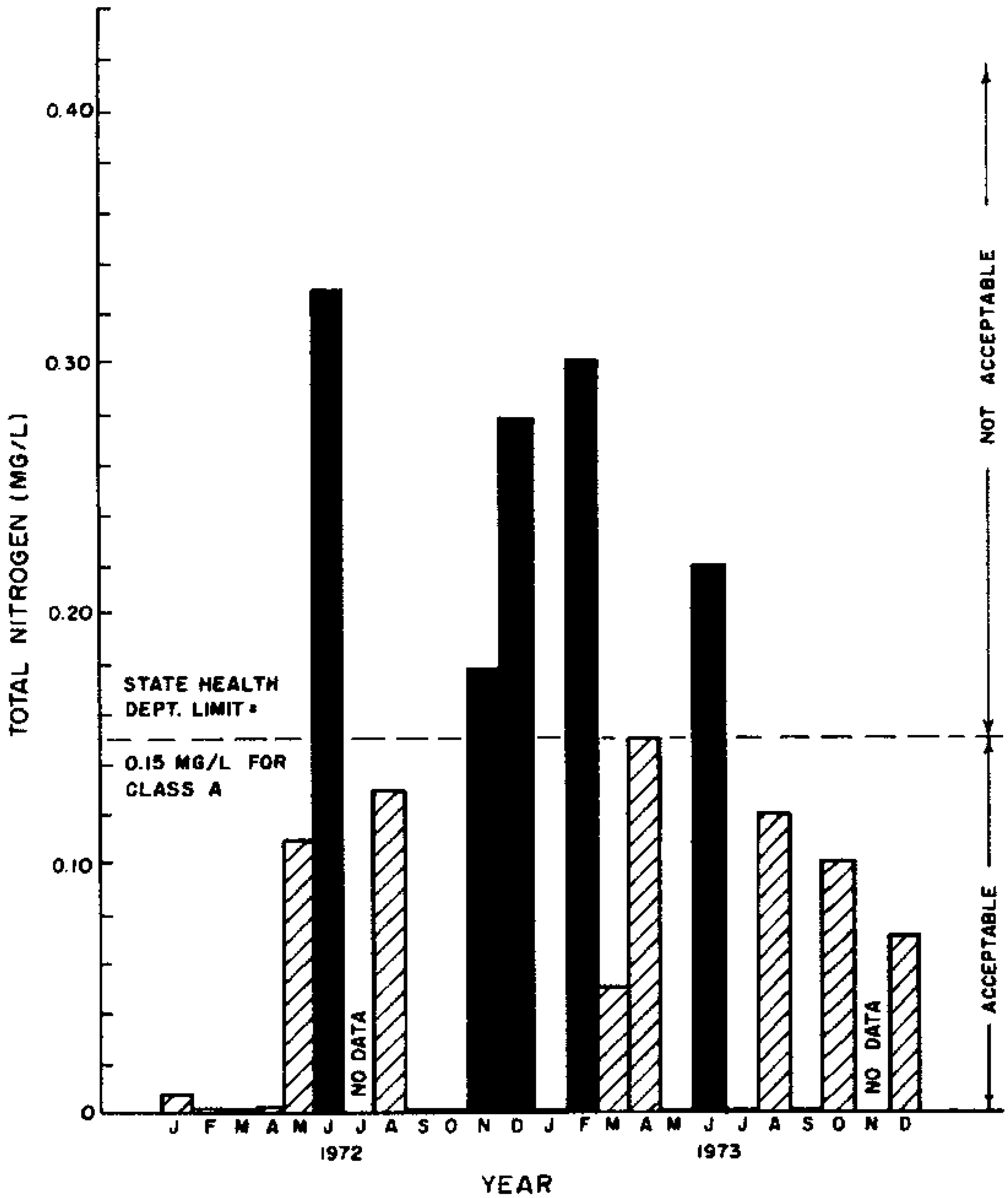


FIGURE 3.6. TOTAL NITROGEN AT SAMPLING STATION 3, SANDY BEACH, 1972-73.

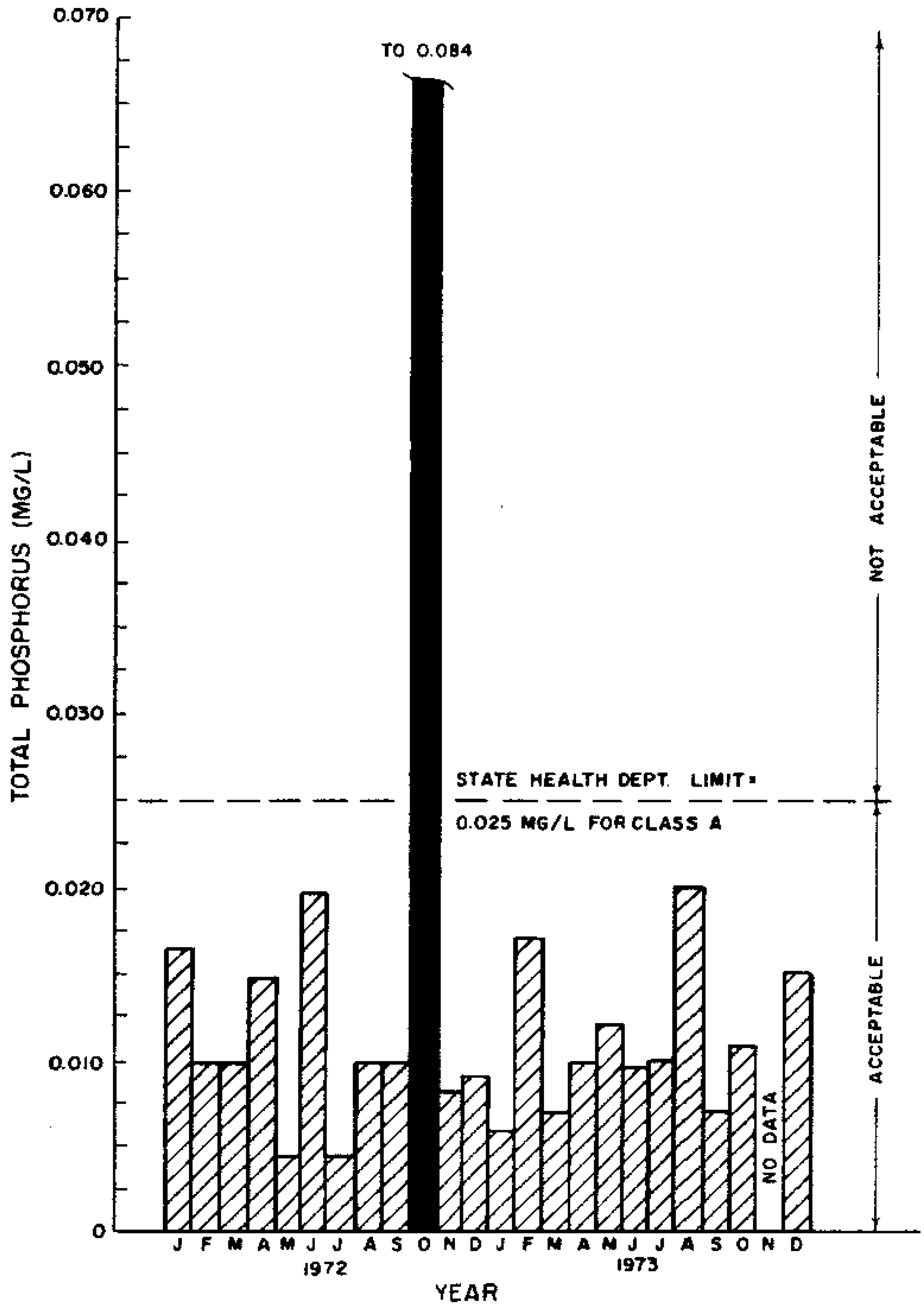


FIGURE 3.7. TOTAL PHOSPHORUS AT SAMPLING STATION 3, SANDY BEACH, 1972-73.

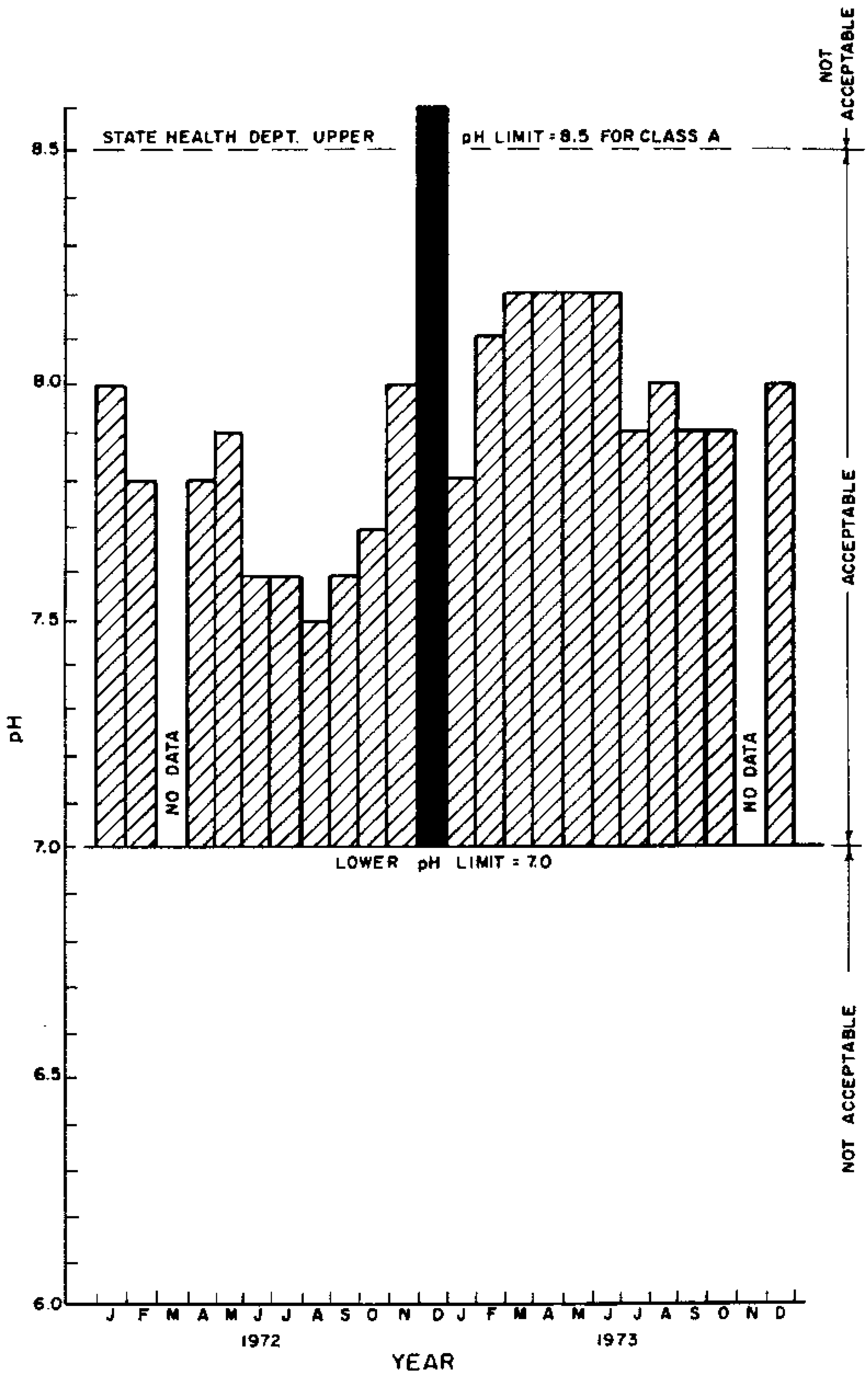


FIGURE 3.8. pH VALUES AT SAMPLING STATION 3, SANDY BEACH, 1972-73.

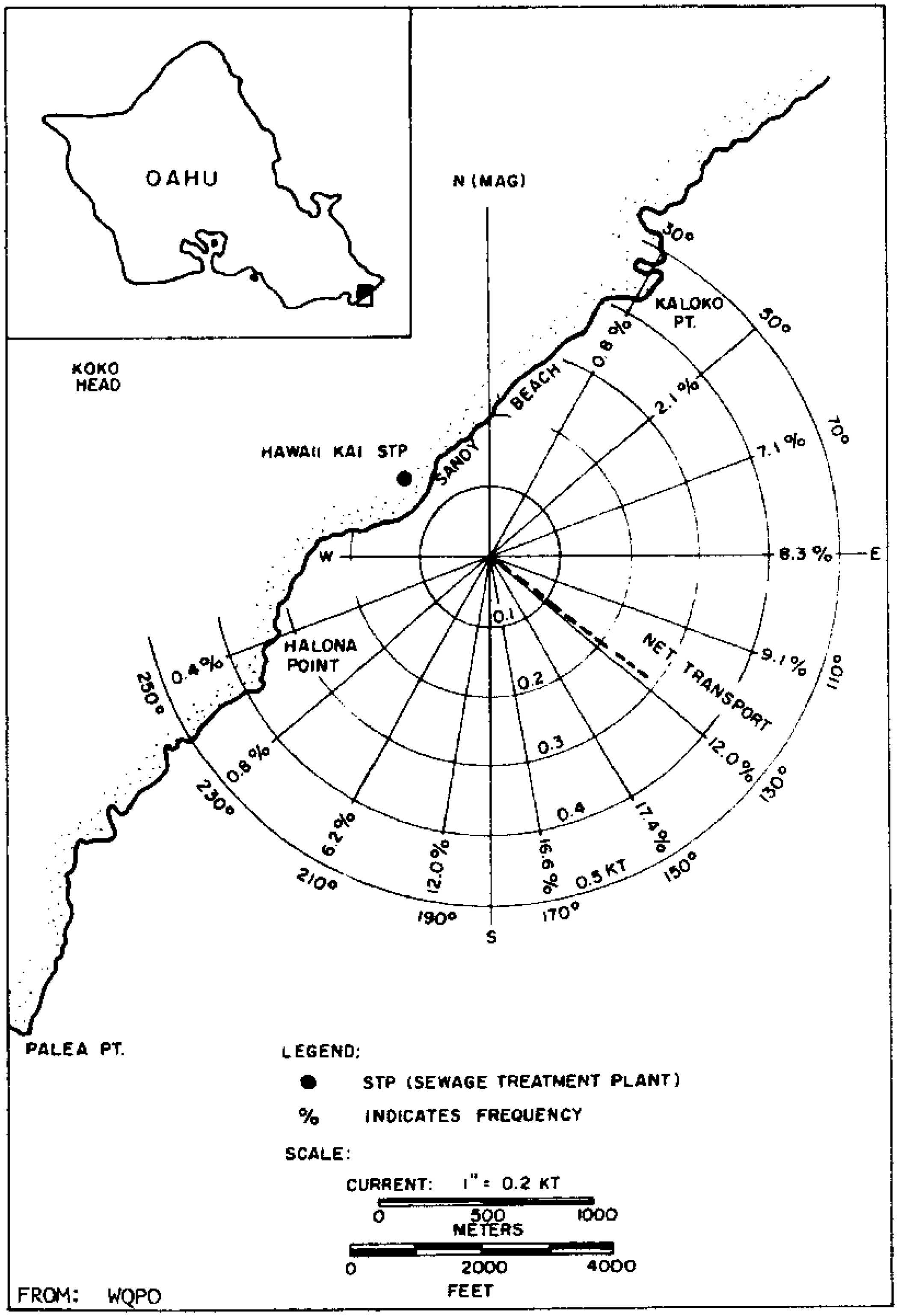


FIGURE 3.9. SURFACE CURRENTS AT SANDY BEACH, NOV. 15-25, 1970.

TABLE 3.14. WATER QUALITY ANALYSES OF SIX STATIONS: SANDY BEACH, MAR. 1972 TO JAN. 1973.

ANALYSIS	DATE	STATION NO. 1	2	3	4	5	6
pH (UNITS)	04-15-72	8.1	8.1	8.1	8.1	8.1	8.1
	07-27-72	8.3	8.3	8.3	8.3	8.3	8.3
	10-24-72	8.0	8.0	8.0	8.1	8.0	8.1
	01-18-73	8.2	8.2	8.3	8.3	8.3	8.3
TOTAL SOLIDS	04-15-72	37106	37032	38106	37900	37318	38942
	07-27-72	38221	38750	39466	37888	39170	38318
	10-24-72	38604	37419	37342	37951	38275	38268
	01-18-73	38140	38720	41700	38550	38060	39950
VOLATILE SOLIDS	07-27-72	4829	5389	5922	4508	5797	4853
	10-24-72	4585	2710	7321	4146	5947	4082
	01-18-73	3930	4070	4200	3800	3785	3040
SUSPENDED SOLIDS	07-27-72	7.6	7.8	10.6	10.2	11.4	6.8
	10-24-72	25.8	35.6	34.0	34.0	32.5	26.0
	01-18-73	38.0	39.0	39.0	40.0	36.0	36.0
VOLATILE SUSPENDED SOLIDS	07-27-72	3.6	3.8	4.6	5.8	4.2	1.2
	10-24-72	4.8	6.4	6.0	4.8	4.4	3.6
	01-18-73	11.0	8.0	10.0	10.0	9.2	10.2
TURBIDITY (FTU)	07-27-72	0.6	0.8	0.5	0.4	—	1.7
	10-24-72	0.8	1.0	0.6	0.8	0.9	0.4
	01-18-73	0.5	0.4	0.4	0.3	0.4	0.5

ANALYSIS	DATE	STATION NO. 1	2	3	4	5	6
CONDUCTIVITY (μmhos/cm)	07-27-72	43200	42400	43000	43000	42000	40000
	10-24-72	33000	30000	33000	33500	33000	34000
	01-18-73	45000	45600	44800	44800	46000	45000
CHLORIDES	04-15-72	18860	18859	18861	18860	18860	18860
	07-27-72	18875	19073	18974	19073	19173	18974
	10-24-72	17994	18094	18194	18094	18094	18194
	01-18-73	19600	19600	19600	19575	19575	19300
TOTAL NITROGEN	04-15-72	0.056	0.104	0.041	0.052	0.119	0.104
	07-27-72	0.197	0.163	0.124	0.193	0.174	0.174
	10-24-72	0.375	0.259	0.182	0.159	0.172	0.140
	01-18-73	0.096	0.099	0.158	0.185	0.144	0.124
TOTAL PHOSPHORUS	04-15-72	0.034	0.031	0.035	0.026	0.037	0.035
	07-27-72	0.062	0.052	0.051	0.048	0.050	0.055
	10-24-72	0.032	0.027	0.015	0.018	0.021	0.023
	01-18-73	0.019	0.017	0.019	0.011	0.028	0.016
ORGANIC CARBON	04-15-72	7.0	11.0	14.0	14.0	12.0	12.0
	07-27-72	10.0	11.0	9.5	6.0	6.0	5.5
	10-24-72	3.0	2.5	3.0	1.7	3.0	4.5
	01-18-73	4.1	4.3	5.1	2.0	3.3	4.6

NOTE: ALL UNITS IN mg/ℓ UNLESS OTHERWISE NOTED.

TABLE 3.15. HEAVY METALS CONTENT IN COASTAL WATERS, SANDY BEACH, MAR. 1972 - JAN. 1973.

METALS	DATE	STATION NO. 1	2	3	4	5	6
LEAD	04-15-72	ND	ND	ND	ND	ND	ND
	07-27-72	1.7	2.3	1.3	ND	ND	2.8
	10-24-72	ND	ND	ND	ND	ND	ND
	01-18-73	2	ND	3	ND	ND	ND
COPPER	04-15-72	2	2	ND	ND	ND	ND
	07-27-72	1.2	.8	.8	1.2	2.6	1.2
	10-24-72	ND	ND	1	1	7	ND
	01-18-73	2	2	2	3	1	3
ZINC	04-15-72	3	3	3	3	3	3
	07-27-72	ND	2.1	2.1	6.3	8.4	9.0
	10-24-72	31	12	23	11	10	ND
	01-18-73	2	1	2	ND	1	3
CADMIUM	04-15-72	ND	ND	ND	ND	ND	ND
	07-27-72	ND	ND	ND	ND	ND	ND
	10-24-72	ND	ND	ND	ND	ND	ND
	01-18-73	ND	ND	ND	ND	ND	ND
MERCURY	04-15-72	ND	ND	ND	ND	ND	ND
	07-27-72	ND	ND	ND	ND	ND	ND
	10-24-72	ND	ND	ND	ND	ND	ND
	01-18-73	ND	ND	ND	ND	ND	ND
CHROMIUM	04-15-72	ND	ND	ND	ND	ND	ND
	07-27-72	ND	ND	ND	ND	ND	ND
	10-24-72	1	ND	ND	8	2	2
	01-18-73	ND	2	2	2	2	2
NICKEL	04-15-72	ND	ND	ND	ND	ND	ND
	07-27-72	ND	ND	ND	2.2	ND	1.5
	10-24-72	ND	ND	ND	ND	ND	ND
	01-18-73	ND	ND	ND	ND	ND	ND

NOTE: ALL UNITS IN μg/ℓ.

TABLE 3.16. PESTICIDES IN COASTAL WATERS, SANDY BEACH, MAR. 1972 - JAN. 1973.

PESTICIDE	DATE	1	2	3 ng/ℓ	4	5	
DDT	04-15-72	ND	ND	ND	3	ND	2
	07-27-72	1	1	<1	<1	1	2
	10-24-72	<1	2	<1	<1	<1	<1
	01-18-73	1	4	2	1	1	1
PCP	07-27-72	5	7	4	5	1	4
	10-24-72	30	8	8	16	24	19
	01-18-73	12	12	9	9	9	13

TABLE 3.17. SUMMARY OF MEAN VALUES OF WATER QUALITY ANALYSES, SANDY BEACH, MAR. 1972 - JAN. 1973.

	SAMPLING DATE				
ANALYSIS	04-15-72	07-27-72	10-24-72	01-18-73	MEAN
HYDROGEN ION CONC. pH	8.1	8.3	8.1	8.3	8.2
TOTAL SOLIDS	37734	38636	37977	39187	38384
VOLATILE SOLIDS	--	5216	4799	3804	4606
SUSPENDED SOLIDS	--	9	31	38	26
VOLATILE SUSPENDED SOLIDS	--	4	5	10	6
TURBIDITY, FTU	--	1.9	0.3	0.4	1.0
CONDUCTIVITY, μmhos/cm	--	42267	32750	45200	40072
CHLORIDES	18860	19024	18111	19541	18884
TOTAL NITROGEN	0.079	0.171	0.215	0.134	0.15
TOTAL PHOSPHORUS	0.033	0.053	0.023	0.018	0.032
ORGANIC CARBON	11.7	8.0	3.0	3.9	6.7

NOTE: ALL UNITS IN mg/ℓ UNLESS OTHERWISE NOTED.

of increased treatment efficiencies at the Hawaii Kai STP, since secondary treatment at this plant was started only in early 1972. As these efficiencies increased, the discharge of dissolved volatiles and organic carbon would be expected to decrease, which is the case over the period of study.

The October 24, 1972 conductivity and chloride measurements were significantly lower than those measured on the other three sampling days. Although no explanation can be made for this decrease, these levels were still within normal ranges. Measurements of pH ranged from 8.1 to 8.3, which is within the 7.0 to 8.5 limits specified for Class A waters.

In general, total nitrogen levels were consistent with Class A standards whereas total phosphorus levels were not. This observation is just the reverse of the 1970-1971 Health Department data. Average total nitrogen observed on two of the four days conformed to Class A standards, and the average value over the four sampling days was 0.15 mg/ℓ. However, the geometric mean for the four days was 0.134 mg/ℓ. In either case it can be concluded that total nitrogen generally conformed with Class A standards.

Total phosphorus levels on two of four sampling days exceeded the Class A standard of 0.025 mg/ℓ. In addition, both arithmetic and geometric means over all four days were 0.032 and 0.029 mg/ℓ, respectively. In either case, the Class A standard of 0.025 mg/ℓ was exceeded; thus, the waters in this area do not generally conform to the Hawaii State Water Quality Standards with respect to phosphorus levels.

Heavy metal analysis of water samples at Sandy Beach shows the presence of copper and zinc at very low concentrations but with significant frequency. On the other hand, mercury and cadmium were both undetected. Chromium, nickel, and lead were present, but less frequently than copper and zinc.

Unlike Kahana Bay waters, both DDT and PCP were detected with significant frequency. The presence of the latter pesticide is probably related to the presence of urban development in Kalama Valley and possibly to the sewage effluent discharges.

Biota at Sandy Beach

Studies of the biota in the waters at Sandy Beach were limited to a survey of intertidal benthic algae at sampling Stations S2, S4, and S6 (Fig. 3.4) and at a fourth site near Station S4, herein designated as Station S4a. Selection of these stations and the nature of the biota to be observed resulted from a field inspection by a number of QWC Project participants on February 19, 1972. On that occasion a few dense growths of benthic algae, especially *Ulva* sp., were observed. Because the presence of *Ulva* sp. is considered by some to be an indicator of increased nutrients in the waters, it was deemed advisable to follow any changes in abundance and species composition of the algae at the selected stations as a method of assessing the effects of changes in water quality, if not indeed of detecting such changes.

Station S2 is located on the large lava outcrop just southwest of Sandy Beach Park and seaward of the outfall pipe in the cliff face. Station S4 is just northeast of Sandy Beach Park and at the sewage outfall which runs seaward along a long rectangular conrete groin. Station S6 is located at the northeast end of Wawamalu Park at the end of a large lava and concrete wall which marks the end of that beach park area. Station S4a, added in May 1972, is on an extensive lava outcrop about 300 ft (91.44 m) northeast of S4. It was included in the study in order to record an extensive growth of *Ulva* sp. which had not been identified in earlier months.

A photographic technique was used to record algae composition. A Nikon F camera with 50 mm, 135 mm, and 200 mm lenses was mounted on a tripod. From a fixed position at each site, selected rock outcrops with dense growths of algae were photographed monthly.

In June 1972 the photographic technique described in Chapter 2 (Kahana Bay) was introduced in order to quantify the algal composition. However, at the time of preparation of the report herein presented, the analysis of photographs necessary to estimate and average the percent algae cover and species composition were not yet available because of manpower limitations. Nevertheless, general abundance and distribution of *Ulva* sp. at the photographic stations can be described.

Station S2: *Ulva* was present only in small isolated patches in tidepools far inshore and free of heavy wave action.

Station S4: In February and March 1972, *Ulva* was abundant on many of the boulders in the shallow, shoreward intertidal region and along the rectangular groin. Most of this algae disappeared in subsequent months, possibly due to long exposure during the low daytime summer tides.

Station S4a: Abundant *Ulva* (estimated 30 percent cover) was present at this station along the entire transect and did not change in the 3-month observation period. Reasons for the lush growth at the isolated location are unclear. It is possible that wave action carried the sewage ashore from the outfall at this location. However, prevailing currents are in a southwest direction and should carry the sewage effluent away from the sampling site.

Station S6: *Ulva* was common on rocks in the more protected shallow intertidal zone in February and March, but decreased in abundance during the April to July period.

Summary and Conclusion

Study of the Sandy Beach situation was planned to secure baseline water quality data during a one-year survey. With the exception of biological information yet to be fully analyzed, the survey was completed as planned. Until a greater degree of development of the Hawaii Kai area or of the immediate environs of Sandy Beach occurs, there is not much more to be learned by continuing the QWC sampling program. This conclusion is supported by the circumstances associated with the Hawaii Kai sewer outfall. Specifically, the Hawaii Kai Development Corporation (through its consultants, Sunn, Low, Tom, and Hara) has monitored the outfall area in order that it may make the necessary environmental impact evaluations associated with obtaining discharge permits and other regulatory requirements upon which its land development depends. Although the results of these observations are not yet public information, they have been assembled over a longer period and in greater detail than was feasible for the QCW project.

Some evidence produced by the QCW study indicates that ongoing development has had some effect during the period of observation of water quality at Sandy Beach. In general, however, the waters were found to be clear and similar to those at Waikiki, but slightly higher in nutrients than the offshore water at Kahana Bay, the reference situation.

The summary of the Sunn, Low, Tom, and Hara study (1973), provided herein, substantiates the position that there is little detrimental effect from the treated sewage discharge off Sandy Beach. The main areas of investigative concern were the dilution and dispersion characteristics of the area, the distributions of water quality parameters, and the biological effects.[1] The results of this work will be used to define, on a rational basis, a recommended zone of mixing, and to have a baseline from which to make management decisions about future developments.

DILUTION AND DISPERSION CHARACTERISTICS. The current structure of the Sandy Beach area is a complex mixture of permanent north equatorial current, tide-induced currents, wind-driven currents, and wave-induced currents. A full description of this structure was not obtained. However, some key characteristics could be defined. By the use of dye, drogues, a fixed current meter, and observation it was determined that the most prominent currents in the area were the tide-induced oscillating currents which, under the influence of the local bathymetric characteristics, result in a net seaward transport in the area of the diffuser similar to that described in the Oahu Water Quality Study (1972). The current velocity distribution was found to have a modal value of about 0.3 knots.

The time of current reversal was determined to be the time of lowest dilution because of the initial slowing of the current velocity. Using the average turnaround time of one hour and a worst dilution condition with a current velocity of 0.1 knots, along with the observation of a counterclockwise current direction change, it was calculated that the water affected by the current change would almost always turn around within 1000 ft (304 m) of the diffuser in the initial direction of the current. This evaluation formed the basis for the recommended 1500-foot mixing zone dimension in the direction of current flow.

The mixing characteristic of the Sandy Beach area was determined by three dye dispersion studies. The dispersion coefficient k was found to be well approximated by:

$$k = 0.002\ L^{4/3}$$

where L is the characteristic length of the dispersion phenomena in feet and k is in units of square feet per second. The average initial dilu-

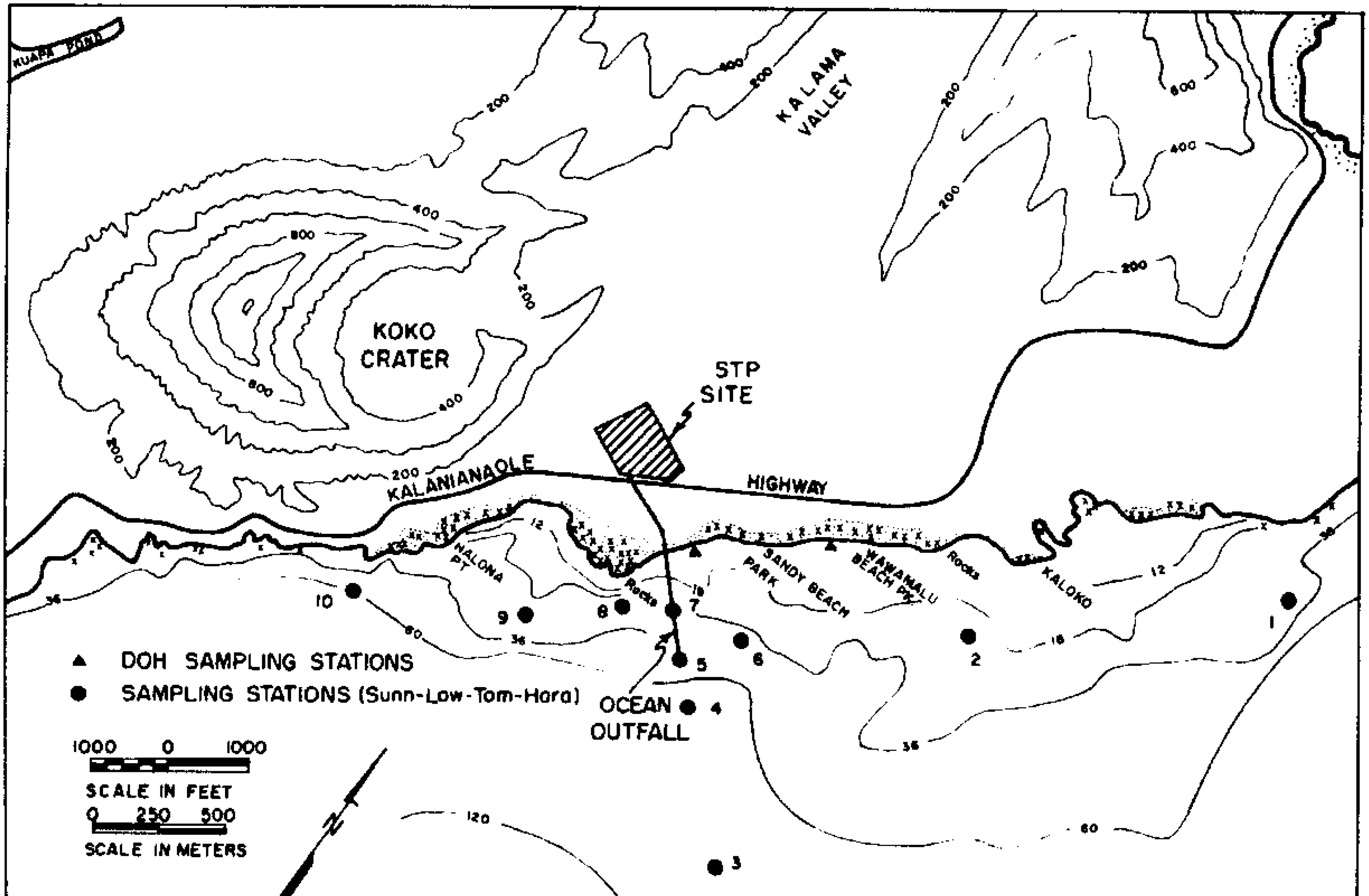
[1] Sunn, Low, Tom, and Hara, Inc. 1973, Chap II.

tion was found to be primarily a function of the current velocity and the amount of discharge. With these factors along with the dispersion theory as formulated by Brooks (1960), it was possible to develop a method to predict the average amount of dilution at any given distance from the diffuser in the direction of the current for a wide range of effluent flows. This method was then used to determine that the 1,500-foot proposed dimension on each side of the diffuser parallel to the shoreline for the zone of mixing should be adequate at the median level of phosphorus concentrations for a secondary effluent discharge rate up to about 5.8 mgd. This number is subject to confirmation by the proposed monitoring program. This evaluation was based on a limiting dilution factor of 450, which in turn was based on the total phosphorus standard of 25 μg/ℓ. This standard is potentially the first to be exceeded at the median level according to the water quality study of the Sandy Beach area. The exceedance of the total nitrogen standard at the median level follows closely behind that for the total phosphorus. The coliform standards should easily be met within the proposed zone of mixing because of the rapid dieoff rate.

WATER QUALITY DISTRIBUTION MEASUREMENTS. A series of 36 water samples were taken over a period of one year at each of ten stations in the Sandy Beach area (Fig. 3.10). The field and laboratory measurements included dissolved oxygen, nitrate nitrogen, total Kjeldahl nitrogen, active phosphorus, total phosphorus, salinity, extinction coefficient, total and fecal coliform, pH, temperature, and chlorophyll-a. With the large number of samples taken under various conditions over a one-year period, it was possible to describe the statistical distribution of these parameters at each station. Most of these distributions were skewed toward the lower values and were reasonably approximated by a log-normal distribution.

A significant aspect of these distributions was that the phosphorus and nitrogen results at stations beyond the range of significant influence from the discharge showed that the Class A Standards for these constituents were exceeded 10 to 20 percent of the time under natural conditions in the waters off Sandy Beach. This type of observation points out the inadequacy of single value standards.

An analysis of the distribution of the sewage effluent using total phosphorus as a tracer indicated that the predominent direction of the effluent field was seaward and Makapuu of the diffuser with some influence toward Blow Hole, but almost none discernible at the station 700 ft (212.8 m) directly shoreward of the diffuser. This observation along with some dispersion calculations was the basis for the proposed 500-foot shoreward dimension for the zone of mixing. Because this shoreward dimension is largely based on the results of the water quality measurements, it should be confirmed by the suggested quarterly monitoring program including monitoring of biological indicators. Further, as the discharge reaches about 4.2 mgd, monthly monitoring should be begun to determine if the shoreward dimensions of the zone mixing should be altered or some other alternative implemented. The 4.2 mgd figure was calculated to give a 450 dilution under a typical current turnaround condition. This condition consists of an initial slowing to about 0.2 knots causing initial dilution, and a subsequent dispersion for a circular travel distance of about 1500 ft at a current velocity of 0.3 knots.



FROM: SUNN, LOW, TOM, AND HARA 1973.

FIGURE 3.10. SAMPLING STATIONS, SANDY BEACH.

The water quality measurement results generally confirm the conclusion, drawn from the current and dispersion pattern of the study, that the predominant transport mechanisms are the tide-induced currents which oscillate roughly parallel to the bottom contours in the area. The bottom configuration in the Blow Hole direction of the diffuser is characterized by a series of spurs pointing seaward, while in the Makapuu direction the contours run relatively smoothly at an angle seaward of the shoreline.

A special study to determine the T_{90} dieoff rate for coliform bacteria showed that the value at Sandy Beach (16.4 minutes) was in line with the value of 18 minutes developed by the Oahu Water Quality Study (1972). Using this value and the 90 percent less-than total coliform level of the closest sampling station to the State Department of Health shore sampling station, the Sunn, Low, Tom, and Hara study showed that the sewage effluent is not a significant contributor to the recently noted increase in coliform at the shore station. The study suggested that a likely factor in this increase is the upsurge of recreational use of the Sandy Beach Park area.

BIOLOGICAL OBSERVATIONS AND MEASUREMENTS. Since the effluent being discharged at Sandy Beach comes from a secondary sewage treatment plant, it contains relatively few settleable solids. Most of the effects on benthic communities around sewage outfalls at other locations have been attributed to solids accumulation. These factors suggest that there should be little effect on the benthic community as a result of the secondary effluent discharge at Sandy Beach. This supposition was confirmed by an extensive biological survey of the area and by comparisons to similar areas that have no sewage outfall.

Benthic effects attributable to the effluent were confined to a radius of 10 to 20 ft (3.04 cm to 6.08 cm) around each of the four active diffuser ports and consisted primarily of a reduction of coral (*Pocillopora*) coverage and a slight increase in the density of a long-spine sea urchin of the genus *Echinothrix*. Outside of this area the *Pocillopora* coverage was found to be principally a function of habitat and the measured diameter growth rate of 2.6 to 3.6 cm/yr was somewhat higher than the 2.2 cm/yr reported by Grigg (personal communication 1972), but judged to be normal for the young heads measured, although the slight increase in particulate organic matter in the vicinity may have been stimulatory.

The coverage of two species of the benthic algae of the genus *Dictyopteris* was found to be primarily influenced by the factors of bottom type, surge, light, and predation. Densities of these algae similar to those at Sandy Beach were reported by Harger (1972) off Waikiki and were also observed north of Makaha, at Wailua-Kapaa (Kauai), and off Niihau where there was no sewage effluent discharge. The net growth rate of *Dictyopteris* at Sandy Beach (42 grams [dry weight] per month per square meter) was very similar to the 50 grams/mo/m^2 reported by Harger (1972) for Waikiki. The short-spined sea urchin *Tripneustes* was found to feed on *Dictyopteris* and effectively clear large areas of the algae. The periodic deposition of this algae on the beach is due to surf and surge actions and cannot be connected with the outfall, according to the Sunn, Low, Tom, and Hara study.

The effect of the sewage effluent on the organisms in the water column appeared to be limited to the immediate vicinity of the diffuser. Median chlorophyll-a levels (which indicate phytoplankton density) at the water quality sampling stations showed no discernible influence of the sewage effluent. There was, however, a probable influence on the numbers and types of fish in the vicinity of the diffuser. This was especially noticeable at the most seaward diffuser port where the effluent was higher in suspended solids. At this diffuser there consistently were large numbers of maomao which were observed to feed on the effluent particulate matter. The eggs of these maomao in turn were observed to serve as a food source for several other types of fish.

KANEOHE AND KAILUA BAYS

Nature of the Situation

Kaneohe Bay, located on the eastern or windward coast of Oahu, is the largest and, perhaps, the finest bay in the Hawaiian Islands. Every source of quality factors generated by urbanization of land is to be found in the bay area and exerts its own special influence upon the quality of bay waters. Sewage effluents, at least ten surface streams, and storm water from urbanized and drained land all discharge into Kaneohe Bay which is periodically dredged. The bay is used for swimming, water skiing, fishing, boating, and other water-oriented sports. It is the source of bait-fish for commerical fishing and a haven of aquatic life of great marine importance. It is also probably the most researched body of water in Hawaii, challenging the ingenuity and the curiosity of men and women with almost every conceivable interest in water-associated phenomena and aquatic life relationships.

As a situation in which to evaluate the effects of urban land use on coastal water quality, Kaneohe Bay offers little immediate prospect for productive investment of short-term grants to the QCW Project. The difficulty of associating any observed coastal water quality effect with the aspect of urbanization most responsible for that effect has already been cited in this Chapter. Moreover, the massive research effort which has been previously focused on Kaneohe Bay has long since found its ecosystem to be under stress (Smith, Chave, and Kam 1973). Many observers have pointed to toxicity of sewage effluents, previously thought to be harmless, as a major cause of adverse biological conditions within the bay's waters. This conclusion has led engineers and scientists to propose intercepting all sewage now discharged to the bay and discharging it through an ocean outfall off Mokapu Point, after appropriate treatment.

From the standpoint of studies intended to reveal the relationship between coastal water quality and urbanization of land, for the purpose of assisting public officials and institutions in generating effective control measures and systems, the Kaneohe Bay situation presents two major challenges:

1. A study to observe the changes in the water quality and aquatic biota of Kaneohe Bay following the diversion of sewage effluents.
2. A study of the changes, if any, which occur in the waters of Kailua Bay once the deep ocean outfall is in operation beyond its inshore waters.

Both of these are extremely high priority studies in the interests of coastal water quality management. The first, however, is infeasible until some later date, the vast literature on Kaneohe Bay having already established the baseline against which its findings can be evaluated (Cox et al. 1969).

The second, however, has both long-range and immediate aspects. Obviously data on the effects on coastal waters of an ocean outfall cannot be obtained until the facility is in operation. Such data, however, cannot be evaluated without baseline data on Kailua Bay. Thus, the Kaneohe Bay situation creates a need for studies of Kailua Bay. To such a study the QCW Project turned its attention in 1972-73.

Both the Kaneohe Bay situation and the proposed sewer outfall off Mokapu Point are summarized from several sources in the *First Annual Progress Report* (1972) and are not herein repeated in any detail. Basically, the proposed outfall would extend eastward from Mokapu Point, a distance of 5000 ft (1524 m) from shore, with the final 960 ft (292.61 m) serving as a diffuser section in depths ranging from 90 to 105 ft (27.43 to 32.0 m). The effluent, estimated to reach 33 cfs (56.1 cu m/min) by the year 1993, would be diluted at least 100 times by sea water under seasonal conditions, with an expected dry weather dilution of about 200 times. Due to lack of density stratification, the effluent is expected to surface. Therefore, design criteria will require that all aesthetically objectionable material, visible suspended solids, flotage, or obvious sources of discoloration must be removed.

Most of the ocean bottom material at the outfall site is coral formation with small pockets of coarse sand. Live coral is found down to 30 or 40 ft (9.14 or 12.19 m). A huge and lush coral reef at the 10-foot depth is at the site of the proposed diffuser. Below this depth the bottom is composed of much dead coral. The ocean water in the general area of the outfall has been described as relatively pristine, probably due to the strong ocean currents at the proposed diffuser depth. To establish baseline data on such parameters as nutrients, clarity, pH, temperature, and salinity, the City and County of Honolulu had its consultants monitor waters in the outfall area at several depths down to 50 ft (15.24 m) at 14 stations over a period of one year.

Unanticipated adverse effects of the Mokapu Point outfall could, of course, be corrected: the degree of treatment of sewage and the processes involved in treatment, could be changed if necessary to meet discharge standards considered appropriate at the time.

A study of the biota of Kailua Bay, including a fish survey and a survey of micromolluscan assemblages, was made by the Water Resources Research Center of the University of Hawaii in 1972-73 under a contract with the Department of Public Works of the City and County of Honolulu. The work was performed by Dr. S. Arthur Reed and Dr. E. Alison Kay, both participants in the QCW Program. With the permission of the authors and the sponsoring agency, the results of this study are hereinafter presented to establish a baseline for interpreting the effects of urban sewage upon the quality of coastal waters.

A BASELINE SURVEY OF BENTHIC BIOTA IN KAILUA BAY, OAHU

Introduction

The purpose of this study is to survey six stations in Kailua Bay, Oahu to provide a general description of the benthic conditions and to quantitatively determine the dominant benthic flora and fauna at each station. The report of survey of fish species and abundance and an analysis of micromolluscs in sand samples collected at each station follows.

The information from this survey will add to data already collected in Kailua Bay in other studies: an oceanographic survey (Bathen 1972) and the Mokapu Outfall Baseline Study (Western, in preparation). The latter report is also a biological survey but covers stations other than those included here.

Four shallow water stations (10 to 20 ft deep or 3.05 to 6.10 m) and two deeper stations (45 ft deep or 13.72 m) were selected to coincide with the physical parameter stations of Bathen's survey (Fig. 3.11).

Station 1 (Bathen Station 12) is 18 ft (5.49 m) deep about midway between the present sewage outfall and the proposed Mokapu outfall alignment.

Station 2 (Bathen Station 11) is in 20 ft (6.10 m) of water within 200 ft (60.96 m) of the present sewage outfall.

Station 3 (Bathen Station 10) is 20 ft (6.10 m) deep on the coral "barrier" reef about midway between the present sewage outfall and Popoia Island (Flat Island).

Station 4 (Bathen Station 9) is 10 ft (3.05 m) deep in a channel between Popoia Island and the barrier reef.

Station 5 (near Bathen Station 7) is in 45 ft (13.72 m) of water directly seaward (NE) of Popoia Island.

Station 6 (Bathen Station 8) is 45 ft (13.72 m) deep in line with the northern Mokulua Island and Wailea Point on shore.

Survey Methods

A number of different data collection techniques were used depending on the type of substrate, depth, surge, and water clarity.

One Meter^2 Quadrat: At Stations 1, 2, and 4, where algae constituted the dominant benthic organism, a 1 meter^2 quadrat constructed of aluminum tubing was dropped to the bottom. Locations were chosen that appeared by visual inspection to generally typify the algal distribution and abundance of the station. Five separate meter^2 quadrat samples were gathered at each station. Within each quadrat as much algae as possible was carefully

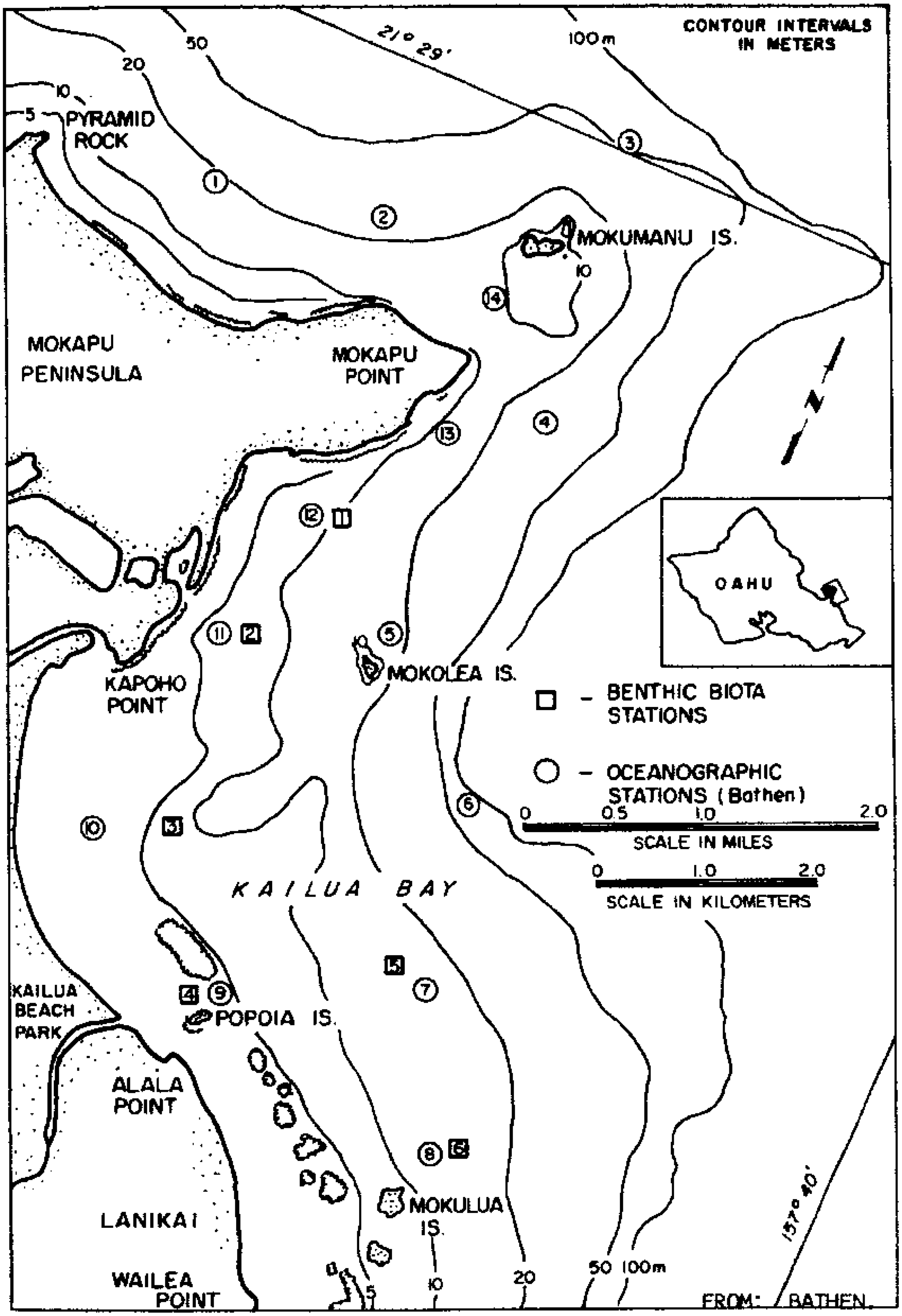


FIGURE 3.11. BENTHIC BIOTA STATIONS 1 TO 6 AND ASSOCIATED OCEANOGRAPHIC STATIONS, KAILUA BAY, OAHU.

picked by hand from the bottom and placed in a plastic bag. Each quadrat sample was later sorted into species, dried in an oven at 110° F (43.29° C) for 24 hours and then weighed on a Mettler H15 single pan balance to the nearest milligram.

Photographic Transect: At stations where water clarity and surge permitted color photographs of the bottom were taken using a Nikonos camera with a 28 mm lens and Honeywell 770 electronic flash enclosed in an Ikelite underwater housing and mounted on an aluminum support frame. The frame positioned the camera a fixed distance from the bottom so that an area exactly 1 m by 2/3 m was photographed. The color transparencies were later projected on a gridded screen to determine percent substrate cover.

Joint Point and Nearest Neighbor Technique: This technique, modified from Batchelor (1971) was used to measure density and distribution of heads of the coral *Pocillopora meandrina* at Station No. 3. A 30 m transect line, marked at each meter was laid on the bottom. Distance was measured from a random meter point along the transect line to the nearest coral head and from that coral head to its nearest neighbor. Twenty five such measurements were taken. Diameters of the coral heads were also measured. Density, distribution, and percent cover of coral was calculated.

Linear Transect: A 30 m nylon transect line was laid on the bottom and drawn taut. The length of transect line lying directly above the separate living coral heads of different species was measured. The line was then moved to a new, nearby location and measurements again taken. Measurements were summed and used to calculate percent coral cover.

Meter^2 Quadrat Transect: To estimate sea urchin density at Stations No. 5 and No. 6. a 1 m^2 quadrat constructed of aluminum tubing was laid on the bottom and all sea urchins of the dominant species within the quadrat was then flipped over repeatedly and sea urchins counted in a total of 30 m^2.

Survey Results

Station 1: The bottom at this station slopes gently seaward and consisted of a flat, hard limestone substrate of coral and coralline algae origin. Occasional wide shallow depressions contained pockets of sand a few inches deep. The bottom was pockmarked with many small holes, the results of characteristic abrading action of the sea urchin, *Echinometra matthaei*. Dominant benthic organisms were algae and, to a much less extent, living coral.

Algal abundance, reported as dry weight of all algae gathered within 5 one m^2 quadrats (see Table 3.18) averaged 45.577 g/m^2. Fourteen species of algae were identified in the samples, the most abundant being *Dictyopteris* sp. and *Galaxaura* sp., together contributing over 50 percent of the total dry weight. In all algae samples a large fraction was impossible to separate into species because of dense matting and interlacing of filaments and branches. This combined fraction is reported as mixed

TABLE 3.18. DRY WEIGHTS (g) OF SPECIES OF BENTHIC ALGAE COLLECTED WITHIN 5 ONE-METER^2 QUADRATS AT STATION 1.

SPECIES	1A	1B	1C	1D	1E	TOTAL	%
Dictyopteris sp.	14.218	19.816	7.633	12.303	17.804	71.774	31.5
Galaxaura sp.	9.906	13.162	10.964	14.627	8.078	55.927	24.5
RED ALGA, UNIDENT.	4.923	1.333	--	10.854	3.630	20.740	9.1
RED ALGA, UNIDENT.	1.743	2.991	--	--	--	4.734	2.1
Microdictyon sp.	0.521	2.024	—	1.065	--	3.610	1.6
Trichogloea sp.	1.692	--	--	1.106	0.552	2.350	1.0
Halimeda discoidea	--	0.541	1.168	--	0.621	2.330	1.0
Dictyota acutiloba	2.047	--	--	--	--	2.047	0.9
Laurencia sp.	--	--	--	1.441	--	1.441	0.6
Dictyosphaeria cavernosa	0.027	--	1.075	--	--	1.102	0.5
Codium edule	0.525	--	0.202	--	--	.726	0.3
Turbinaria sp.	0.120	--	--	--	0.486	.606	0.3
Codium arabicum	--	--	--	0.450	--	.450	0.2
Padina japonica	0.338	--	--	--	--	.338	0.2
MIXED SPECIES	7.632	5.103	10.155	19.684	17.135	59.709	26.2
TOTAL	42.882	43.637	32.529	60.530	43.306	227.884	100

NOTE: AVERAGE DRY WEIGHT = 45.577 g/m^2.

species.

Coral cover was very sparse and, measured by the photographic transect method, was calculated to be less than 5 percent. Dominant species were small patches of the encrusting coral *Porites lobata* and occasional heads of *Pocillopora meandrina*. A few patches of *Montipora verrucosa* were also seen.

Sea urchins seen during the dives were *Echinometra matthaei*, *Tripneustes gratilla*, *Echinothrix calamaris*, and *Echinostrephus aciculatus*. Sea urchin abundance was too low to be measured by any of the quantitive transect methods used.

Station 2: This station is located within 100 m of the present sewage outfall. The bottom consists of a hard, flat limestone substrate with occasional shallow, broad, sand filled depresssions. As at station 1, numerous small holes in the rock indicate the presence of the sea urchin *Echinometra matthaei*. Algal abundance averaged 55.062 g/m^2 (Table 3.19). Fourteen species of algae were identified in the samples, eight of which were also found at Station 1. *Dictyopteris* sp. made up 58.5 percent of the total dry weight. *Ulva fasciata*, although it made up only 4.8 percent of the total dry weight, was prominent visually on the reef.

Coral cover was estimated to be less than 2 percent, using the photographic transect technique. Only two species of coral were seen, *Porites lobata* and *Pocillopora meandrina*.

TABLE 3.19. DRY WEIGHTS OF SPECIES OF BENTHIC ALGAE COLLECTED WITHIN 5 ONE-METER^2 QUADRATS AT STATION 2.

SPECIES	2A	2B	2C	2D	2E	TOTAL	%
Dictyopteris sp.	56.790	27.922	39.061	26.730	10.563	161.066	58.5
Codium arabicum	--	10.729	8.972	3.358	--	23.059	8.4
Ulva fasciata	2.152	4.037	2.060	1.702	2.627	12.578	4.6
Galaxaura sp.	.188	6.072	1.281	3.014	--	10.555	3.8
Dasya sp.	--	--	--	--	8.336	8.336	3.0
Asparagopsis sp.	--	--	--	8.086	--	8.086	2.9
Jania sp.	3.060	2.580	--	--	--	5.640	2.1
Halimeda discoidea	--	1.276	--	1.296	2.615	5.187	1.9
RED ALGA, UNIDENT.	--	--	--	4.754	0.155	4.909	1.8
Gracilaria sp.	4.142	--	--	--	--	4.142	1.5
Trichogloea sp.	0.390	0.616	--	2.660	0.238	3.904	1.4
Chondrococcus sp.	0.082	--	0.464	--	0.088	0.634	0.2
Dictyosphaeria sp.	--	0.177	--	--	--	0.177	0.1
Dictyota sp.	--	--	0.050	--	--	0.050	0.0
MIXED SPECIES	--	--	--	--	--	23.938	9.4
TOTAL	66.804	53.409	52.386	51.600	25.173	275.310	100

NOTE: AVERAGE DRY WEIGHT = 55.062 g/m^2.

Sea urchins seen were *Echinometra matthaei*, *Tripneustes gratilla*, and *Echinothrix calamaris*. Low numbers of these species prevented accurate quantitative abundance measurements.

Station 3: This station is located in about 20 ft (6.10 m) of water on the poorly developed barrier reef which extends intermittently along the length of the bay. It receives the full energy of large open ocean waves and, during storm conditions, is the region of heavy surf action. The bottom consists of a very irregular hard limestone substrate interrupted frequently by large mounds and crevices up to 10 ft (3.05 m) deep and 6 to 8 ft (1.83 to 2.44 m) wide. These crevices generally run perpendicular to shoreline and contain sand several feet in depth. Even in calm seas this station experiences strong surge currents.

The coral *Pocillopora meandrina* was the dominant benthic organism. Density of these coral heads was 1.27/m^2 (n=25) using the joint point, nearest neighbor technique. Average diameter of the coral heads was 16 cm. Assuming the heads to be spherical, the average bottom surface area covered per head was 207 cm^2. From these values, coral cover was calculated to be 2.6 percent. A few very small colonies of other coral species were seen during a 10-minute search period in the area including *Pavona explanulata*, *Montipora verrilli*, *Montipora flabellata*, *Fungia scutaria*, *Cyphastrea ocellina*, and *Pavona varians*. Total percent cover of these species was negligible.

Station 4: This station is located in a shallow channel between Popoia Island (Flat Island) and the barrier reef in about 10 ft (3.05 m) of water. During high storm wave conditions, heavy surge action is present. The bottom is flat with a thin layer of sand over a hard limestone substrate. The sand is firmly held in place by a dense and closely cropped mat of algae.

No coral was seen in the channel area, although small patches were growing on the mounds of the barrier reef to the north of the station. Algal abundance averaged 63.148 g/m^2 (Table 3.20). Seventeen species of

TABLE 3.20. DRY WEIGHTS OF SPECIES OF BENTHIC ALGAE COLLECTED WITHIN 5 ONE-METER^2 QUADRATS AT STATION 4.

SPECIES	4A	4B	4C	4D	4E	TOTAL	%
Halimeda discoidea	22.276	16.699	5.983	11.132	28.547	84.637	26.8
Sargassum sp.	9.867	3.365	--	16.460	3.969	33.661	10.7
Trichogloea sp.	10.370	3.459	8.351	--	4.593	26.773	8.5
Dictyopteris sp.	2.017	3.990	5.837	6.460	1.673	19.977	6.3
Dictyota acutiloba	0.156	1.859	0.076	8.770	--	10.861	3.4
Galaxaura sp.	--	8.865	--	1.056	--	9.921	3.1
Hypnea sp.	1.847	0.183	0.521	2.061	1.762	6.374	2.0
Padina japonica	0.095	1.373	1.463	2.116	--	5.047	1.6
Laurencia sp.	1.937	0.506	--	--	2.018	4.461	1.4
Dictyosphaeria sp.	0.540	0.399	0.989	0.050	0.389	2.367	0.8
RED ALGA, UNIDENT.	--	1.604	--	--		1.604	0.5
Sciana sp.	--	--	--	--	1.397	1.397	0.4
Asparagopsis sp.	--	--	--	0.952	--	0.952	0.3
Codium arabicum	--	0.303	--	--	0.364	0.667	0.2
Colpomenia sp.	--	--	0.259	--	--	0.259	0.1
Acanthophora sp.	0.138	--	--	--	--	0.138	0.0
Bornatella sp.	--	0.022	--	--	--	0.022	0.0
MIXED SPECIES	12.278	26.199	10.471	35.485	22.190	106.623	33.8
TOTAL	61.521	68.826	33.950	84.542	66.902	315.741	100

NOTE: AVERAGE DRY WEIGHT = 63.148 g/m^2.

algae were identified. *Halimeda discoidea* was dominant, comprising 26.8 percent of the total dry weight. With the exception of a single specimen of the holothurian, *Holothuria atra*, no other benthic organisms were seen during the survey.

Station 5: The bottom at this station was hard limestone and presented a gently rolling profile with a few crevices up to two-feet (0.61 m) deep which contained small amounts of sand. Coral was the dominant living organisms affixed to the substrate. Using the linear transect technique, coral cover (Table 3.21) was calculated to be 13.5 percent with *Porites lobata* and *Montipora verrucosa* accounting for 10 percent.

TABLE 3.21 PERCENT CORAL COVER AT STATION 5 MEASURED BY THE LINEAR TRANSECT METHOD.

SPECIES	LENGTH OF LIVE CORAL UNDER TRANSECT LINE (cm)	PERCENT COVER
Porites lobata	326	5.4
Montipora verrucosa	285	4.6
Pocillopora meandrina	161	2.7
Montipora verrilli	29	0.5
Pocillopora ligulata	13	0.2
Pavona varians	8	0.1
TOTAL	822	13.5

NOTE: TOTAL TRANSECT LENGTH WAS 60 METERS.

Six species of coral were measured. A few large heads of *Porites lobata* about 3 ft (0.91 m) in diameter and 2 ft (0.61 m) high were seen in the area, although they did not fall under the transect line.

Density of the sea urchin, *Tripneustes gratilla*, was calculated to be 1.5 urchins/m^2 in a total of 30 m^2 using the meter^2 quadrat transect method.

Station 6: The bottom was relatively flat, hard limestone with broad, shallow depressions which contained sand a few inches deep. A few mounds of dead and heavily eroded coral skeletons occasionally rose above the substrate. Only small patches of living coral a few inches across and widely separated were seen. Coral cover using the linear transect method was calculated to be considerably less than 1 percent.

Density of the sea urchin, *Tripneustes gratilla*, was 1.4 urchins/m^2 using the meter^2 quadrat transect method.

No algae were seen within the transect area, although large and dense patches of *Dictyopteris* sp. have been observed growing in this general region.

A summary of results of the quantitative measurements at all six stations is shown in Table 3.22.

Discussion

Stations 1 and 2 were very similar in appearance. Both of these locations receive the full force of large, open ocean waves which move into the bay during most of the year. Bottom surge is strong and continuous, except during the calmest seas. These factors are probably important selective factors in determining settlement and growth of coral. The flatter, encrusting coral *Porites lobata* and the robust coral heads thrive

TABLE 3.22. SUMMARY OF ABUNDANCE OF DOMINANT BENTHIC ORGANISMS AT SIX STATIONS IN KAILUA BAY.

STATION	ORGANISMS MEASURED	DOMINANT SPECIES	TOTAL ABUNDANCE OR AREA COVERED	TOTAL DISTANCE OR AREA SAMPLED	METHOD OF MEASUREMENT
1	ALGAE	*Dictyopteris* sp. (31.5%)	45.577 g/m^2	5 m^2	DRY WEIGHT
	CORAL	*Porites lobata*	<5%	20 m^2	PHOTOGRAPHIC TRANSECT
		Pocillopora meandrina			
2	ALGAE	*Dictyopteris* sp. (58.5%)	55.062 g/m^2	5 m^2	DRY WEIGHT
	CORAL	*Porites lobata*	<2%	20 m^2	PHOTOGRAPHIC TRANSECT
		Pocillopora meandrina			
3	CORAL	*Pocillopora meandrina*	2.6%	--	JOINT POINT NEAREST NEIGHBOR
4	ALGAE	*Halimeda discoidea* (26.8%)	63.148%	5 m^2	DRY WEIGHT
5	CORAL	*Porites lobata* (5.4%)	13.5%	60 m	LINEAR TRANSECT
	SEA URCHIN	*Tripneustes gratilla*	1.5/m^2	30 m^2	m^2 QUADRAT TRANSECT
6	CORAL	*Porites lobata*	<1%	60 m	LINEAR TRANSECT
	SEA URCHIN	*Tripneustes gratilla*	1.4/m^2	30 m^2	m^2 QUADRAT TRANSECT

in regions of strong wave action (Grigg and Maragos, in press).

Algal growth at the two stations was similar both quantitatively and qualitatively. Fourteen species were identified at both locations with eight of these being common to the two. *Dictyopteris* sp. made up a much larger percentage of the total algal dry weight at Station 2, near the outfall, than at Station 1.

It is also notable that *Ulva fasciata* was abundant at Station 2, but absent at Station 1. This species is often cited as an indicator of increased nutrient load and fresh water outfalls.

Coral abundance and diversity at Station 3 is typical of other regions around Oahu of equal depth exposed to strong wave action. *Pocillopora meandrina* is usually the dominant coral with other species of encrusting corals present, but in very small and widely separated patches.

The two deep Stations 5 and 6 appeared to be subjected to the same environmental conditions. They were quite similar in general bottom topography and about equally exposed to wave action. Density of the sea urchin, *Tripneustes gratilla*, was also comparable. The great difference in abundance of coral may therefore be merely a function of sampling site selection rather than differences in environmental factors.

Based upon the measurements made at these stations and on observations made during other dives in these waters, a general description of the distribution of benthic biota can be given. Most of the inner bay between the Kawainui Canal to the north and Wailea Point to the south is a sand bottom extending from the shoreline to about 20 ft (6.10 m) deep. Constant moving and grinding action of the sand particles by wave action effectively prevents the settling and growth of fauna and flora and the region is devoid of any benthic algae or coral. A ridge of coral rock parallel to and about 1/4 to 1/2 mi (0.402 to 0.805 km) from shore in the southern half of the bay serves as a weak barrier reef and receives the brunt of strong open ocean waves. Near Popoia Island this reef is exposed during extreme low tides. Sparse coral growth on this ridge, largely *Pocillopora meandrina* serves to add new coral material and maintain the reef. Beyond this barrier reef in the southern part of the bay and extending almost to shore in the northern part, the bottom is made up of flat or gently rolling limestone substrate covered intermittently with patches of algae and coral. Extensive beds of the algae, *Dictyopteris* sp. can be seen on days of good water clarity growing at depths of 20 to 50 ft (6.10 to 15.24 m) in the southern regions of the Bay. Dominant corals in the deeper (30 to 50 ft or 9.4 to 15.24 m), more seaward regions are *Porites lobata, Pocillopora meandrina,* and *Montipora verrucosa.* Other common invertebrates associated with the coral rock substrate are sea urchins, *Tripneustes gratilla, Echinometra matthaei,* and *Echinothrix calamaris.*

Chapter 4

COASTAL WATER QUALITY AND SUGARCANE MANAGEMENT

COASTAL WATER QUALITY AND SUGARCANE MANAGEMENT

Sugarcane management and adjacent coastal water quality, discussed in the first annual QCW progress report, WRRC Tech. Rep. No. 60, involved initial evaluation of two specific situations on the island of Kauai, although reference was also made to a study conducted by R.W. Grigg (1970) on the Hamakua coast of the island of Hawaii. The two situations on Kauai were the Kilauea Plantation area on the north coast and the McBryde Plantation on the south coast. There situations offered unique opportunities to investigate both the rather abrupt changes in sugar management of solid and liquid waste practices at the McBryde Sugar Company and the actual ceasing of operations at the Kilauea Sugar Company.

The changes in the McBryde Sugar Company's operations involved the installation of more than 70 small settling basins to control irrigation tailwater and storm water runoff and adopting positive controls to reduce the malfunctioning of a hydroseparator which is used for the sediment removal of cane washdown waste water. Limited analyses from two previous reports (Kennedy Engineers 1967; EPA Report 1971) were reviewed in the first QCW progress report in which the various operational aspects of the plantations were also outlined. The QCW project's experimental aspects of the study were minimal until the summer of 1972; thus, the first progress report was concerned mainly with relevant background information. Therefore, the progress report herein presented does not repeat the already documented results of the McBryde Company's present and past operations and cultural practices. Instead, it concerns the experimental results obtained from the QCW coastal monitoring program and their evaluations.

Cessation of the Kilauea Sugar Company's operations in November 1971, after 94 years in business, occurred at such a time as to afford a "before and after" study situation. The decision to close out the company's operations was apparently made for several reasons, the least of which was the fact that their tonnage of raw sugar harvested per acre was the lowest of the seven sugar companies on Kauai. The principal reason for this low production was believed to be the plantation's location on the wind swept north coast.

The waste water from the milling operation, which was located approximately one-half mile (.805 km) from the ocean, was flumed for a distance and discharged into nearby Niu Stream, which subsequently entered the ocean and produced a characteristic plume that generally extended for several miles. For the last three years before ceasing operations, bagasse and cane trash were removed from the waste water flow, however, approximately one-third was still transported by the waste water flow to the coastal waters where bagasse and cane trash were built-up on the beach in depths that exceeded 2 ft (.6096 m). In addition to this point pollution source, nonpoint discharges also occurred on occasion from irrigation tailwater overflow, storm runoff, and intentional irrigation water bypass.

The "before" study involved: an extensive physical, chemical, and biological study during July 1971 of the coastal waters and sediments in the area believed to be affected by the waste water in Niu Stream; physical and chemical analyses of waste waters; and review of the company's past records of operation, including cultivation practices, and fertilizer and pesticide applications. The "after" study involved quarterly monitoring of selected coastal water stations and Niu Stream.

The first progress report included a rather thorough study which comprised not only the company's past practices and the coastal station studies previously mentioned, but also studies involving soil, geology, hydrologic budget, and approximately one-half year of coastal monitoring after milling operations had ceased. As was mentioned for the McBryde Sugar Company's operation, the present progress report covering the Kilauea Plantation area does not repeat the background material already documented in the first progress report, except when necessary for clarity, but is primarily concerned with the QCW monitoring program.

FIELD AND LABORATORY OBSERVATIONS

Inasmuch as various specialized laboratories were participating in the sampling program, such matters as the size of sample, method of sampling, type of container, and special handling requirements were determined in advance of any sampling trip so that any single sample would serve the needs of the various specialized laboratories. Because of the distance between the McBryde and Kilauea Plantation areas two separate sampling boats were required.

Due to the urgency of obtaining samples before and immediately following the shutdown of the Kilauea Plantation activities, a greater initial effort was expended in this area than in the McBryde Plantation area.

Kilauea Plantation Area

The "after" phase at the Kilauea Plantation area, or more appropriate the former plantation area, is based on the premise that the mill discharge was the primary detriment to coastal water, sediment, and biota quality. This assumption was prompted by observation of a characteristic plume and waste deposition in the adjacent coastal water when the mill was operating and discharging waste water and was covered in the QCW first progress report.

Of less apparent magnitude in generating changes, if any, in the coastal environment are the nonpoint pollution sources. In all probability these will be altered by the substitution of sorghum culture and pasture operations for the original sugarcane culture. A description of the essential difference between sugarcane and sorghum culture has already been adequately described in the QCW first progress report. Cattle grazing is being introduced during this period of transition.

The most notable physical change that occurred following the cessation of mill activities in November 1971 was the general absence of the thick mats of bagasse and cane stalks on the beach, especially within one-quarter mile (.402 km) of the Niu Stream discharge point. By the following May (1972), after one winter's storm, these had essentially disappeared. Bagasse and cane stalks were still contained within the soil delta of Niu Stream but only a very small amount of cane stalks was noted near the high water mark within 1 mi (1.609 km) of the beach. Since the QCW study began, the beach configuration has been observed to have altered seasonally in height by an estimated 15 ft (4.57 m) and in width of nearly 100 ft (30.48 m), although a baseline topography survey was not performed. Sampling stations for the QCW studies in the Kilauea Plantation area were selected to complement the July 1971 study by Russo. The location of these sampling stations are shown in Figure 4.1.

Changes in Quality of Ocean Water

Some of the apparent effects on ocean water quality, as a result of cessation of operations of the Kilauea Sugar Company are suggested by Table 4.1, 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 (Fig. 4.1). The stations are located in water depths of 30 to 40 ft (9.14 to 12.19 m). The data show that by July 1973 (20 months after the mill had ceased operations), the concentration of the nutrients, potassium and phosphorus, had decreased to levels of about 490 mg/ℓ and <0.01 mg/ℓ, respectively. Nitrogen data were not reported. Lead was detected in the 1 to 4 μg/ℓ range, but cadmium and mercury were not detected. DDT and PCP were also not detected, in contrast to earlier reported results.

The potassium data reflect little change from the conditions observed during the period immediately before and after the cessation of Kilauea Mill operations. The phosphorus level is within the stipulated requirements of the water quality standards for Class A waters. There has been a decrease of from 75 percent to 85 percent in lead levels in the coastal waters since the mill has stopped operating. The overall net result can be categorized as a marked improvement in water quality as measured by these parameters.

Nutrients, Metals, and Pesticides in Sediments

Inasmuch as numerous compounds, especially those involving heavy metals, pesticides, and phosphorus are more likely to be absorbed in soil particles than dissolved in water, it was anticipated that sediments rather than water might be more revealing of effects of land use activities, especially milling operations, on the coastal water environment. Sediments, and especially the fines and clayey fractions, by their very nature of sorption, tend to serve as a sink in which some quality factors accumulate. 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.

Sediment input to coastal waters should theoretically decrease by the quantity of sediment reduction experienced with the cessation of the

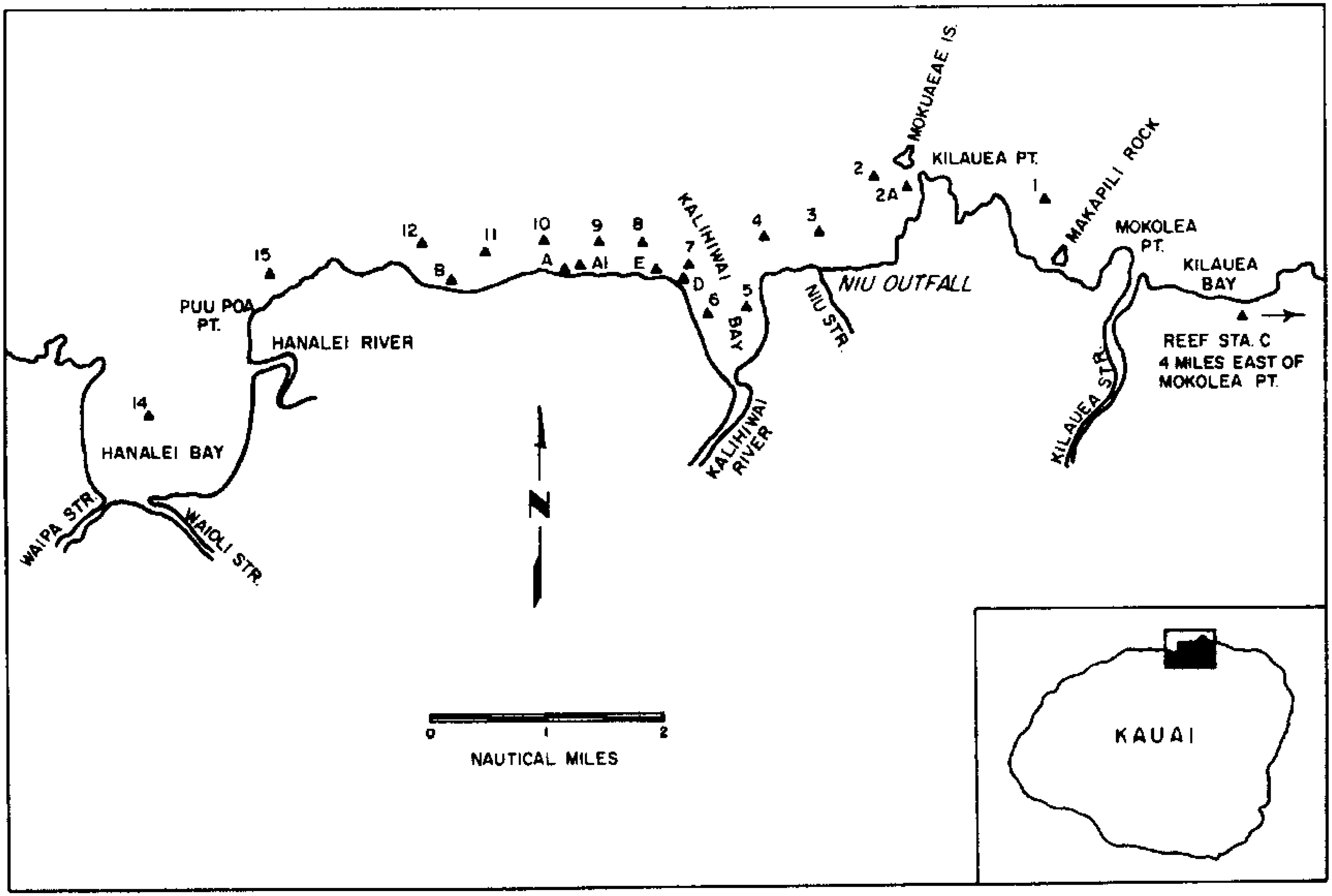


FIGURE 4.1. LOCATION OF OFFSHORE AND REEF STATIONS, KAUAI.

TABLE 4.1. NUTRIENTS, METALS, AND PESTICIDES IN OCEAN WATER, NORTH KAUAI, 1971-73.

DATE OF SAMPLING	STATION NUMBER	K (mg/ℓ)	P (mg/ℓ)	N (mg/ℓ)	Pb (μg/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		
01/13/72	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	
05/22/72	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
07/27/73	1	482	<0.01		3	ND	ND	ND	ND
	2	482	<0.01		2	ND	ND	ND	ND
	2A	482	<0.01		2	ND	ND	ND	ND
	3	518	<0.01		1	ND	ND	ND	ND
	4	490	<0.01		2	ND	ND	ND	ND
	5	490	<0.01		ND	ND	ND	ND	ND
	6	490	<0.01		4	ND	ND	ND	ND
	7	490	<0.01		2	ND	ND	ND	ND
	8	490	<0.01		2	ND	ND	ND	ND
	9	490	<0.01		2	ND	ND	ND	ND
	12	490	<0.01		2	ND	ND	ND	ND
07/27/73 AVERAGE CHEMICAL COMPOSITION OF SEA WATER*		380	0.07	0.5	0.03	0.11	0.03	—	—

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

*AFTER GOLDBERG 1963.

waste water load from the mill's activities in addition to the difference in sediment production between sugarcane culture, and sorghum culture and pasture land. Sorghum culture requires only about 70 percent of the water that sugarcane requires. However, numerous cultivation practices, soil types, topography, and land management practices are involved, therefore, it is not feasible to extrapolate, without extensive analysis, the sediment output from two different crop cultural practices.

Another influencing factor is the accumulated material from the mill's solid and liquid waste in the bed and sides of Niu Stream from the point of the mill's discharge to the stream's outlet on the coast. Such was observed in a field trip up Niu Stream during October 1971. Niu Stream has not been traversed again since that time by QCW personnel. Cursory observations of the stream bed condition within a few hundred feet of the coastal outlet were made in May 1972. The indications were that heavy storms during the winter and spring, especially one in early May 1972, had removed the major portion of the accumulated stream bed deposits. Thus, the effect of the residual from the mill's activities on the coastal region since its cessation, particularly for the time period starting after the end of the first winter season, should cease to be significant.

Sediment samples collected along Niu Stream between the mill discharge point and the coastal outlet were collected in October 1971 and the data presented in Table 4.2. Also collected on that same date were sediment samples from the beach area in the delta reach of Niu Stream as shown in Figure 4.2 and Kalihiwai Bay, located more than one-half mile (.8045 km) west of the Niu Stream outlet as shown in Figures 4.1 and 4.3.

As can be observed from Table 4.2, the nutrient levels in the sediments obtained at the beach sites in 1973 were less by a large degree than the amounts found in Niu Stream below the mill discharge in 1971; in fact, the nitrogen decrease was from 85 percent to 90 percent. The levels of the metals in 1973 were of the same order of magnitude for the Niu Beach and Kalihiwai Beach as in 1971 and considerably lower than was present in the 1971 Niu Stream sediment.

The Kalihiwai Bay beach area is undoubtably most influenced by the Kalihiwai River. However, as was noted in the first QCW project report, the plume originating from the milling operations often drifted to the west from the Niu Stream discharge point.

Nutrients, metals, and pesticides in ocean sediments, both before and after closing down the Kilauea Sugar Company activities, are presented for comparison purposes in Table 4.3. There was relatively little change in 1973 from the improved quality noted in January 1972 after the cessation of mill operations. A noteable difference was the measurement of DDT at all stations in the range from 125 to about 380 ppt. with Station 1 having the highest value of 642 ppt. It is not readily apparent whether this difference in DDT levels from earlier surveys represents some changed quality condition resulting from the changeover at Kilauea from sugarcane to sorghum operations.

COASTAL WATER ENVIRONMENTS AND BIOTA

Analyses of Micromollusc Assemblages

The marine ecosystems of the coastal area adjacent to the Kilauea Plantation were intensively surveyed and sampled for composition, diversity, and abundance of the biota over a period of four weeks in August 1971, with additional surveys and sampling at selected stations on

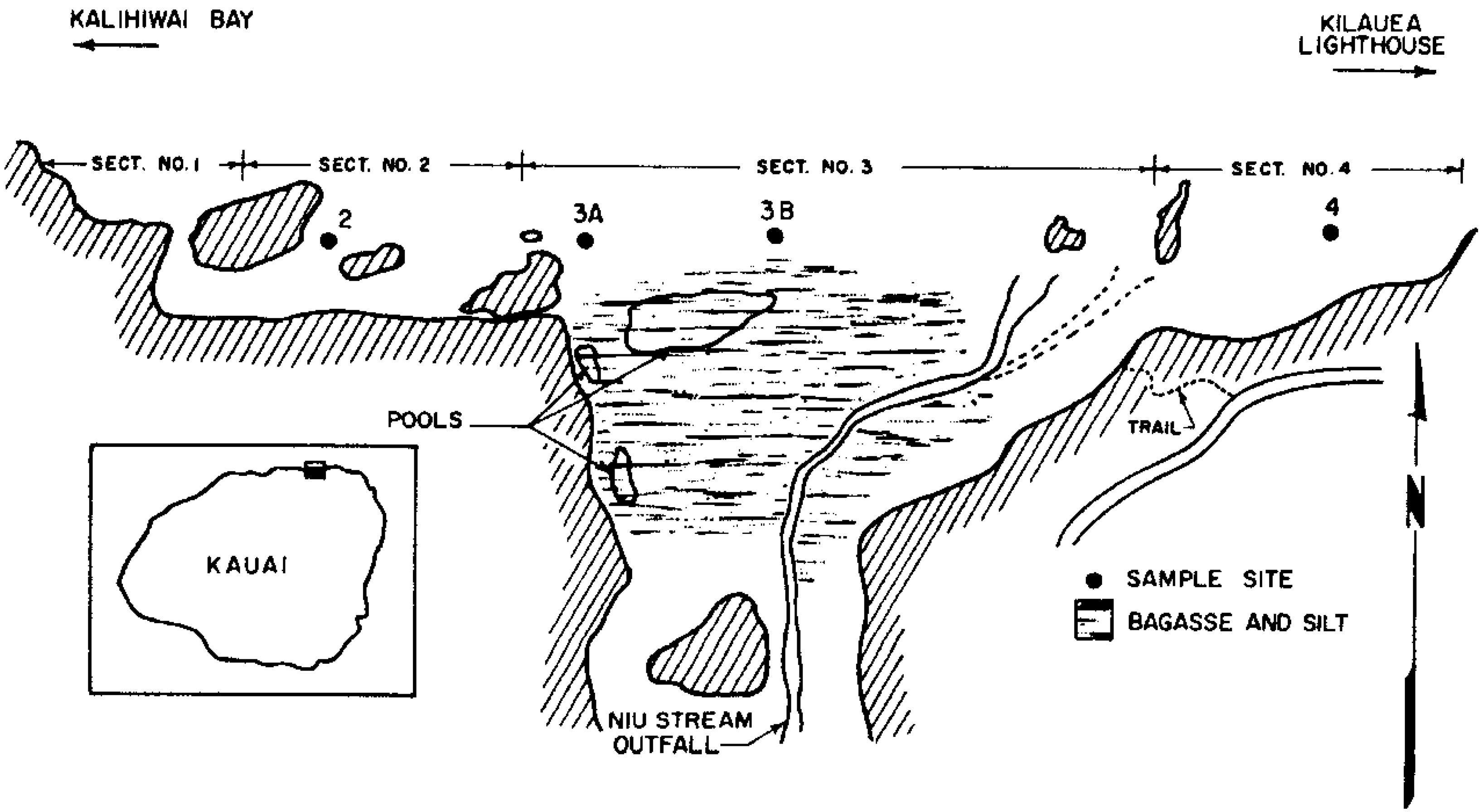


FIGURE 4.2. NIU STREAM DELTA AND BEACH SAMPLING AREA, KAUAI.

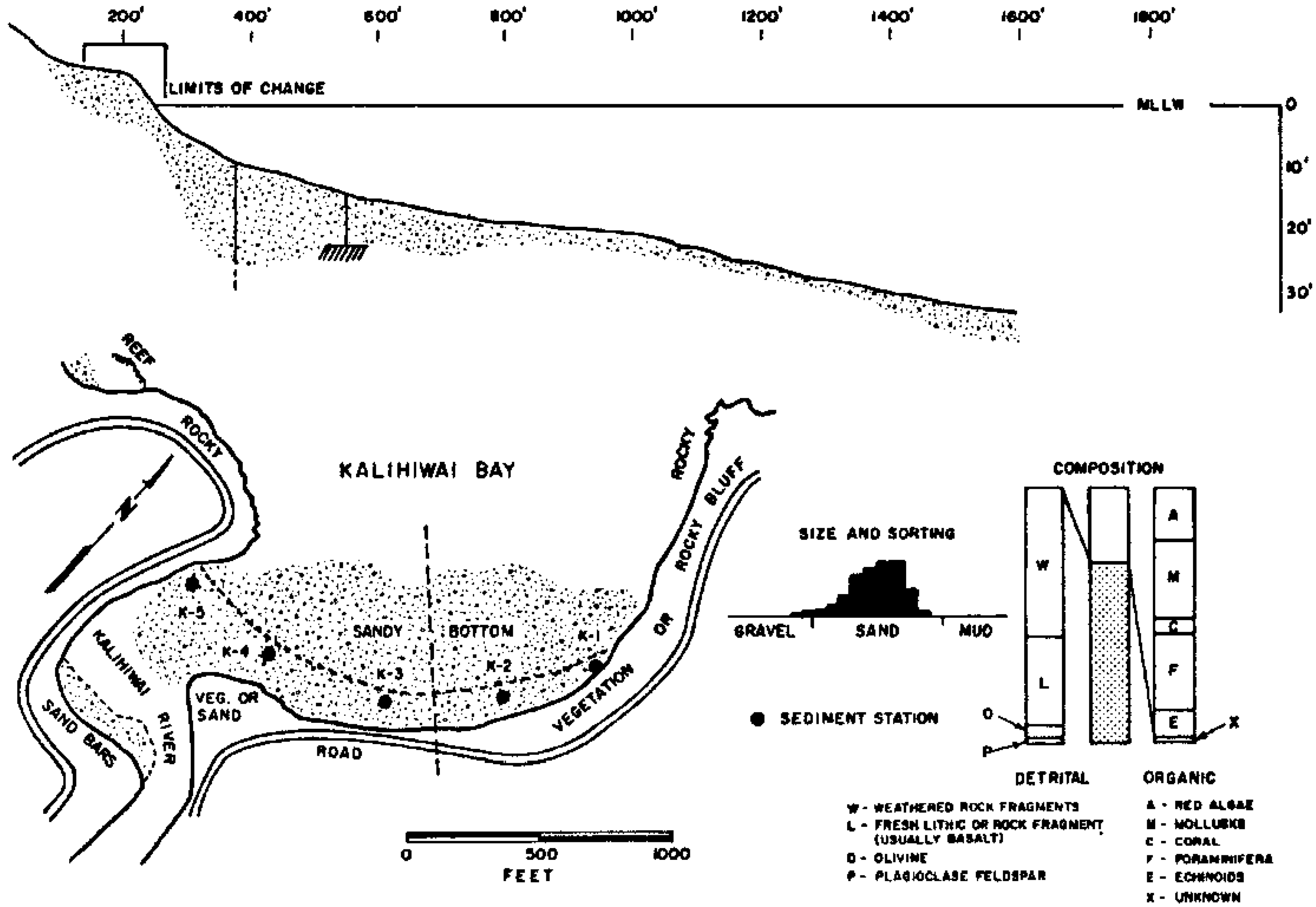


FIGURE 4.3. KALIHIWAI BAY BEACH SAMPLING AREA, KAUAI.

TABLE 4.2. NUTRIENTS AND METALS IN NIU VALLEY STREAM AND KALIHIWAI BAY BEACH SEDIMENTS, KAUAI.

SOURCE OF SAMPLE	SAMPLE SITE	CHEMICAL CONSTITUENTS (mg/kg, DRY BASIS) K	P	N	Cd	Cu	Hg	Pb	Zn
NIU STREAM (DOWNSTREAM FROM DISCHARGE PLUME) 10/71	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
NIU STREAM MOUTH 1973	KIL-2	2094	1956	1606	ND	84.4	0.78	26.6	92.6
KALIHIWAI BAY BEACH 10/71	K1	ND	ND	ND	2.6	19.9	ND	26.2	44.9
	K2	ND	ND	ND	1.3	21.4	0.09	26.8	50.3
	K3	ND	ND	ND	4.2	20.2	0.08	26.7	39.7
	K4	ND	ND	ND	4.6	25.0	0.08	35.6	44.2
	K5	ND	ND	ND	4.1	19.7	0.07	28.2	9.5
BEACH AT NIU STREAM OUTFALL 10/71	2	ND	ND	ND	2.7	7.9	0.06	26.9	3.5
	3A	ND	ND	ND	2.8	11.1	0.10	30.1	7.6
	3B	ND	ND	ND	2.8	8.4	0.22	15.6	8.4
	4	ND	ND	ND	3.2	12.0	0.06	28.8	7.6
KALIHIWAI BAY BEACH 07/25/73	K1	704	543	77	3.7	15.9	0.08	33.5	33.3
	K2	591	524	ND	2.2	13.9	ND	50.6	33.7
	K3	703	640	82	3.6	14.2	ND	35.5	30.5
	K4	606	464	83	3.5	16.4	ND	29.4	36.4
	K5	321	252	66	2.1	8.9	ND	24.4	11.3
BEACH AT NIU STREAM OUTFALL 07/26/73	2	211	396	39	3.8	2.8	ND	12.5	6.0
	3A	237	413	155	3.4	4.6	ND	16.3	7.1
	3B	215	414	64	2.6	3.9	ND	19.4	7.8
	4	318	547	51	3.0	5.2	ND	15.2	13.1

September, October, and November, 1971 prior to the cessation of mill operations in November 1971. The coastal marine communities were also monitored in May and November, 1972, and again in the spring of 1973 to attempt to ascertain changes that may have been influenced by the mill's activities.

Three coastal ecosystems are distinguished in the 1971 survey: the subtidal, which includes offshore assemblages of corals, fish and micro-molluscs at depths of 30 ft (9.14 m) in the area of the former mill discharge point (Stations 1 to 4, Fig. 4.1); the offshore frontal edge of the reef which fringes the coastline from Kalihiwai Bay to Hanalei at depths of 30 ft (9.14 m) (Stations 7 to 13, Fig. 4.1); and the intertidal reef flat which fringes the northern section of the area under study (Stations A to E, Fig. 4.1).

In the area immediately offshore of the former mill outfall (Stations

TABLE 4.3. NUTRIENTS, HEAVY METALS, AND PESTICIDES IN OCEAN SEDIMENTS, NORTH KAUAI AREA, 1971 AND 1973.

STATION	DATE	T-N mg/kg	T-P mg/kg	T-K mg/kg	Pb mg/kg	Hg mg/kg	Cd mg/kg	Cu mg/kg	Zn mg/kg	DDT ng/kg
A	07/07/71	437	294	300	17.3	ND	2.4	8.8	12.8	-[a]
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	-
1	07/26/73	354	319	504	20.5	0.03	3.9	4.1	9.4	642
2	"	344	402	532	31.6	ND	4.3	6.1	14.2	183
2A	"	311	340	316	25.0	ND	3.7	5.9	8.9	332
3	"	125	396	246	26.2	ND	3.9	4.1	8.7	184
4	"	196	369	388	28.5	ND	4.8	4.1	8.4	189
5	"	80	539	512	20.2	0.05	3.6	12.9	34.2	379
6	"	194	510	703	25.4	ND	2.4	13.2	30.0	125
7	"	219	343	163	22.2	ND	3.8	2.9	4.2	197
9	"	215	382	215	25.5	ND	4.1	1.8	4.1	224
12	"	311	341	233	30.0	ND	4.3	8.2	4.3	309

[a]IN ALL SEDIMENTS THE FOLLOWING PESTICIDES WERE NONDETECTABLE: 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.

1 to 4), there was little or no coral growth or other benthic biota. The micromolluscs from sediments at the four stations are few in number (2.8/cu cm of sediment) and species, and are of a mixed subtidal-shallow water composition. The epibenthic community at the 30-foot (9.144-m) depth stations fronting the reef (Fig. 4.1, Stations 7 to 13) which exhibit 50 to 80 percent coral cover, is dominated by *Montipora*, but the community shows little coral diversity. Sea urchins, which comprise a significant part of the subtidal communities along many Hawaiian shorelines, are less abundant and diverse than in comparable areas elsewhere. There is, however, an abundance and variety of *in situ* shells of micromolluscs in the sediments from these stations with a standing crop estimated at 10.7 shells/cu cm of sediment. Species composition, dominated by rissoids and diastomids, is similar to that elsewhere in the Hawaiian Islands at comparable depths. The reef flat is characterized by a predominantly cerithioid/rissoinid assemblage of micromolluscs, with standing crops of from 5.8 to 11.8 shells/cu cm, and with numbers of species ranging from 29 to 40 in the samples examined.

During the months of mill operation at Kilauea Plantation, discharge from the mill discolored the receiving waters off the north coast of Kauai for distances of at least 5 miles (8.05 km) from the outfall, and at times increased the urbidity of the water thirtyfold. Bagasse and other cane debris were found both on the intertidal reef flat and subtidally for distances as great as 3 miles (4.83 km) from the outfall. In the first QCW progress report, it was suggested that both the low abundance and diversity of the biota of the subtidal stations offshore of the mill outfall (in Niu Stream) and also offshore of the reef front may have either been caused by the effects of wastes discharged by mill operations, or may have resulted naturally from wave abrasion and complex currents in the area.

Since the cessation of mill discharge in the Kilauea area, several changes have occurred. The turbidity of the offshore waters has decreased, and bagasse and other cane trash are noticeably disappearing from the area. Fish populations have reportedly increased.

Monitoring of Stations 1 to 4 subsequent to initial observations, however, shows little or no change has occurred in the epibenthic communities in the area. These observations, although based on a relatively short span of time, would tend to confirm the hypothesis proposed in the 04 Program Year that the sparseness of the biota in the region formerly associated with the mill outfall is largely determined by the physical parameters of wave action and currents rather than by the effects of agricultural practices.

In 1971 Stations 1 to 4 were characterized by worn sedimetns with low species counts and abundance of micromolluscs (Table 4.5). The species composition suggested an assemblage of micromolluscs transported from both shallow water areas inshore and from offshore subtidal communities some distance from the area. Data obtained subsequent to 1971 are shown in Table 4.5 A: the sediments and shells remain as they were in 1971, worn, poslished, and species composition remains a mixture of shallow water and subtidal forms. Both species numbers and standing crop

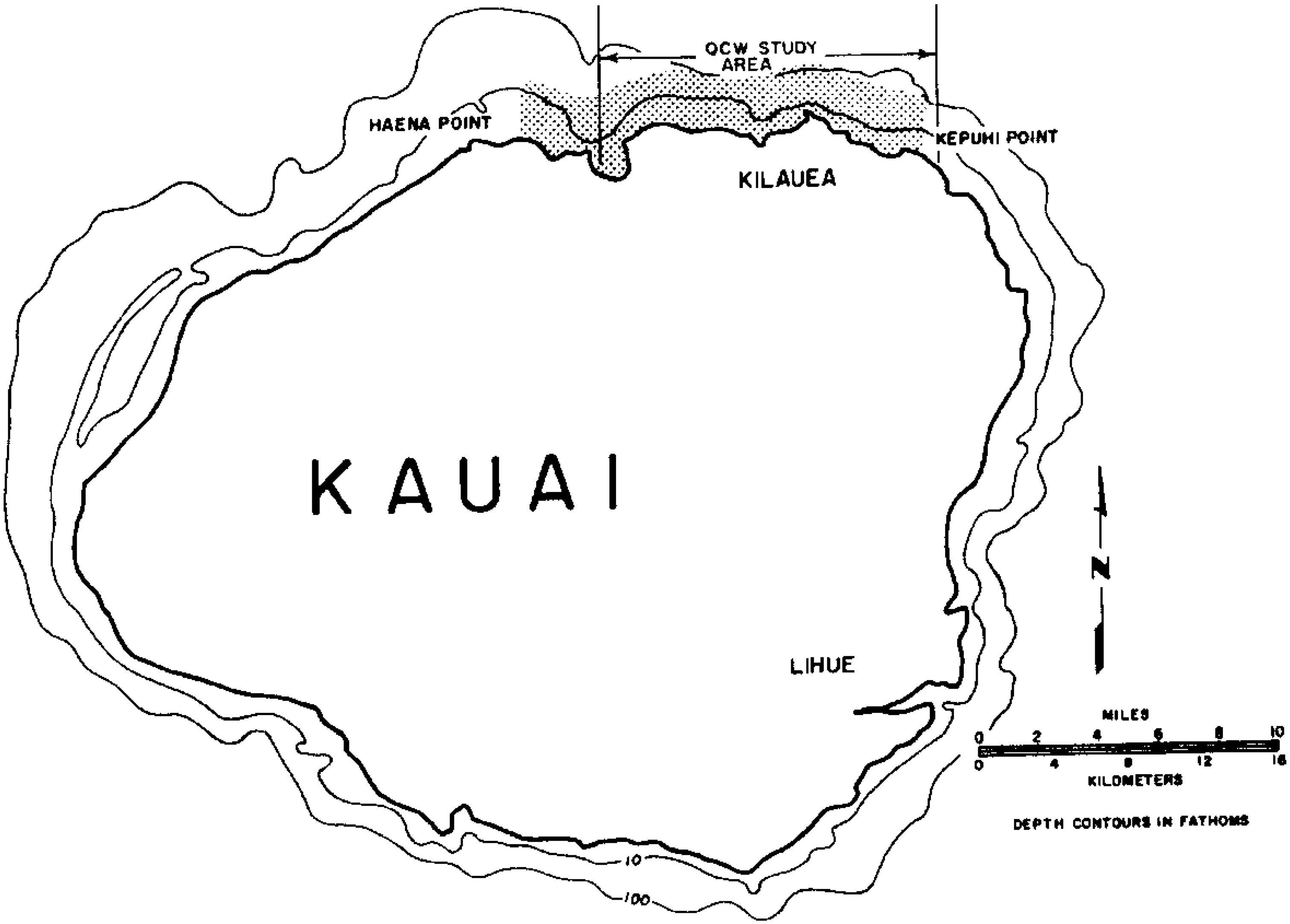


FIGURE 4.4. LOCATION OF FISH CATCH AREA 503, KAUAI.

TABLE 4.4 COMMERCIAL FISH CATCH AREA 503 (BY CALENDAR YEAR).

	OMILU	ULUA	AKULE	HAHALALU	MULLET	MANINI	MOI	OPELU	OPIHI[a]	LIMU[b]	MENPACHI	KUMU	AWEOWEO	OCTOPUS	TOTAL
1973															
WEIGHT[c]	--	975	38,906	428	2014	67	2893	19,248	72	103	336	5	156	428	65,631
VALUE[d]	--	771.80	14,311.42	220.00	2592.23	37.55	2888.34	7586.90	140.00	366.50	347.00	7.50	90.40	534.25	29,893.39
1972															
WEIGHT	7	597	55,440	59	1169	304	3974	1413	608	171		10	140	95	63,987
VALUE	8.35	714.91	18,799.49	26.55	1550.35	182.40	5284.05	702.95	584.10	598.50	--	10.20	93.20	104.50	28,659.55
1971															
WEIGHT	300	765	20,332	314	1045	1470	965	6238	168	156	9	14	66	309	32,151
VALUE	300.00	256.17	8510.22	82.95	992.46	914.50	1274.20	1671.09	197.90	510.90	6.55	14.80	28.35	324.00	15,084.09
1970															
WEIGHT	--	264	21,364	15	1628	367	3251	2355	114	361	18	14	40	415	30,206
VALUE	--	209.15	7676.63	5.25	2048.88	216.55	3819.59	1104.56	123.75	1087.00	14.20	14.50	14.90	389.35	16,724.31
1969															
WEIGHT	--	272	7922	45	3639	1444	1578	--	5	303	16	11	19	612	15,866
VALUE	--	196.25	2658.70	20.25	3952.60	801.64	1598.30	--	3.03	483.00	12.50	13.10	6.95	527.20	10,273.52
1968															
WEIGHT	690	306	8429	128	4148	1338	2082	7360	115	--	9	2	101	991	25,699
VALUE	586.97	302.05	5610.70	56.10	3754.43	696.71	1782.01	1795.84	92.00	--	5.00	1.00	36.90	774.59	15,494.30
1967															
WEIGHT	549	63	5712	1339	1887	1744	4298	--	50	5	--	--	399	1531	17,571
VALUE	382.25	41.75	2272.20	575.75	1684.50	944.55	3237.26	--	60.00	7.50	--	--	148.30	1146.85	10,500.91
1966															
WEIGHT	--	96	13,673	20,452	2455	1628	2164	153	--	--	8	31	202	2130	42,992
VALUE	--	91.75	5965.17	4427.90	2178.08	820.24	1709.95	33.60	--	--	4.30	31.60	59.20	1527.70	16,849.49
1965															
WEIGHT	345	128	1622	--	2934	993	2105	83	--	--	6	2	156	1500	9874
VALUE	309.60	128.20	1171.05	--	2523.95	496.50	1664.65	33.20	--	--	2.70	0.85	60.40	1011.35	7402.45
1964															
WEIGHT	138	235	3087	22	3290	1203	1684	111	--	--	--	--	--	1576	11,346
VALUE	136.00	196.80	2327.95	16.50	2742.61	585.75	1386.49	46.05	--	--	--	--	--	1043.85	8482.00
1963															
WEIGHT	101	315	851	4369	4097	870	1503	--	--	--	--	--	--	1829	13,935
VALUE	90.90	132.90	606.25	2434.32	3242.45	440.25	1279.67	--	--	--	--	--	--	1223.88	9450.62
1962															
WEIGHT	--	1061	1831	4401	3114	379	2386	13,909	--	--	--	--	--	400	27,481
VALUE	--	628.80	1057.85	2136.90	2413.60	191.50	1405.90	2397.22	--	--	--	--	--	285.95	10,517.72

[a] OPIHI = LIMPET.
[b] LIMU = SEAWEED.
[c] WEIGHT IN POUNDS.
[d] VALUE IN DOLLARS.

TABLE 4.5. ANALYSIS OF MICROMOLLUSCS FOR KILAUEA STATIONS, 1971-72.

A. STATIONS 1 TO 4

	STATION 1		STATION 2					STATION 3			STATION 4			
	VIII-71	V-72	VII-71	I-72	V-72	VII-72	VII-71	XI-72	V-72	VII-72	VII-71	XI-71	V-72	VII-72
NO. SHELLS	40	38	74	26	10	135	96	23	176	36	115	42	32	25
NO/cm²	1.6	1.5	30	1.0	.40	5.4	1.8	.92	7.0	1.4	9.6	1.7	1.3	1
NO. SPECIES	18	18	27	11	8	27	23	15	25	18	24	17	16	7

B. STATION 7

	STATION 7			
	VII-71	XI-72	V-72	VII-72
NO. SHELLS	212	476	186	622
NO./cm²				
NO. SPECIES	28	45	36	54
COMMON ABUNDANCE VALUES FOR VII-72		65%	68%	60%

remain low and are variable.

Station 7, off the fringing reef, was also monitored during the current project year 05. It too apparently remains relatively little changed (Table 4.5 B). Although both numbers of species and abundance vary in the four samples analyzed, there is no apparent pattern to the variation; the differences which do occur may be attributed to different sampling sites at the station. Common abundance values (based on Wieser, 1960) comparing the August 1971 sample with three subsequent samples in 1972 range from 60 percent to 68 percent (Fig. 4.5). These figures are among the highest for all stations compared by this method, indicating sampling is from a stable assemblage. Species composition over the four sampling periods also remains relatively stable: *Rissoina miltozona* is the dominant species in three of the four assemblages, and second in the fourth. Shannon-Weaver diversity indices (Pielou 1969), calculated according to the formula $D = -\Sigma P_i \log_2 P_i$, where P_i equals the fraction of the total individuals represented by each species, for the samples show values ranging from 4.03 to 4.78 (Table 4.5).

The reef flat stations were not monitored during the program year 05, but the results of the program year 04 are analyzed in more detail than they were formerly and compared with those of other fringing reefs in the islands in Chapter 5 of this report.

From the data several tentative generalizations can be made about the effects of mill discharge on the receiving waters off the Kilauea coast of Kauai: 1) there was no evidence that the coastal waters were subjected to eutrophication, but there is evidence that they were subject to the physical effects of the discharges, notably in the turbidity of the water and the presence of discharge wastes, bagasse and trash, along considerable areas of the coastline; 2) the adverse effects of the discharges are transitory, as shown by the decrease in turbidity and disappearance of bagasse and other trash and by the increased occurrence of fish in the area; and 3) it would appear that the epibenthic communities, at least at depths of 30 ft (9.14 m), are more strongly influenced by the effects of waves, currents, and general coastal topography than by the effects of millwaste.

SOUTH COAST OF KAUAI: McBRYDE SUGAR COMPANY

General Description of the McBryde Sugar Company Area and Operation

As indicated in the Introduction the McBryde Sugar Company, located on the south coast of Kauai, was selected as a second major coastal zone study on Kauai because it afforded an opportunity to observe various quality coastal zone parameters in a situation where sugarcane land use management and waste water practices have undergone extensive changes in recent years, and the willingness of the McBryde Sugar Company to cooperate with the Quality of Coastal Waters project in the study. The McBryde study differed markedly from the situation at Kilauea where urgency necessitated, by the rather abrupt announcement of cessation of sugar mill operations, that to obtain a "before" and "after" study extreme expediency in the

STATIONS MO.-YEAR	KIL.7 7-71	KIL.7 1-71	KIL.7 5-72	KIL.7 7-72	KIL.9 7-71	KIL.13 7-71	K.L. 7-71	K.L. 5-72	KUK. 7-71	LAW. 7-71	LAW. 5-72
KIL.7 7-71		0.65	0.68	0.60	0.55	0.65	0.93	0.46	0.61	0.35	0.38
KIL.7 1-71					0.55	0.59	0.49	0.52	0.59	0.39	0.38
KIL.7 5-72					0.53	0.54	0.38	0.37	0.54	0.32	0.30
KIL.7 7-72					0.49	0.59	0.41	0.54	0.53	0.50	0.50
KIL.9 7-71						0.48	0.39	0.36	0.42	0.20	0.28
KIL.13 7-71							0.41	0.45	0.59	0.41	0.43
K.L. 7-71								0.55	0.54	0.38	0.28
K.L. 5-72									0.61	0.49	0.40
KUK. 7-71										0.47	0.36
LAW. 7-71											0.63
LAW. 5-72											

LEGEND

> 60 %

> 50 %

< 50 %

KIL. = KILAUEA
K.L. = KOLOA LANDING
KUK. = KUKUIULA
LAW. = LAWAI
KIL.7 → STATION NUMBER
7-71 → MONTH-YEAR

NUMBERS REPRESENT PERCENT EXPRESSED AS A FRACTION

FIGURE 4.5. TRELLIS DIAGRAM SHOWING COMMON ABUNDANCE VALUES FOR MICROMOLLUSCS AT KILAUEA AND McBRYDE STATIONS, KAUAI.

initiation of the study would be required. Moreover, a modest amount of data on the quality of coastal waters in the area had been made at about the time the McBryde Sugar Company instituted land use management and waste water control measures. 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 Sugar Company provided an excellent place to evaluate the quality of the ocean water and water environment in terms of what the industry was not discharging.

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 have been relatively minimal.

The general location of the separately designated land areas (field plots) are depicted in Figure 4.6. The site of the company's mill and plantation offices are located in land area 5B. As shown in Figure 4.6, the company lands front on the southern coast of Kauai for a distance of 6.5 mi (10.47 km) from Hanapepe Bay on the west to Poipu Road, south of Koloa, on the east. The plantation covers an area of approximately 22,500 acres (13,162.5 ha), of which greater than 5900 acres (2389.5 ha) are cultivated for sugarcane. Primarily because the long-term average annual rainfall has ranged from approximately 24 to 60 in. (60.96 to 152.4 cm), only about 250 acres (101.25 ha) of sugarcane land is not irrigated. Nearly all water is applied by furrow irrigation; however, the company has been utilizing overhead sprinkler systems on a limited amount of acreage in order to evaluate their water conserving and field water retention capacities, as well as economic aspects. Experiments are also being conducted with drip irrigation.

The various classifications of recent land use for the McBryde Sugar Plantation are presented in Table 4.6. With the exception of pineapple lands taken into cultivation during 1962 and 1963, the McBryde Sugar Company has been cultivating the same land since the early 1900's. Cultural practices including fertilization application and techniques have changed in method over the years as improved equipment has become available. The average quantities of various types of fertilizers, herbicides, and chemicals used in the sugar milling process are detailed in the first progress report (Lau et al. 1972).

The McBryde Plantation obtains its irrigation water from a number of sources. A potential surface water storage capacity of 2 billion gal (7,570,000 m^3) is stored behind some 19 dams and other small reservoirs, the largest of which is the 814 million gal (3,080,990 m^3) capacity reservoir behind Alexander Dam which is located near the headwaters of Wahiawa Stream, an area which receives approximately 160 in. (406.40 m) of rain per year. Part of the water behind Alexander Dam is used as a county water supply, however, enough is still available to irrigate 1100 acres (445.5 ha) of sugarcane land after it is transferred through tunnels for electric power generation.

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

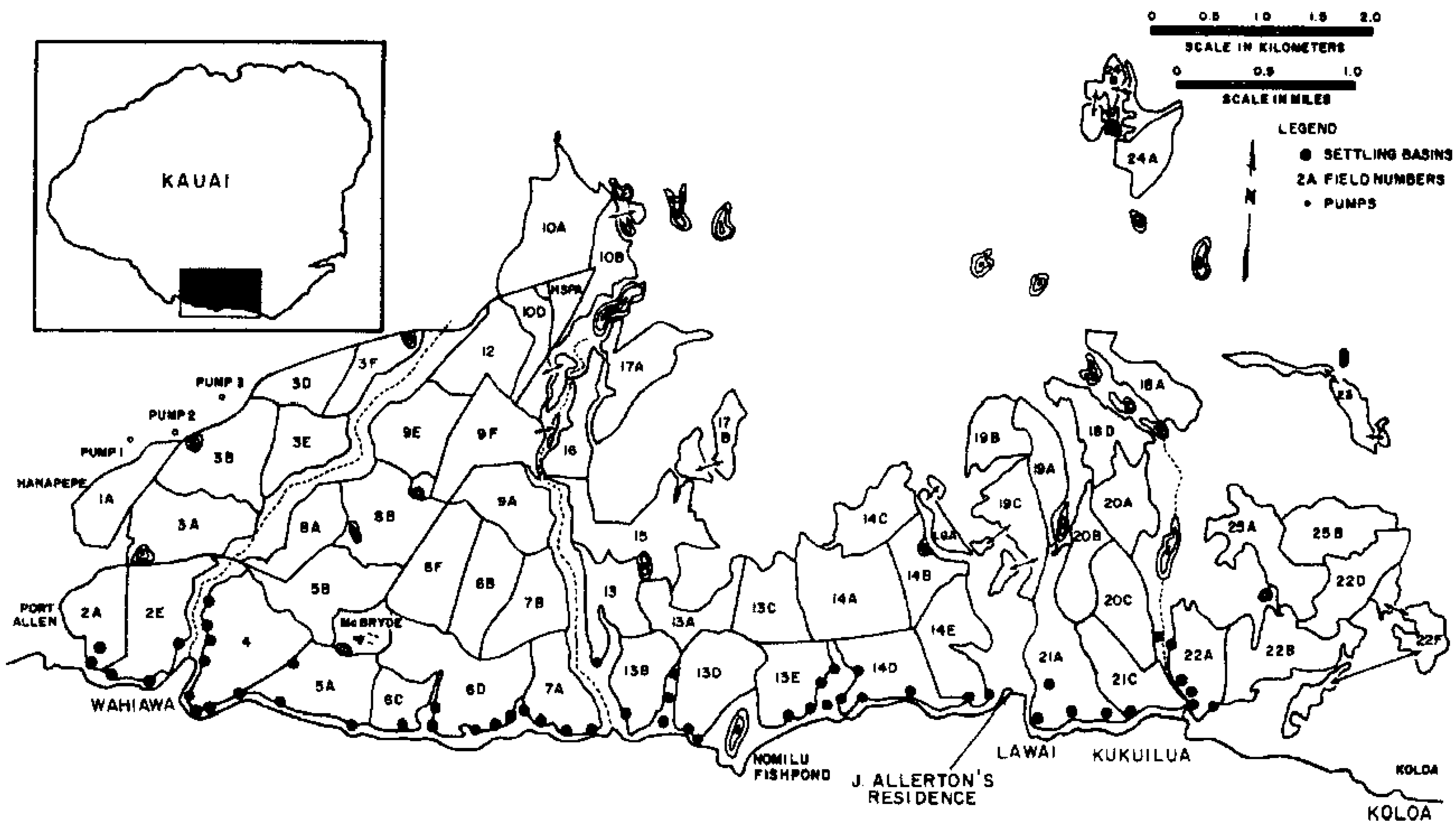


FIGURE 4.6. MAP OF FIELDS AND TAILWATER RETENTION PONDS, MCBRYDE SUGAR COMPANY, KAUAI.

TABLE 4.6. LAND USE, McBRYDE SUGAR CO., LTD., 1972.

LAND USE	ACREAGE
SUGARCANE	5,931
FOREST	12,969
FIELD 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

capacity of 6 mgd (22.710 m^3/day) from which water is pumped into reservoirs or irrigation ditches. However, the largest pumping works extract water from horizontal infiltration tunnels in Hanapepe Valley and delivers it to canefields in an area extending from Hanapepe Valley to Lawai Valley.

Waste Water Management

Two major coastal water quality control measures are construction of some 70 random-sized small ponds at the lowest end of the furrow system and the use of a hydroseparator followed by retention in a mill reservoir before the supernatant is recycled back to the irrigation water system. Accumulation of solids in the mill reservoir are allowed to dry after each milling season and then transported to a low lying land area which is being reclaimed by this practice. Line grades of the furrows have also been flattened from 3 to 5 percent to 1.5 to 2 percent in an effort to reduce the potential of tailwater overflow. The ponds 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 except in relatively rare occasions when flood flows exceed the reservoirs' capacity; however, the frequency of occurrence, although not documented to a high degree of accuracy, is estimated to occur only a total of ten times or so per year from one pond or another. Consequently, the quantity of sediment entering coastal waters by means of tailwater runoff over a period of one year is considered essentially negligible. Whether or not the occasional spill is likely to carry a significant quantity of agricultural chemicals can only be evaluated through an extensive coastal zone monitoring program.

Previous Studies

Two previous studies of sugarcane culture and milling operations in the State of Hawaii from November 1966 through September 1968, which are relevant to the McBryde Plantation study area, were conducted by Kennedy Engineers for the Hawaiian Sugar Planters' Association and by a federal agency now known as the Environmental Protection Agency (EPA). The various aspects of these two reports, as they apply to the McBryde Plantation area and to a limited extent to other sugar culture and milling activities on the neighboring islands, are adequately outlined in the first progress report (Lau et al. 1972). Thus, the limited quantity of coastal water quality data generated in the McBryde Sugar Plantation area will only be referred to when applicable in the present progress report. The Kennedy report involved studies of secchi disc readings, dissolved oxygen, suspended solids, BOD_5, and coliform measurements in the coastal waters while the EPA report was limited to turbidity studies of the offshore waters.

The quality of the McBryde sugarcane mill waste water at various points of treatment, as sampled on three surveys between July 1967 through March 1968 by the EPA report (1971), is shown in Table 4.7.

Malfunctions in the hydroseparator at the McBryde Milling Operation during this study period, according to company records, occurred 82 times in 1967 and 85 times in 1968. During periods of malfunctions the mill washwater was bypassed to a ditch that terminated in the ocean. In 1969 the number of discharges to the ocean declined to 26 and thereafter from 1970 there were no occasions of direct discharge of mill waste water to the ocean. When malfunctions of the hydroseparator occurred, the mill waste water was discharged directly into the mill waste water reservoir. Malfunctions of the hydroseparator were reduced in 1970 by means of lighter loadings to the equipment by diverting the mud press from the vacuum filters onto the leafy trash carrier for land disposal, and by increasing the horsepower of the hydroseparator underflow pump motor.

The ability of the mill waste water reservoir to remove suspended and settleable solids and to a lesser degree other constituents is readily apparent in Table 4.7. The type of constituents surveyed in Table 4.7 represent a typical "sanitary" survey. Since the 1967 to 1968 time period,

TABLE 4.7. QUALITY OF THE MILL WASTE WATER RESERVOIR McBRYDE SUGAR CO., 1967-68.

SOURCE OF SAMPLE	MPN COLIFORMS TOTAL	MPN COLIFORMS FECAL	SOLIDS (mg/ℓ) TOTAL	SOLIDS (mg/ℓ) SUS-PENDED	SOLIDS (mg/ℓ) SETTLE-ABLE	BOD	COD	TOC	TOTAL N	TOTAL P
INFLUENT	905	116	250	13	8	8	6	4	0.4	0.03
CONDENSER	475	126	30	20	10	14	42	13	0.6	0.15
WASHWATER	4.85×10^{6}	4880	12,000	10,700	10,500	800	2300	710	44.0	13.00
HYDROSEPARATOR 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

SOURCE: EPA 1971.

there has been considerable interest on the national and local levels to determine the level of additional constituents, mainly heavy metals and pesticides.

Field and Laboratory Observations

Various standard constituents, heavy metals, and pesticides from the McBryde Sugar Company mill waste water reservoir were collected and analyzed on five occasions from August 1971 to July 1973. Unfortunately, a portion of the July 1973 samples was lost. As can be observed in Table 4.8, the November 1971 sample was very high in solids, although when compared to the remaining corresponding constituents, it appears that the high solids were primarily inorganic in nature and actually lower in dissolved solids than the samples from the other four sampling dates. Neglecting the November 1971 sample, the total solids are nearly the same as found in Table 4.7, and the remaining corresponding constituents are much lower. The heavy metals and pesticide values are very low, except for the August 1971 PCP value of 260 ng/ℓ; however, this is still only approximately one-quarter ppb.

The results of the quality of irrigation tailwater at five selected locations as ascertained by the EPA in the same study (EPA 1971) is presented in Table 4.9.

As was the case with the constituents in Table 4.7 from samples collected from the mill waste water reservoir, the constituents evaluated in Table 4.9 represent a "typical" sanitary survey. It must be appreciated, however, when analyzing grab samples from irrigation tailwater that the time of collection in relation to numerous environmental factors,

TABLE 4.8. QUALITY OF THE MILL WASTE WATER RESERVOIR, IN LAND AREA NO. 5A, McBRYDE SUGAR CO.

CONSTITUENT	DATE				
	AUG 1971	SEP 1971	NOV 1971	DEC 1971	JULY 1973
pH, UNITS	6.5	6.5	6.9	7.5	—
TOTAL SOLIDS, mg/ℓ	1956	504	8564	362	—
VOLATILE SOLIDS, mg/ℓ	1356	406	1310	108	—
SUSPENDED SOLIDS, mg/ℓ	600	44	8202	36	—
TURBIDITY, FTU	800	HIGH	HIGH	32	—
CONDUCTIVITY, μmhos/cm	620	600	310	420	—
DO, mg/ℓ	2.0	3.2	0.4	—	—
BOD, mg/ℓ	700	16	—	—	—
COD, mg/ℓ	740	24	116	84	—
TOTAL-N, mg/ℓ	0.10	7.98	1.1	0.7	—
TOTAL-P, mg/ℓ	0.97	0.25	0.02	0	—
Cl^-, mg/ℓ	230	147	88	112	—
Pb, μg/ℓ	8	10	14	ND*	2
Cu, μg/ℓ	—	—	2	4	2
Zn, μg/ℓ	—	—	12	14	6
Cd, μg/ℓ	2	1	ND	ND	ND
Hg, μg/ℓ	ND	1.2	ND	ND	ND
Cr, μg/ℓ	—	—	—	—	ND
Ni, μg/ℓ	—	—	—	—	35
As, μg/ℓ	—	—	—	—	2
DDT, ng/ℓ	8.0	ND	3.0	1.0	—
PCP, ng/ℓ	260	45	35	ND	—

*NONDETECTABLE

especially rainfall intensity and duration and the sequence of irrigation water application and management, has a vast effect on the quality of the sample. Other subtle factors are also involved, for example, during periods of heavy storms the roads leading to the sampling sites may be inaccessible, thus inhibiting the collection of samples during extreme conditions. As shown in Table 4.9 for the 1967 to 1968 period, total solids ranged 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 25.1 mg/ℓ, and coliforms from 500 to 250,000/mℓ. All the high values noted, however, appeared in Field 5B. Of the five fields examined, only 5B showed much evidence of a serious pickup of material from the field, although Field 12 was somewhat high in solids. It must be emphasized, however, that the values presented in Table 4.9 were obtained from samples of excess tailwater before the major construction of tailwater interception ponds

TABLE 4.9. QUALITY OF IRRIGATION TAILWATER, McBRYDE SUGAR CO., 1967-68.

PARAMETERS ANALYZED	FIELD NUMBER				
	13A	8B	12	9A	5B
TOTAL SOLIDS (mg/l)	574	204	900	92	3,390
SUSPENDED SOLIDS (mg/l)	248	112	584	40	3,230
SETTLEABLE SOLIDS (mg/l)	174	106	288	34	2,280
COD (mg/l)	37	14	55	1	347
TOTAL ORGANIC CARBON (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
TOTAL-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 (UNITS)	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

SOURCE: EPA 1971.

occurred, although it should be noted that the first pond was constructed in 1967.

The quality of water collected from an irrigation tailwater interception pond in McBryde's Field No. 14D is shown in Table 4.10. As noted previously, these ponds only experience overflow on relatively rare occasions when an extreme storm occurs, thus, in terms of effects on the coastal water biosystem, the values in Table 4.10 are not necessarily comparable to the values in Table 4.9 for the excess irrigation tailwater. However, it is interesting to note that the solids content for the September 1971 sample was approximately three times higher than the high values reported for Field 5B in Table 4.9. One important aspect regarding any evaluation of water quality from a settling pond is the quantity of water in the pond. After heavy rains and/or excessive irrigation tailwater runoff the collected samples may be very dilute, whereas, after a long dry spell the effects of evaporation and percolation may produce very concentrated water in the pond, thus vastly altering the solids concentration. As can be noted in Table 4.10, the heavy metals and pesticide values are quite low.

From a consideration of the two past coastal water quality studies conducted near the McBryde Sugar Plantation coastline (Kennedy Engineers 1967; EPA 1971), it is evident that the parameters of water quality used in 1967 to 1968 for coastal waters are not adequate, for the 1970's. Both the intensity of concern for aesthetic values and the range of quality factors of concern have increased markedly in the interval. Nevertheless,

TABLE 4.10. QUALITY OF IRRIGATION TAILWATER INTERCEPTION POND IN FIELD NO. 14D, McBRYDE SUGAR CO., 1971-72.

CONSTITUENT	DATE					
	AUG 1971	SEP 1971	NOV 1971	DEC 1971	JULY 1972	JULY 1973
pH, UNITS	7.1	7.9	7.7	7.5	7.7	--
TOTAL SOLIDS, mg/ℓ	744	9050	434.00	1718	547	--
VOLATILE SOLIDS mg/ℓ	698	700	128.00	284	147	--
SUSPENDED SOLIDS mg/ℓ	46	8350	10.00	1434	9	--
TURBIDITY, FTU	100	32	75.00	HIGH	9.2	--
CONDUCTIVITY, μmhos/cm	540	590	480.00	400	680	--
DO, mg/ℓ	7.7	7.0	7.30	--	--	--
BOD, mg/ℓ	12	14	--	--	--	--
COD, mg/ℓ	270	843	0.00	18	--	--
TOTAL-N, mg/ℓ	0.63	1.80	0.00	0.7	0.59	--
TOTAL-P, mg/ℓ	0.16	0.30	0.00	0.02	0.057	--
Cl, mg/ℓ	240	112	131.00	110	22	--
Pb, μg/ℓ	8	12	ND[1]	ND	--	2
Cu, μg/ℓ	3	6	5.00	2	--	ND
Zn, μg/ℓ	2	7	12.00	7	--	10
Cd, μg/ℓ	2	ND	ND	ND	--	ND
Hg, μg/ℓ	ND	ND	ND	ND	--	ND
Cr, μg/ℓ	--	--	--	--	--	ND
Ni, μg/ℓ	--	--	--	--	--	ND
As, μg/ℓ	--	--	--	--	--	2
DDT, ng/ℓ	3.0	ND	2.8	2.0	--	
PCP, ng/ℓ	280	36	42	40	--	

[1]NONDETECTABLE

data from past studies are important background information for evaluating current and future field and laboratory observations.

The analytical results from samples collected on three separate occasions during 1972 to 1973 at various coastal water sites: Koloa, McBryde, Wahiawa, the Allerton's, and Kukuiula are shown in Table 4.11. The McBryde and Wahiawa nitrogen values of 0.196 and 0.252 mg/ℓ respectively, exceed the State of Hawaii's water quality standards for Class A coastal waters which is established at 0.15 mg/ℓ; and the Wahiawa sample value of 0.038 mg/ℓ exceeds the phosphorus standard of 0.025 mg/ℓ; however, the state standards are generally recognized as being too severe and also unattainable even under natural conditions and will in all probability be redefined in the near future when sufficient coastal water quality data are available. The heavy metals and pesticides are all either below analytical detection levels or are very low values.

TABLE 4.11. NUTRIENTS, HEAVY METALS, AND PESTICIDES IN OCEAN WATER, SOUTH KAUAI AREA.

DATE	STATION	N mg/ℓ	P mg/ℓ	K mg/ℓ	Pb µg/ℓ	Cu µg/	Zn µg/ℓ	Cd µg/ℓ	Hg µg/ℓ	Cr µg/ℓ	Ni µg/ℓ	As µg/ℓ	DDT ng/ℓ	PCP ng/ℓ
06/27/72	KOLOA	—	—	838	ND	ND	ND	ND	ND	ND	ND	—	<1	<1
	ALLERTON'S	—	—	845	ND	ND	ND	ND	ND	5	ND	—	1	<1
	KUKUIULA	—	—	825	2	ND	ND	ND	ND	2	ND	—	<1	10
08/22/72	KOLOA	0.104	0.021	482	—	—	—	—	—	—	—	—	2	1
	McBRYDE	0.196	0.001	452	—	—	—	—	—	—	—	—	<1	ND
	WAHIAWA	0.252	0.038	476	—	—	—	—	—	—	—	—	—	—
07/25/73	KOLOA	—	—	544	1	ND	3	ND	ND	ND	ND	1	—	—
	McBRYDE	—	—	541	2	ND	3	ND	ND	ND	ND	ND	—	—
	WAHIAWA	—	—	546	3	ND	6	ND	ND	ND	ND	ND	—	—

Ocean sediment samples were collected at various locations off the McBryde Sugar Plantation coastline on four occasions during 1971 to 1973 and analyzed for concentrations of nutrients, heavy metals, and pesticides, as shown in Table 4.12. The last two sampling dates and locations coincide with the same in Table 4.11. Sediments serve as an excellent indicator of long-term quality changes, thus, the values presented in Table 4.12 can be construed as background data for possible future quality changes. No particular trend can be noted in most of the various values except that total nitrogen appears to be increasing uniformly while total phosphorus is decreasing at the Koloa site; however, this is a relatively short period of sediment sampling to form any firm evaluations. In addition sediment samples are not for practical reasons of identification necessari-

TABLE 4.12. NUTRIENTS, HEAVY METALS, AND PESTICIDES IN OCEAN SEDIMENTS, SOUTH KAUAI AREA, 1971-73.

DATE	STATION	T-N mg/kg	T-P mg/kg	T-K mg/kg	Pb mg/kg	Hg mg/kg	Cd mg/kg	Cu mg/kg	Zn mg/kg	DDT ng/kg
07/26/71	KOLOA	272	940	175	15.3	0.19	3.0	8.4	22.3	ND
	ALLERTON'S	425	315	500	19.2	0.20	2.0	9.0	15.7	ND
	KUKUIULA	462	287	250	6.4	0.19	1.9	7.8	11.6	ND
05/22/72	KOLOA	300	494	184	17.0	ND	ND	10.6	7.1	180
	ALLERTON'S	363	386	362	9.0	ND	ND	7.1	5.4	107
	KUKUIULA	437	401	111	16.8	ND	ND	3.1	6.8	45
08/22/72	KOLOA	302	345	378	—	—	—	—	—	—
	McBRYDE	308	693	384	—	—	—	—	—	30
	WAHIAWA	258	286	327	—	—	—	—	—	22
07/25/73	KOLOA	452	313	202	46.3	ND	3.5	3.6	9.5	221
	McBRYDE	299	714	650	32.9	0.04	2.4	15.4	38.0	223
	WAHIAWA	443	371	544	28.0	ND	3.3	12.0	22.4	291

ly collected at the same exact location although they are collected in the same general location. It is interesting to note that the concentration of lead increased two- to threefold at all three sample locations for the July 25, 1973 samples. DDT also increased sharply during this same sampling date, although its use has, at the most, supposedly been only minimal in recent years.

Offshore Biological Observations

The McBryde coastline of Kauai, on the southwest coast of the island, extends along an area bordered by a basalt shoreline alternating with short stretches of sandy beach. There are no fringing reefs in the area under study. The communities sampled consist of offshore, subtidal coral communities at depths of about 30 ft (9.144 m), extending from the northern perimeter of McBryde Sugar Company at Lawai to a control area, Koloa Landing, 2 mi (3.22 km) north of Lawai (Fig. 4.6). Three sampling sites were monitored in 1971 and 1972.

Table 4.4 represents fish catches from the years 1962 to 1973 for Area 503. The ocean waters around the State of Hawaii are divided into "blocks", and the coastal waters are divided into strips about 2 mi (3.22 km) wide (extending seaward from the shore) and from 4 to 40 mi (6.44 to 64.4 km) long. The area of concern is Area 503, which is roughly between Haena and Kepuhi Points, with Kilauea situated roughly in the middle. Most of the fish catches originate from this area. Every commercial fisherman in the state is required by law to report monthly on their fish catch and the area where the fish were caught. Thus, accurate records of the various areas have been kept over these years.

Abatement of mill discharge occurred in November 1971. Since then, in 1972 there has been a threefold increase in fish catch as compared with the previous year 1971. A slightly higher fish catch has been recorded for the year 1973. It should be noted that the Table does not represent all the fish that were caught in Area 503. Only the species of fish that are of commercial value were included. These are: omilu (*Caranx melampygus*), ulua (*Caranx* sp.), akule (*Trachurops crumenopthalmus*), hahalalu (*Juuimile T. cremenopthalmus*), mullet (*Mugil cephalus*), manini (*Acanthurus sandvicensis*), moi (*Polydactylus sexfilis*), opelu (*Decapterus pinnulatus*), menpachi (*Myripristis* sp.), and kumu (*Parupeneus porphyreus*). Also edible seaweed, limu-kohu (*Asparagopsis sandfordianus*) and opihi (*Cellana calcosa C. exerata*) were recorded to ascertain any effects that discharge may have had on the shore environment.

Micromolluscs from sediments at the three stations were analyzed for species composition, diversity, and abundance. The micromolluscan assemblages from all three stations are those characteristic of subtidal coral communities at depths of 30 to 40 ft (9.14 to 12.19 m) in other areas of the Hawaiian Islands (see Comparative Discussion). The dominant families represented are the Rissoidae and Diastomidae as at Stations 7 to 13 at Kilauea (see Fig. 5.9, S16). Standing crops and common abundance values (based on Weiser, 1970) are shown in Table 4.13 where the common abundance values may also be compared with calculations for the

TABLE 4.13. ANALYSIS OF MICROMOLLUSCS FOR McBRYDE STATIONS, 1971-72.

	STATION 1 (KOLOA)		STATION 2 (KUKUIULA)	STATION 3 (LAWAI)	
	VII-71	V-72	VII-71	VII-71	5.72
NO. SHELLS	202	254	244	116	122
NO./CM^3	8.1	10.2	9.8	4.6	4.9
NO. SPECIES	40	55	44	33	31

Kilauea stations. The Lawai samples show the least faunal resemblance to the other stations and exhibit the lowest standing crop. Although the project has quantitative data to confirm the observation, our impression is that the low abundance and low faunal affinity of the Lawai stations compared with stations in the McBryde and Kilauea areas may be associated with lesser amounts of coral coverage in that area.

SUMMARY OF PROGRESS: SUGARCANE vs. WATER QUALITY

Significant progress was made during 1971 to 1973 toward evaluating the effects of sugarcane culture and milling on the quality of coastal waters and coastal water environments. Although a discussion of the various findings were presented throughout the chapter a recapitulation of the most significant of these findings are presented in Table 4.14.

TABLE 4.14. SUMMARY OF PROGRESS: SUGARCANE STUDIES

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.

13. THE SOLIDS CONCENTRATION IN THE IRRIGATION TAILWATER INTERCEPTION SETTLING PONDS VARIED GREATLY AMONG THE DIFFERENT SAMPLING DATA.

Chapter 5

EVALUATIVE ASPECTS OF PROJECT

EVALUATIVE ASPECTS OF PROJECT

Introduction

As summarized in Chapter 1, the general objectives of the QCW 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. This overall general objective was, of course, broken down into specific objectives by which the project goal might be approached, and the priority of each aspect, together with the intensity of investigative effort to be applied, was established on the basis of such factors as:

- Urgency of problem or situation of coastal water quality degradation
- Opportunity to cooperate with other agencies or projects concerned with the problem or situation
- Budgetary constraints on project scale and scope
- Interests and knowledge of participatory investigators
- Changing institutional and social emphasis on environmental problems
- Changes in federal and state legislation as the study progressed from phase to phase

A final and detailed evaluation of the findings of the project in terms of its general objectives is appropriately deferred until the final report of the project. However, some of the findings of the project, and changes in institutional constraints accruing during the report period, are significant at this time.

SCIENTIFIC OBSERVATIONS

Chemical Quality of Water and Sediments

The chemical quality of water and sediments reaching coastal waters from the several situations of land development involved in the study are presented and discussed in relation to the type of land use in the various chapters of the annual progress reports (Lau 1972; present report 1973). In several cases, specific comparison with the control situation--Kahana Bay--has been introduced. For the purpose of this report, however, comparisons are presented for only the three parameters of greatest current interest--heavy metals, pesticides, nutrients, and sediment--as they have been observed in the coastal water samples analyzed in several study areas and types of situations.

Heavy Metals

The concentration of heavy metals observed in ocean sediments and water in situations of relatively undeveloped land (Kahana Bay); urban land development (Maunalua Bay, Waikiki, and Sandy Beach); and sugarcane culture (Kilauea and McBryde Plantations) are summarized in Table 5.1. Because in many samples any concentration of metal which may have been present was below the level of detectability, the frequency of positive values in comparison with the total number of samples analyzed is shown in the Table along with the range of concentrations observed.

As might be expected, heavy metals are more concentrated in sediments than in water. This fact, although seemingly obvious, has not been widely grasped by readers or researchers. Hence the concentration of heavy metals in marine organisms has often been judged by comparing the metals content of aquatic creatures with the background concentration of metals in water rather than in benthic sediments where the food chain begins. The result is, of course, some alarmingly high values which, unfortunately, tend to be taken seriously by regulatory agencies concerned with established guidelines or standards. An idea of the magnitude of the error of assumption possible in careless evaluation of the possible source of metals in living tissue, might be drawn from the values reported for lead at Kahana Bay. Here the maximum observed in water was but 10 $\mu g/\ell$, whereas the maximum concentration of lead in sediments was about 41 mg/ℓ--a concentration difference of some 4100 times. Similar rough comparisons may be made for other metals listed in Table 5.1.

It should be particularly noted that from the data in Table 5.1 no valid comparisons can be made between types of land use. This is true for the principal reason that coastal sediment consists of a large quantity of soils of terrestrial origin and the rocks from which the soils are derived vary in heavy metals content from location to location. Furthermore, the rates of erosion and deposition of sediment in any geographical situation vary. Thus, comparisons are valid only between the source of sediments and the adjacent coastal water; such comparisons are made herein in the sections dealing with specific situations. In the case of urban uses of land, the situation is further complicated by industrial and commercial wastes which may contribute to the presence of one or more heavy metals.

The general conclusions that can be drawn from Table 5.1 are that:

- Heavy metals of a considerable variety may be expected to be present in the sediments of coastal waters in any situation in Hawaii.
- In setting standards for coastal waters in Hawaii care must be taken lest unrealistic values, impossible of attainment, be adopted.
- Research should be encouraged to determine:
    1. The extent of the food chain associated with sediments containing heavy metals.
    2. Whether biota further up the food chain are limited by any catastrophic effect of metals on organisms lower in

TABLE 5.1. HEAVY METALS IN COASTAL SEDIMENTS AND WATER SAMPLES BY LAND USE CATEGORY, 1971–73.

LAND USE CATEGORY	TYPE OF SAMPLE	Pb RANGE	Pb FREQ.	Cu RANGE	Cu FREQ.	Zn RANGE	Zn FREQ.	Cd RANGE	Cd FREQ.	Hg RANGE	Hg FREQ.
UNDEVELOPED											
KAHANA BAY	SEDIMENT, mg/kg	4.6 - 40.9	56/56	ND - 160.1	54/56	ND - 94.5	55/56	ND - 3.5	40/56	ND - 0.60	43/56
	WATER, μg/ℓ	ND - 10.0	21/52	ND - 11.0	51/52	ND - 15.0	29/52	ND - 3.0	10/52	ND	0.52
URBAN											
MAUNALUA BAY	SEDIMENT, mg/kg	11.7 - 58.2	54/54	2.7 - 122.8	53/53	2.8 - 105.4	54/54	ND - 9.7	42/54	ND - 2.0	48/54
	WATER, μg/ℓ	ND - 6.0	37/61	ND - 14.0	49/61	ND - 98.0	29/61	ND - 7.7	3/61	ND -	0/61
SANDY BEACH	SEDIMENT, mg/kg	---	---	---	---	---	---	---	---	---	---
	WATER, μg/ℓ	ND - 3.0	6/24	ND - 7.0	17/24	ND - 31.0	21/24	ND -	0/24	ND	0/24
WAIKIKI	SEDIMENT, mg/kg	28.1 - 52.6	22/22	1.8 - 11.8	22/22	2.2 - 21.1	22/22	0.3 - 1.3	22/22	ND - 0.18	20/22
	WATER, μg/ℓ	---	---	---	---	---	---	---	---	---	---
AGRICULTURE											
KILAUEA	SEDIMENT, mg/kg	6.2 - 57.0	27/27	3.8 - 24.0	27/27	3.3 - 55.7	27/27	1.5 - 5.1	27/27	ND - 0.22	12/27
	WATER, μg/ℓ	ND - 12.0	9/18	---	---	---	---	ND - 2.0	6/18	ND - 0.4	1/18
McBRYDE	SEDIMENT, mg/kg	6.4 - 46.3	9/9	3.1 - 15.4	9/9	5.4 - 38.0	9/9	ND - 3.5	6/9	ND - 0.20	4/9
	WATER, μg/ℓ	ND - 3.0	4/6	ND	0/6	ND - 6.0	3/6	ND	0/6	ND	0/6

LAND USE CATEGORY		Cr RANGE	Cr FREQ.	Ni RANGE	Ni FREQ.	As RANGE	As FREQ.
UNDEVELOPED							
KAHANA BAY	SEDIMENT, mg/kg	1.0 - 121.8	56/56	5.4 - 349.8	56/56	2.0 - 18.5	35/35
	WATER, μg/ℓ	ND - 14.0	25/52	ND - 8.0	15/52	ND - 0.8	3/20
URBAN							
MAUNALUA BAY	SEDIMENT, mg/kg	4.9 - 114.6	54/54	20.3 - 254.6	54/54	0.5 - 14.6	36/36
	WATER, μg/ℓ	ND - 68.8	17/56	ND - 4.0	6/56	0.6 - 1.2	7/7
SANDY BEACH	SEDIMENT, mg/kg	---	---	---	---	---	---
	WATER, μg/ℓ	ND - 8.0	9/24	ND - 2.2	2/24	---	---
WAIKIKI	SEDIMENT, mg/kg	9.4 - 20.8	22/22	ND - 54.4	21/22	---	---
	WATER, μg/ℓ	---	---	---	---	---	---
AGRICULTURE							
KILAUEA	SEDIMENT, mg/kg	---	---	---	---	---	---
	WATER, μg/ℓ	---	---	---	---	---	---
McBRYDE	SEDIMENT, mg/kg	8.4 - 66.2	9/9	56.4 - 86.7	9/9	2.7 - 18.9	9/9
	WATER, μg/ℓ	ND - 5.0	2/6	ND	0/6	ND - 1.0	1/6

the chain.

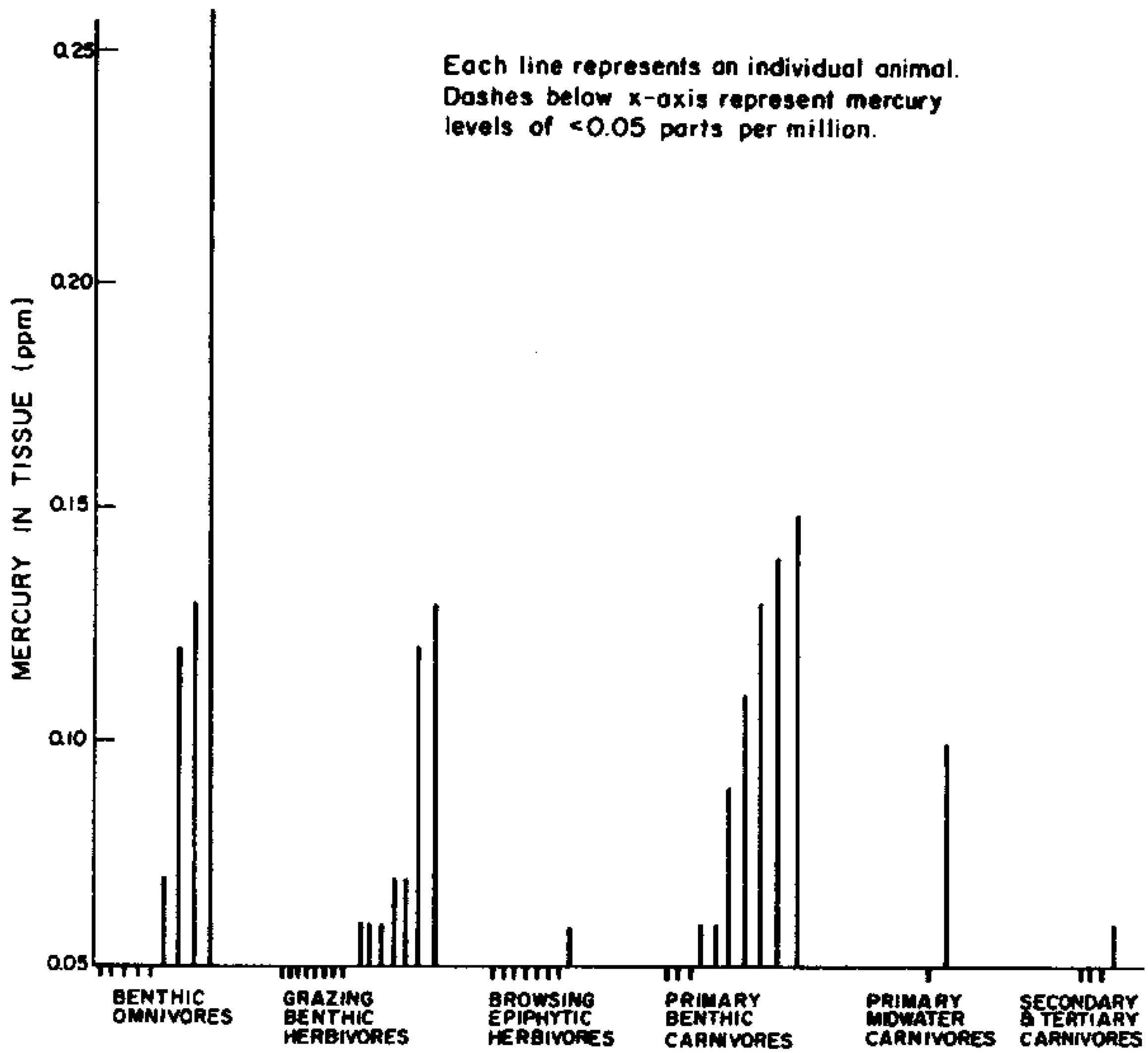
3. The relationship between the concentration of metals in coastal water sediments and in the tissue of organisms indigenous to the area.

Research of the type suggested for heavy metals has been conducted in relation to mercury by the QCW project. Mercury was selected for primary attention for several reasons. First, it has received worldwide attention because of its serious or even disastrous effects on some commercial fisheries. Next, mercury ranks as the sixteenth most common element in the crust of the earth and yet, because of its chemical reactivity, is widely distributed in a variety of organic and inorganic forms. Worldwide commercial usage of the metal and its release from the burning of fossil fuel, estimated recently at some 23 million lbs (10,442,000 kg) annually has created an extensive continuing redistribution.

Increasing awareness of problems caused by the redistribution of mercury in both organic and inorganic forms has resulted from outbreaks of major acute and chronic poisonings in human, bird, animal, and fish populations. However, our understanding of this metal is still very incomplete as to the nature of its entry into specific biological systems, whether it accumulates through biological concentrations at different trophic levels, and whether it reaches toxic levels in either inorganic or organic form at any trophic level.

As part of the Quality of Coastal Waters project, recent studies of mercury levels in a wide range of biota collected from a nearshore area on Kauai indicate that benthic feeders at all trophic levels show a greater ability to accumulate mercury than animals feeding above the sediment-water interface (Fig. 5.1). Of the organisms feeding on benthic organic material, 53 percent show detectable mercury concentrations (>0.05 ppm) while only 15 percent of the organisms classed as browsing epiphytic herbivores or midwater and higher trophic level carnivores, contain mercury at reliably detectable levels. QCW studies have already shown that mercury concentrations in related sediments far exceed those in the water column in most areas, so the disparate mercury level found in benthic and nonbenthic biota may not be too surprising and actually make sense. What is intriguing, however, is that the study suggests, contrary to traditional assumption, the most effective pathway of mercury transport may not be through a linear food chain from plankton to herbivore to carnivore, but that greater concentrations of mercury may be found in organisms associated with short food chains linked directly to the benthos.

In deeper Hawaiian waters, the pelagic carnivores, marlin, tuna, and dolphin, appear to contain appreciably higher levels of total mercury than five nearshore species of fish, as indicated by measurements made recently and summarized in Table 5.2. Mean levels of total mercury in tuna are near the 0.5 ppm level established by the U.S. Food and Drug Administration as the maximum permissible level for mercury in edible fish. Total mercury levels in marlin far exceed this tolerance limit and, consequently, the local sale of marlin for human consumption has been banned by the Hawaii State Department of Health.



MEAN CONCENTRATION (ppm)*					
0.071	0.038	0.007	0.086	0.050	0.015
NUMBER OF ANALYSES					
9	15	8	10	2	4

* VALUES BELOW THE LEVEL OF RELIABLE DETECTABILITY (<0.05 PPM) WERE ASSUMED TO BE 0.

FIGURE 5.1. MERCURY LEVELS IN ORGANISMS FROM NEAR SHORE WATERS, KAUAI.

TABLE 5.2. TOTAL AND ORGANIC MERCURY FOUND IN MUSCLE TISSUE OF FISH CAUGHT IN HAWAIIAN WATERS.

COMMON (LOCAL) SCIENTIFIC NAME	NO. OF FISH ANALYZED	ORGANIC MERCURY (ppm)[a] RANGE	AVG.	TOTAL MERCURY (ppm)[a] RANGE	AVG.
PELAGIC SPECIES:					
PACIFIC BLUE MARLIN (A'U) *Makaira ampla*	29	0.23 - 1.79	0.93	0.35 - 14.0	4.78
YELLOW FIN TUNA (AHI) *Neothunnus macropterus*	22	0.25 - 1.00	0.48	0.24 - 1.32	0.54
SKIP JACK TUNA (AKU) *Katsuwonus pelamis*	20	0.20 - 0.57	0.41	0.27 - 0.52	0.38
DOLPHIN (MAHIMAHI) *Coryphaena hippurus*	10	0.15 - 0.30	0.25	0.17 - 0.31	0.25
INSHORE SPECIES:					
SQUIRREL FISH (UU, MENPACHI) *Myripristis arayomus*	14	0.10 - 0.40	0.21	0.10 - 0.43	0.21
BIGEYE SCAD (AKULE) *Trachurops crumenophthalmus*	10	0.07 - 0.11	0.10	0.07 - 0.11	0.09
RED GOAT FISH (WEKE-ULA) *Mulloidichthys auriflamma*	10	-- --	<0.05	-- --	<0.05
MULLET (AMAAMA) *Mugil cephalus*	10	-- --	<0.05	-- --	<0.05
PARROT FISH (PANAHUNUHU) *Scaridae*	10	<0.05 - 0.10	0.05	<0.05 - 0.08	0.05

SOURCE: RIVERS, PEARSON, AND SHULTZ 1972.
[a] MERCURY CALCULATED AS INORGANIC MERCURY.

As shown in Table 5.2, organic mercury levels measured tended to equal total mercury levels in all species analyzed except marlin, indicating that most of the mercury stored in muscle tissues is organic. In marlin muscle tissue, organic mercury levels are much lower than those for total mercury, a finding that has been confirmed through independent measurements made by Dr. Westoo's group in Sweden, who also identified the organic fraction as methyl mercury. Prior to this finding, it has been assumed that 90 percent or more of all mercury in fish tissue was in organic form. Why mercury in marlin tissue differs so drastically is not known. Perhaps a biotransformation occurs from the organic to the more oxidized inorganic form, or alternatively, marlin may absorb and store greater levels of inorganic mercury from sea water.

Controlled laboratory experiments are needed to properly study the fate of mercuric ions in marine ecosystems. A series of such experiments is being undertaken within the QCW project. This research involves a simplified food chain featuring marine annelids and one or more predator fish that can be maintained in the laboratory.

The objectives of the experiments are threefold: 1) to study the biotic transport of mercury in a simplified, short food chain ecosystem characteristic of stressed environments; 2) to study the role polychaetous annelids may play in cycling mercury from the sediments to the upper trophic levels of the ecosystem; and 3) to provide information useful in selecting organisms which can be used in monitoring for mercury in

Hawaii's marine water.

Results of the study of mercury, suggest that similar work is needed on other heavy metals as a basis for rational controls of the quality of coastal water environments.

Insecticides

Comparison of organo-chlorine pesticides are shown in Table 5.3. These compounds being relatively insoluble with the exception of PCP, tend to be absorbed in particles such as sediments. DDT, being ubiquitous, appears in all the study areas. However, Maunalua Bay and the Hawaii Kai Marina with its high residential density, show higher concentrations of dieldrin, DDT, DDE, DDD, α and γ chlordanes as compared with all the other study areas, with maximum values ranging up to several orders of higher magnitude. The use of insecticides by individual householders in the area is another probable source of the residues.

The relatively high levels of dieldrin and α and γ chlordanes reflect the popularity of these substances as termite control agents in the pre-treatment of slab constructed houses which predominate in the Hawaii Kai area. The presence of DDT and congeners, which are not normally used for termite control, may represent residues remaining from the time prior to extensive development when the area contained several ornamental plant nurseries and the majority of lei carnation growers on Oahu.

PCP is used as a termite preventive compound in construction timber. It is water soluble and is not absorbed by sediments. Again, the urban development area of Maunalua Bay shows the greatest maximum concentration in the water samples. PCP also appears in the waters off Sandy Beach where the treated sewage effluent from Hawaii Kai is discharged.

PCP is a volatile compound, is readily absorbed by the human body, and appears in waste excrements. These facts, along with infiltration of groundwater into the sewers, would explain the presence of PCP at Sandy Beach. PCP is also found in water samples offshore Kilauea where no sewage effluent is present. This compound could become as ubiquitous as DDT.

Small quantities of dieldrin, PCP, and chlordane are found in Kahana Bay sediments, possibly indicating their very minor use by the few families living at the valley entrance. These compounds do not appear in the sediments offshore of Kilauea Plantation on Kauai probably because of the constant shifting sands caused by ocean currents. The dilutional effect of the open ocean is so great that the detection of these compounds in such minute quantities as observed in the more confined Kahana Bay is far beyond the best instrumental capabilities today.

TABLE 5.3. ORGANO-CHLORINES IN COASTAL SEDIMENTS AND WATER, 1971-73.

LAND USE	TYPE OF SAMPLE	DIELDRIN RANGE	DIELDRIN FREQ.*	DDE RANGE	DDE FREQ.	DDT RANGE	DDT FREQ.	DDD RANGE	DDD FREQ.
UNDEVELOPED URBAN									
KAHANA BAY	SEDIMENT, ng/kg	ND - 46	29/58	ND - 37	22/58	ND - 565	55/58	ND	0/58
	WATER, ng/ℓ	ND	0/36	ND	0/36	ND - 5.0	35/36	ND	0/36
URBAN									
MAUNALUA BAY	SEDIMENT, ng/kg	ND - 4839	45/54	ND - 960	34/54	ND - 7105	49/54	ND - 334	5/54
	WATER, ng/ℓ	ND - 3.0	24/33	ND	0/33	0.5 - 2.0	33/33	ND	0/33
SANDY BEACH	SEDIMENT, ng/kg	---	---	---	---	---	---	---	---
	WATER, ng/ℓ	ND	0/24	ND	0/24	ND - 4.0	20/24	ND	0/24
SUGARCANE CULTURE									
KILAUEA	SEDIMENT, ng/kg	ND	0/17	ND	0/17	ND - 150.0	3/17	ND	0/17
	WATER, ng/ℓ	1.0	8/12	ND	0/12	1.0 - 26.0	12/12	ND	0/12
McBRYDE	SEDIMENT, ng/kg	ND - 6	1/11	ND - 180	3/11	ND - 291	5/11	ND	0/11
	WATER ng/ℓ	ND	0/5	ND	0/5	1.0 - 2.0	5/5	ND	0/5

LAND USE	TYPE OF SAMPLE	α CHLORDANE RANGE	α CHLORDANE FREQ.	γ CHLORDANE RANGE	γ CHLORDANE FREQ.	PCP RANGE	PCP FREQ.	LINDANE RANGE	LINDANE FREQ.
UNDEVELOPED URBAN									
KAHANA BAY	SEDIMENT, ng/kg	ND - 41.0	24/58	ND - 43.0	24/58	ND	0/58	ND	0/58
	WATER, ng/ℓ	ND	0/36	ND	0/36	ND - 14.0	23/36	ND	10/36
URBAN									
MAUNALUA BAY	SEDIMENT, ng/kg	ND - 9570	44/54	ND - 8760	44/54	ND	0/54	ND	0/54
	WATER, ng/ℓ	ND - 2.0	11/33	ND - 2.0	12/33	ND - 41.0	26/33	ND - 2.0	17/33
SANDY BEACH	SEDIMENT, ng/kg	---	---	---	---	---	---	---	---
	WATER, ng/ℓ	ND	0/24	ND	0/24	1.0 - 30.0	18/18	ND	0/24
SUGARCANE CULTURE									
KILAUEA	SEDIMENT, ng/kg	ND	0/17	ND	0/17	---	---	ND	0/17
	WATER, ng/ℓ	1.0	7/12	1.0	7/12	1.0 - 18.0	6/6	1.0	12/12
McBRYDE	SEDIMENT, ng/kg	ND - 17	2/11	ND - 18	2/11	ND	0/11	ND	0/11
	WATER, ng/ℓ	ND - 1.0	2/5	ND - 1.0	2/5	ND - 1.0	4/5	ND - 1.0	3/5

*NUMBER OF POSITIVE SAMPLES DIVIDED BY TOTAL NUMBER OF SAMPLES

Herbicides

Herbicides in coastal waters and sediments were considered separate from insecticides in the pesticide study activity of the QCW project. The reason is that herbicides are associated more with agricultural land development than with urban or undeveloped land areas, yet analyses for atrazine and ametryne in sediment samples taken on Kauai and Oahu during the Sea Grant Year 04 did not show evidence of these herbicides even though they were used in large amounts in the situations studied. Both atrazine and ametryne were expected to degenerate more rapidly than diuron, so in the Program Year 05 herein reported, effort was directed toward an adaptation of a diuron analysis method in sediments and soils. This approach allowed an assessment of atrazine, ametryne, and diuron in all sediment and soil samples taken in the Year 05.

The study areas chosen for analysis by other activities on the QCW project were not considered appropriate for the herbicide assessment owing to (1) the lack of significant acreages of sugarcane and pineapple in the watersheds draining into the coastal waters being studied (such as Maunalua Bay or Sandy Beach areas) or (2) the absence of a protected estuary which would tend to accumulate sediments derived from eroded field soil. Thus, two estuaries considered likely candidates for herbicide contamination were selected: West Loch of Pearl Harbor on leeward Oahu, and Kaiaka Bay between Waialua and Haleiwa on the North Shore of Oahu. Arrangements were made with personnel of the Navy's Environmental Protection Data Base Program for sediment samples to be taken in Pearl Harbor and at the mouth of Waikele Stream at sites considered likely to contain herbicide-contaminated sediments. QCW project personnel obtained sediment samples from Kaiaka Bay and Paukauila Stream (a major stream draining into Kaiaka Bay). The locations sampled are shown in Figures 5.2 and 5.3.

In addition to stream and estuary sediment samples, soil samples were taken in two sugarcane fields on Oahu (Waialua Sugar and Oahu Sugar Plantations), one pineapple field on Oahu (Pineapple Research Institute), one sugarcane field on Kauai (McBryde Sugar Plantation), and corn and sorghum fields on Kauai (Metcalf Farms, previously Kilauea Sugar Company). The field samples were taken to provide an assessment of the rate of disappearance of herbicides in the top 3 in. (7.62 cm) of soil subsequent to herbicide application. To minimize the effects of random variations in herbicide concentrations within a field, we sampled two transects in each field with 50 core samples taken in each 200- to 300-yard (182.8- to 272.2-m) transect. The samples were composited and subsampled for analyses.

A major portion of the project time was required for the development of a method by which the three herbicides of interest could be simultaneously extracted from sediment or soil, and the extracts purified for analysis by gas-liquid chromatography. In brief, the procedure involves air-drying the sample, extraction by refluxing in a methanol-ethyl acetate mixture, extract clean-up on an alumina column (separate steps are required to recover the three herbicides and 3,4-dichloroaniline, DCA, a persistent degradation product derived from diuron), and finally

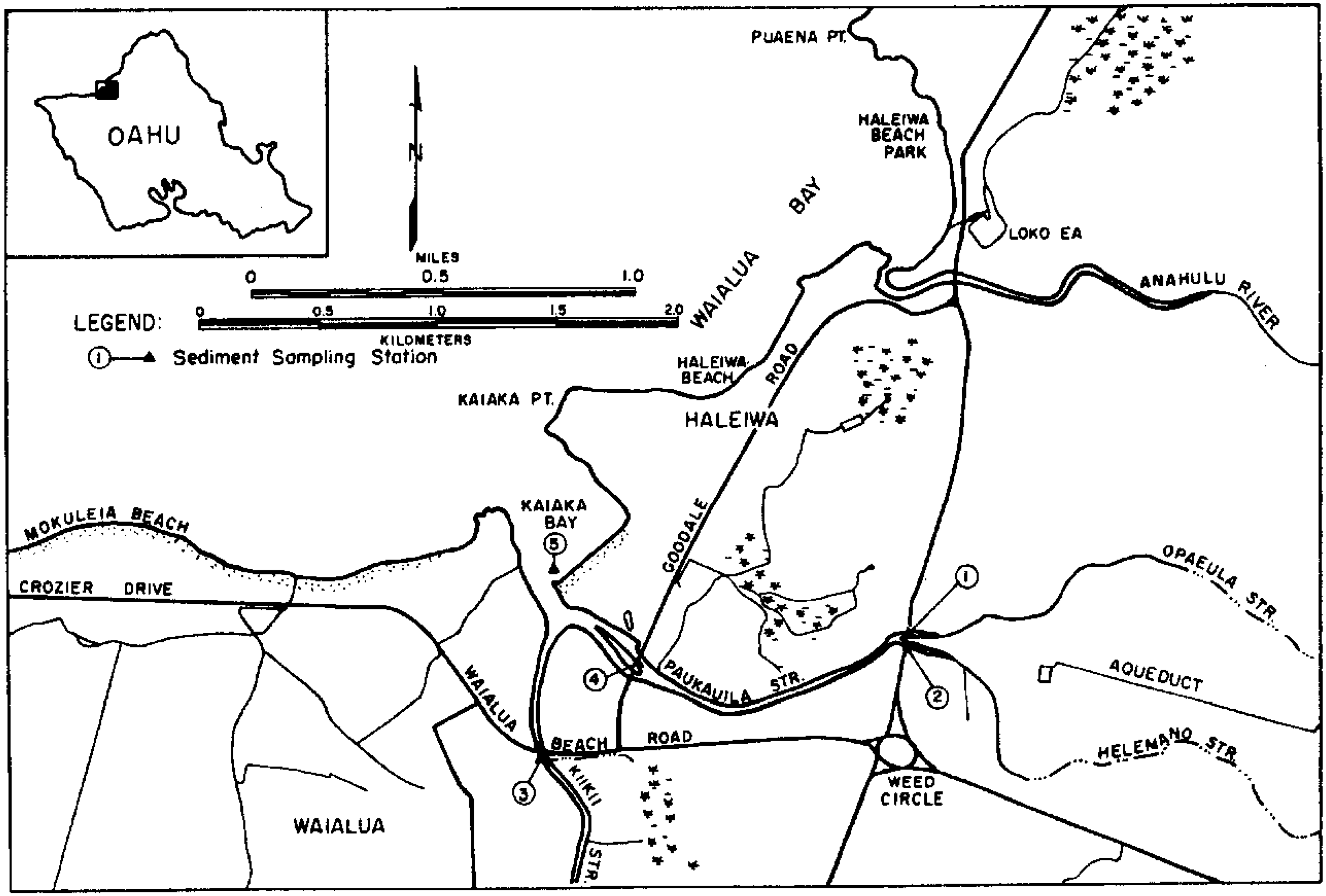


FIGURE 5.2. LOCATION OF SEDIMENT SAMPLING STATIONS FOR HERBICIDES, KAIAKA BAY AND PAUKAUILA STREAM, OAHU.

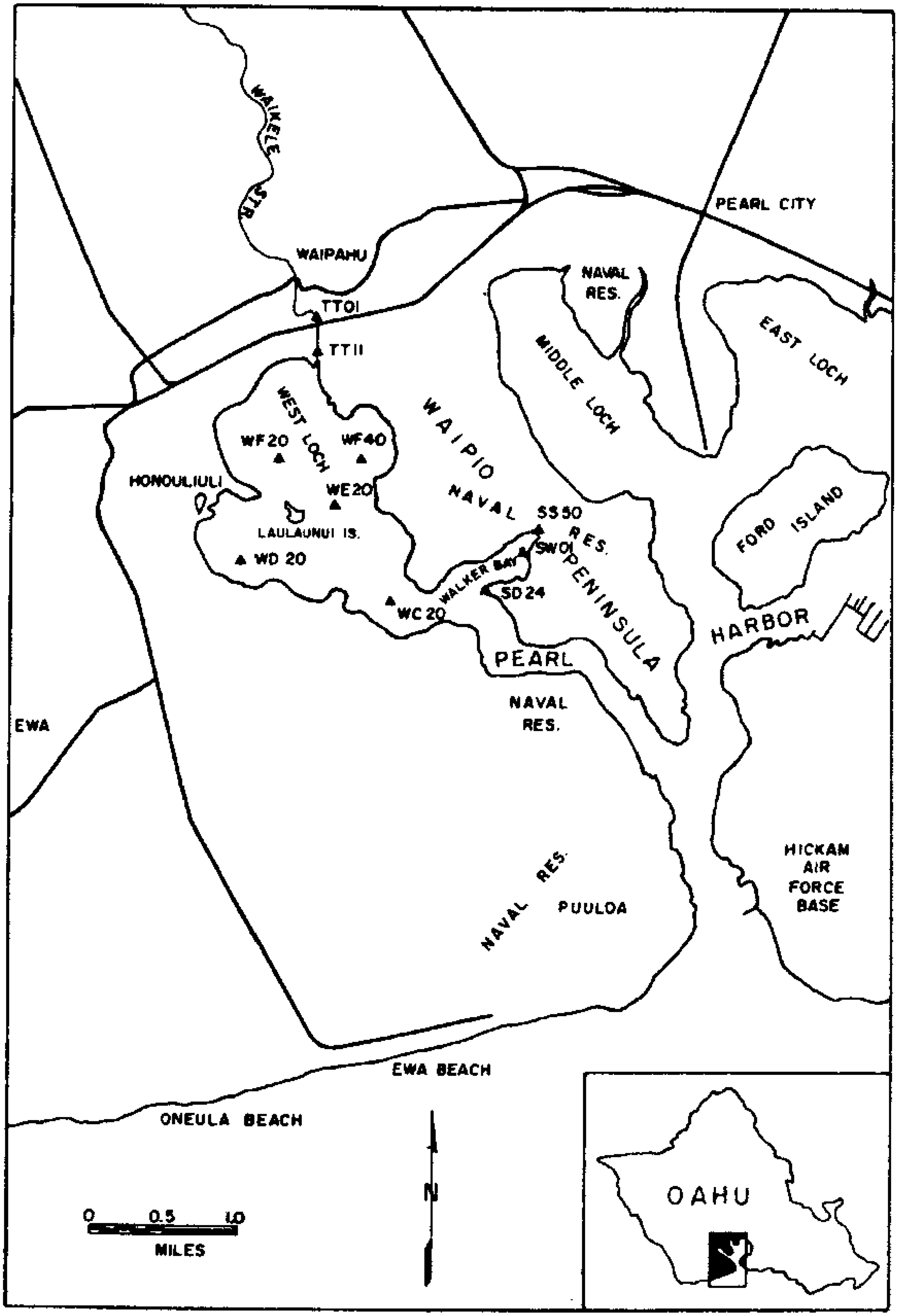


FIGURE 5.3. LOCATION OF SEDIMENT SAMPLING STATIONS FOR HERBICIDES, PEARL HARBOR AND WAIKELE STREAM, OAHU.

TABLE 5.4. HERBICIDES IN SEDIMENTS OF KAIAKA BAY AND ASSOCIATED INFLUENT STREAMS, OAHU, 1972-73.

LOCATION	STATION NUMBER	DATE OF SAMPLING	ATRAZINE (ppm)	AMETRYNE (ppm)	DIURON (ppm)	DCA (ppm)
PAUKAUILA ST.	1	7/31/72	ND[a]	ND	0.111	TR[b]
		1/27/73	ND	ND	0.055	TR
PAUKAUILA ST.	2	7/31/72	ND	ND	0.074	1.05
		1/27/73	ND	ND	0.441	4.65
PAUKAUILA ST.	4	7/31/72	ND	ND	0.128	0.65
		1/27/73	ND	ND	0.179	0.16
KAUKONAHUA ST.	3	7/31/72	ND	ND	0.020	ND
		1/27/73	ND	ND	0.008	TR
KAIAKA BAY	5	7/31/72	ND	ND	0.146	ND
		1/27/73	ND	ND	0.018	0.04

[a]NONDETECTABLE
[b]TRACE QUANTITY BELOW LEVEL OF QUANTIFICATION

TABLE 5.5. HERBICIDES IN SEDIMENTS OF WALKER BAY WEST LOCH, PEARL HARBOR, AND ITS ASSOCIATED INFLUENT STREAM, WAIKELE, OAHU, 1972-73.

LOCATION	NUMBER	DATE OF SAMPLING	ATRAZINE (ppm)	AMETRYNE (ppm)	DIURON (ppm)	DCA (ppm)
WAIKELE ST.	TT01	9/20/72	ND	ND	0.238	ND
		2/22/73	--*	--	0.270	ND
WAIKELE ST.	TT11	9/20/72	ND	ND	ND	ND
		2/22/73	--	--	0.566	ND
WALKER BAY	SD24	9/20/72	ND	0.16	1.049	ND
WALKER BAY	SW01	9/20/72	ND	1.44	147.786	16.86
		2/22/73	--	--	0.532	0.10
WALKER BAY	SS50	9/20/72	ND	0.365	0.851	ND
		2/22/73	--	--	1.376	ND

*AN INSTRUMENT BREAKDOWN PRECLUDED OBTAINING DATA ON ATRAZINE AND AMETRYNE FOR THIS SAMPLING

G.C. analysis using the Coulson electrolytic conductivity detector for atrazine and ametryne and a nickel electron capture detector for diuron and DCA. The lower limits of detection expressed as ppm in soil or sediment (oven-dry basis) for each of the chemicals were: atrazine and ametryne, .05 ppm; diuron, .002 ppm; and DCA, .02 ppm.

Preliminary tests on Pearl Harbor sediments demonstrated that sediments could be analyzed either wet (as received) or air-dried with negligible difference in the quantities of herbicides recovered. Analysis of air-dried samples allowed soil and sediment samples to be treated identically, thus, this was the procedure chosen.

Results: Although sediment samples from Kaiaka Bay (and influent streams) did not contain atrazine and ametryne at detectable levels, most of the same samples contained appreciable quantities of diuron and, in some cases, DCA, a degradation product of diuron (see Table 5.4). The sediments in Kaukonahua Stream (Station 3, Fig. 5.2) appear to contain less diuron than those in Paukauila Stream (Stations 1, 2 and 4).

Sediments from Walker Bay, an inlet of Waipio Peninsula and adjacent to the channel leading to West Loch of Pearl Harbor, contained no atrazine, but ametryne and diuron were found at all stations (Table 5.5). Diuron levels were high in Walker Bay and lower in the sediments of the influent Waikele Stream. The extremely high levels of diuron and DCA and the higher-than-usual level of ametryne at Station SW01 on September 20, 1972 are probably due to direct contamination of the bay from a nearby herbicide mixing and loading area. The January 1973 sample from this same area contained diuron and DCA at about the same level as sediments from other stations in Walker Bay and Waikele Stream.

Soil samples from sugarcane fields which had received herbicides before and after planting, as shown in the "application columns of Table 5.6 contained decreasing amounts of diuron in successive post-application samplings. Since a given herbicide may have been applied a second or even third time after the original pre-emergence application (see information on application dates and amounts) the change in concentration over time is not necessarily an indication of decay rate for the original application but rather gives the status of herbicides in the surface soil after cane planting.

Analyses of a limited number of sediment samples from sediment basins which catch irrigation return flow and storm runoff from three sugarcane areas on McBryde Plantation showed diuron in all the basins and atrazine and ametryne in only one (Table 5.7). Basin 13D is uppermost of two basins which receive runoff waters from Field 13D for which soil data are shown in Table 5.6.

Field soils of Metcalf Farms (formerly Kilauea Plantation) were also analyzed for the three herbicides and DCA, the principal interest being in atrazine which is currently used for weed control in sorghum and corn. The results in Table 5.8 show that atrazine disappears rapidly in these crop-soil situations. The absence of ametryne was expected since ametryne had never been used on these fields. The relatively high level of diuron

TABLE 5.6. HERBICIDE APPLICATIONS AND RESIDUES IN FIELD SOILS CROPPED WITH SUGARCANE ON KAUAI AND OAHU, 1972-73.

LOCATION	FIELD STATION NUMBER	DATE	ATRAZINE APPLICATION lbs/ACRE[a]	ATRAZINE RESIDUE ppm[b]	AMETRYNE APPLICATION lbs/ACRE	AMETRYNE RESIDUE ppm	DIURON APPLICATION lbs/ACRE	DIURON RESIDUE ppm	DCA RESIDUE ppm
McBRYDE SUGAR CO.	13D	06/26/72 (PREAPPLICATION)		TR		ND		1.335	ND
		07/08/72	2.4		2.4		0		
		08/29/72		1.46		3.52		4.575	0.6
		09/06/72	0		0		2.2		
		10/31/72	0		0		1.6		
		12/01/72		—		—		1.600	1.2
OAHU SUGAR CO.	417	09/21/72	0		2.6		0		
		09/28/72		0.054		1.083		0.950	0.78
		12/01/72	0		0		1.4		
		02/24/73	0		0		1.4		
		03/02/73		—		—		0.448	ND
WAIALUA SUGAR CO.	6C	07/07/72	0		0		4.0		
		09/28/72		0.04		0.08		1.659	1.0
		10/27/72	0		0		1.5		
		02/16/73		—		—		1.255	TR

[a] EXPRESSED IN TERMS OF ACTIVE INGREDIENT.

[b] EXPRESSED AS A CONCENTRATION ON AN OVEN-DRY BASIS.

TABLE 5.7. HERBICIDES IN SEDIMENT FROM SEDIMENT RUNOFF BASINS FROM SUGARCANE FIELDS ON McBRYDE PLANTATION, KAUAI, 1972.

LOCATION	DATE OF SAMPLING	ATRAZINE (ppm)	AMETRYNE (ppm)	DIURON (ppm)	DCA (ppm)
BASIN 7A	06/26/72	ND	0.09	2.355	0.31
	09/06/72	0.33	2.04	1.342	0.74
BASIN 13D	12/01/72	--	--	0.406	0.53
BASIN 14D	09/06/72	ND	ND	0.286	ND

TABLE 5.8. HERBICIDES IN FIELD SOILS CROPPED WITH CORN AND SORGHUM ON METCALF FARM, KAUAI, 1972.

CROP	STATION NUMBER	DATE OF SAMPLING*	ATRAZINE (ppm)	AMETRYNE (ppm)	DIURON (ppm)	DCA (ppm)
SORGHUM	F-3	06/26/72	1.80	ND	0.945	ND
		08/29/72	0.78	ND	0.717	0.45
		12/01/72	--	--	0.893	ND
CORN	F-8	06/26/72	6.37	ND	--	--
		08/29/72	0.35	ND	0.649	0.24
		12/01/72	--	--	0.796	ND

*ATRAZINE APPLIED PRIOR TO SAMPLING AT 3 lbs ACTIVE INGREDIENT PER ACRE ON THE FOLLOWING DATES: F-3, 6/12/72; F-8, 6/25/72.

measured was not expected since this herbicide had not been applied to the soils for at least four years, the last application occurring during establishment of the last cane crop.

Discussion: The absence of the triazine herbicides, atrazine and ametryne, in estuarine and stream sediments is not surprising when one considers the combined effects of rapid and progressive deterioration in the sugarcane root/soil zone, leaching, and dilution of runoff waters and eroded soil. The presence of diuron in sediments on the other hand, suggests that diuron is more persistent in field soils and in sediments than the triazines. Another factor may be the quantity of diuron used in sugarcane and pineapple: in 1968, total diuron use in the state was 745,000 lbs (338,230 kg) active compound, while ametryne and atrazine use was reported to be 395,000 and 380,000 lbs (179,330 and 172,520 kg), respectively (Kimura and Hurov 1969). Diuron is used extensively on both sugarcane and pineapple while the triazines are used principally on sugarcane.

The relatively high levels of diuron found in Walker Bay do not likely represent the mean level for sediments in West Loch of Pearl Harbor. Contamination from the herbicide-mixing and loading zone adjacent to Walker Bay undoubtedly results in higher diuron levels in these sediments than would be found in sediments receiving diuron only through transport of eroded soil and runoff from fields to which diuron was applied. Diuron concentrations of 0.05 to 0.5 ppm (dry basis) appear to be normal in the sediments from areas not having a point source of herbicide contamination.

It is significant that diuron concentrations were high in some field soils which had received no diuron for 1.5 to 4 years. If diuron can persist in surface soils by adsorption on organic matter (or some other mechanism) and thus resist microbial or chemical breakdown and leaching, then diuron-treated soils may be a source of diuron in estuarian sediments whenever these soils are eroded and storm runoff reaches an estuary. Although both sugarcane and pineapple plantations utilize soil conserving practices, it is not possible to always contain storm runoff, especially when the fields are open in the period between harvest and about 6 months after planting. The levels of diuron found in settling basins on McBryde Plantation (0.286 to 2.335 ppm) indicate the range of diuron concentrations which might be expected in eroded soil. The lower value (0.286 ppm) is about the same concentration as was found in the sediments of Waikele Stream near the point of entry to West Loch of Pearl Harbor.

In the past several years, there has been an active effort on the part of sugarcane plantations to contain irrigation return flow and runoff waters to avoid contamination of shoreline waters. One wonders if the quantities of diuron entering streams and estuaries has decreased in recent years as a result of these efforts. Perhaps much of the diuron currently measured in Kaika Bay, Pearl Harbor, and their influent streams is the residue of diuron which entered these waters in years past. On the other hand, when fields are open during and soon after harvest, storm runoff is difficult to contain and diuron transport to streams and estuaries is certainly possible. Future project efforts will be directed toward determining the movement of diuron in the study area and assessing the effects of sediment-borne diuron on biota in the estuary.

Nutrients

Nutrients in coastal waters and sediments are summarized in Table 5.9 in order to compare the effects of different land use patterns upon water quality. Median values of total nitrogen concentration in waters adjoining the relatively undeveloped area of Kahana Bay are only two-thirds as great as those found in waters adjoining a rapidly developing urban area

TABLE 5.9. NUTRIENTS IN COASTAL SEDIMENT AND WATERS, OAHU, 1971-73.

LAND USE CATEGORY	TYPE OF SAMPLE	TOTAL NITROGEN RANGE	TOTAL NITROGEN MEDIAN	TOTAL PHOSPHORUS RANGE	TOTAL PHOSPHORUS MEDIAN	POTASSIUM RANGE	POTASSIUM MEDIAN
UNDEVELOPED							
KAHANA BAY	SEDIMENT, mg/kg	25 - 3003	799	240 - 1120	434	215 - 1813	445
	WATER, mg/ℓ	0.028 - 0.230	0.114	0.003 - 0.090	0.025	20 - 648	459
URBAN							
MAUNALUA BAY	SEDIMENT, mg/kg	157 - 2667	712	218 - 1135	607	430 - 5769	2853
	WATER, mg/ℓ	0.036 - 0.840	0.157	0.010 - 0.091	0.035	404 - 540	498
SANDY BEACH	SEDIMENT, mg/kg	—	—	—	—	—	—
	WATER, mg/ℓ	0.041 - 0.375	0.151	0.011 - 0.062	0.030	238 - 850	509
WAIKIKI	SEDIMENT, mg/kg	218 - 405	324	327 - 810	515	207 - 444	294
	WATER, mg/ℓ	0.037 - 0.812	0.111	0.011 - 0.113	0.035	—	—
SUGARCANE CULTURE							
KILAUEA PLANTATION	SEDIMENT, mg/kg	128 - 688	235	286 - 632	414	75 - 675	312
	WATER, mg/ℓ	0.064 - 0.149	0.097	0.027 - 0.041	0.028	125 - 575	490
McBRYDE PLANTATION	SEDIMENT, mg/kg	258 - 462	308	206 - 940	386	111 - 650	356
	WATER, mg/ℓ	0.104 - 0.252	0.196	0.001 - 0.038	0.021	385 - 838	544

LAND USE CATEGORY	TYPE OF SAMPLE	HAWAII STATE 1968 WATER QUALITY STANDARDS: WATER CLASS	TOTAL NITROGEN	TOTAL PHOSPHORUS
UNDEVELOPED				
KAHANA BAY	SEDIMENT, mg/kg			
	WATER, mg/ℓ	AA	0.10	0.020
URBAN				
MAUNALUA BAY	SEDIMENT, mg/kg			
	WATER, mg/ℓ	A	0.15	0.025
SANDY BEACH	SEDIMENT, mg/kg			
	WATER, mg/ℓ	A	0.15	0.025
WAIKIKI	SEDIMENT, mg/kg			
	WATER, mg/ℓ	A	0.15	0.025
SUGARCANE CULTURE				
KILAUEA PLANTATION	SEDIMENT, mg/kg			
	WATER, mg/ℓ	A	0.15	0.025
McBRYDE PLANTATION	SEDIMENT, mg/kg			
	WATER, mg/ℓ	A	0.15	0.025

such as Hawaii Kai and Maunalua Bay. The recreational areas of Sandy Beach and Waikiki also show nitrogen concentrations greater than Kahana Bay.

However, in comparing Sandy Beach waters, in which there is an offshore discharge of secondary treated sewage, with those at Waikiki where highly concentrated use by tourists is a major factor, little difference is noted in mean total nitrogen concentrations. In the case of Sandy Beach, it is difficult to isolate the specific source of nitrogen. The contribution from recreation usage may be a major factor because data from the inshore areas (25-foot depth contour) of Waikiki Beach showed that the maximum values of total nitrogen are twice as great as those at Sandy Beach. This would indicate that a more intensive use of the waters for swimming and surfing would have a direct bearing on the nitrogen contribution.

Coastal waters at Kilauea and McBryde Plantations show higher values of nitrogen or phosphorus as compared with the undeveloped area of Kahana Bay on Oahu. Even though the open ocean fronts the plantation areas, there is sufficient runoff from the land to degrade the offshore waters so that at least one nutrient concentration does not meet the state standards for Class A waters.

A comparison of the various study areas in relation to the state water quality standards show that median nitrogen values slightly exceed the levels set for Kahana Bay, Maunalua Bay, and Sandy Beach.

With the exception of the McBryde Plantation area, all mean total phosphorus concentrations in the study areas exceed the levels set by state standards. The median total phosphorus values at Kahana Bay, Maunalua Bay, Sandy Beach, and Waikiki Beach all exceed the levels set for their respective water class by 20 to 40 percent. At both Kahana Bay and Waikiki Beach the maximum values of phosphorus concentrations exceed the standard levels set by the state 3.5 times, indicating that the two areas have the greatest seasonal variations.

It is interesting to note that in all the study areas on Oahu, the maximum values of nitrogen or phosphorus that occur because of seasonal and other effects can exceed the standards by as much as three- to sixfold.

Analysis of nitrogen and phosphorus in sediments show that Maunalua Bay has the greatest median concentrations of these nutrients.

MICROMOLLUSCS

The utilization of biological data in the assessment of water quality is now an integral part of water quality programs throughout the United States. Aquatic organisms are not only essential components of the recreational, economic, and aesthetic qualities of coastal waters, but also reflect chemical and physical parameters of water quality, and may serve as indicators of environmental changes.

The Hawaiian Islands are surrounded by a variety of shoreline types and offshore habitats: fringing reefs, solution benches, tidepools, and sandy beaches inshore, and subtidal coral communities of varying development and structure at depths of less than 1 m to depths of more than 50 m. Each ecosystem has a characteristic biota and each may be differently affected by pressures generated on land: subtidal coral communities off the Hamakua coast of Hawaii were reported by Grigg (1972) to exhibit reduced numbers and diversity of organisms as a result of heavy siltation and deposits of mill trash caused by the operations of sugar mills along the coastline, and certain aspects of the coastal waters off Kilauea on the north coast of Kauai similarly exhibit reduced numbers of organisms (Lau et al. 1972). Kaneohe Bay and Pearl Harbor, Oahu, are cited as areas where the biota is strongly influenced by eutrophication (Peeling et al. 1972; Lau 1972; Smith et al. 1973), indicated by the dominance of a few species dependent on the primary productivity of the water column.

Despite the numerous studies of the effects of pollution and habitat disruption now available, few studies consider the details of pattern changes. In this discussion we consider one group of organisms common to all marine ecosystems in the Hawaiian Islands, micromolluscs, that is, molluscs with shells less than about 10 mm in greatest diameter. Because molluscs represent a spectrum of trophic structure and a variety of spatial relations in their habitats, the species composition, diversity, and abundance of their assemblages are presumed to reflect the structure and ecological status of the communities of which they are a part. To establish baselines for comparative purposes, we ask three questions: 1) What species are present? 2) What are the patterns of species distribution, abundance, and trophic structure? 3) What are the patterns of change in different ecosystems?

METHODS. There is considerable evidence that micromolluscan shells are deposited *in situ* in sediments, with little or no long distance transport. Volumetrically micromollusc shells may comprise as much as one-third of the sediments of reefs, tidepools, solution benches, and sandy beaches; hence, analysis of unconsolidated sediments samples large numbers of species with a minimum of effort, and allows quantitative and qualitative inter-area comparisons. The shells analyzed represent in general species with maximum size of not more than 10 mm. When shells of larger size occurred in the samples, they were included in the assemblage counts, but except for stations in Pearl Harbor and Honokohau Boat Harbor none of the species comprises a dominant portion of the samples.

Surficial sediment samples were obtained by hand or dredge from a variety of areas on the islands of Kauai, Oahu, Maui, Molokai, and Hawaii between 1969 and 1973. Sediments were subsampled in volumes of 25 cu cm, or lesser volumes if they were deemed appropriate. Counts of micromolluscs were made at magnifications of 50 to 100 X. Fragments identifiable to species were counted as one animal, but only apertures or apical whorls were counted in each sample. The size of the sample was arbitrarily chosen and appears to be satisfactory in that it gives maximum counts of up to 600 shells/cu cm. Greater numbers would have been difficult to deal with in a routine manner.

Several techniques were utilized to gain a quantitative insight into the distribution of molluscs in relation to habits and habitat type. Average relative abundance values were calculated by computing the percentages of species and family groups. Frequency, the number of occurrences of a species in each group of stations divided by the total number of stations in the group, is also considered. Standing crops were estimated by dividing the number of shells obtained from a station by the volume sediment analyzed. Trophic structure was determined by calculating the number of individuals associated with a particular feeding habit and dividing by the total number of individuals in the sample. Species diversity was calculated using the function $H = -\Sigma p_i \log_2 p_i$, where p_i equals the fraction of the total number of individuals represented by each species (Pielou 1969). This measure takes into account numbers of individuals within the sample as well as number of species. Diversity values were calculated on an APL/360 computer at the University of Hawaii.

Habitat Descriptions

In this study four habitats, which may be broadly termed ecosystems, are distinguished on the basis of topographical and depth characteristics: 1) fringing reef flats; and 2) subtidal habitats at depths of 1 to 3 m; 3) at depths of 4 to 15 m; and 4) at depths of 16 to 50 m. Stations representing the habitats are shown in Figures 5.4 and 5.5, with each habitat type distinguished by a letter.

The fringing reefs on the windward and protected shores of Kauai, Oahu, and Molokai are wide, shallow platforms extending as much as 1600 m seaward from the shore. The shoreward portions of the reefs are usually characterized by a predominantly sandy substrate interspersed with patches of living coral and coralline algae, and are cut by more or less numerous channels which usually mark the places where streams flow from the land. Depth of water on the reef flat is usually 0.3 to 2 m at low tide, deeper at high tide and when there is heavy wave action. The reef flat is topographically heterogeneous: portions of the flat are solid with an algal cover of corralline algae as well as frondose species such as *Padina*, *Colpomenia*, *Sargassum*, etc.; other sections are sandy flats with some cover of *Lyngbya*, and/or *Acanthophora* inshore and *Sargassum* spp. toward the seaward edge. The outer edge is from 2 to 3 ft (.6096 to .9144 m) below low tide and often densely fringed with the frondose brown alga, *Sargassum* sp. The seaward edge (algal ridge or crest), is usually somewhat higher than the inner portion, and awash at low tide; the outer wall is steep and descends gradually to depths of 10 m or more where it is characterized by vigorous coral growth.

Three of the reef flats sampled are conspicuously affected by the

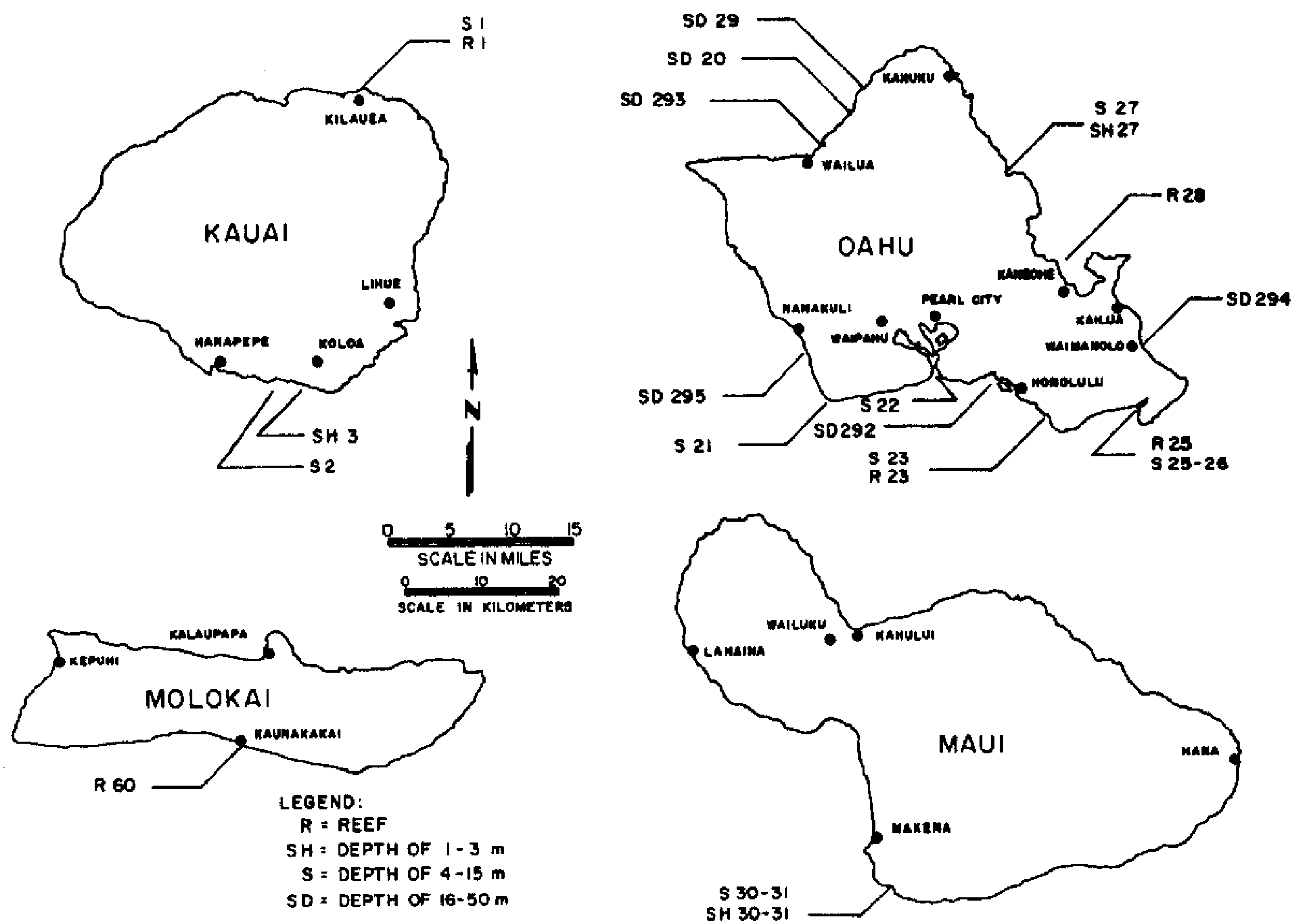


FIGURE 5.4. AREA AND STATION LOCALITIES FOR THE ISLANDS OF KAUAI, OAHU, MOLOKAI, AND MAUI.

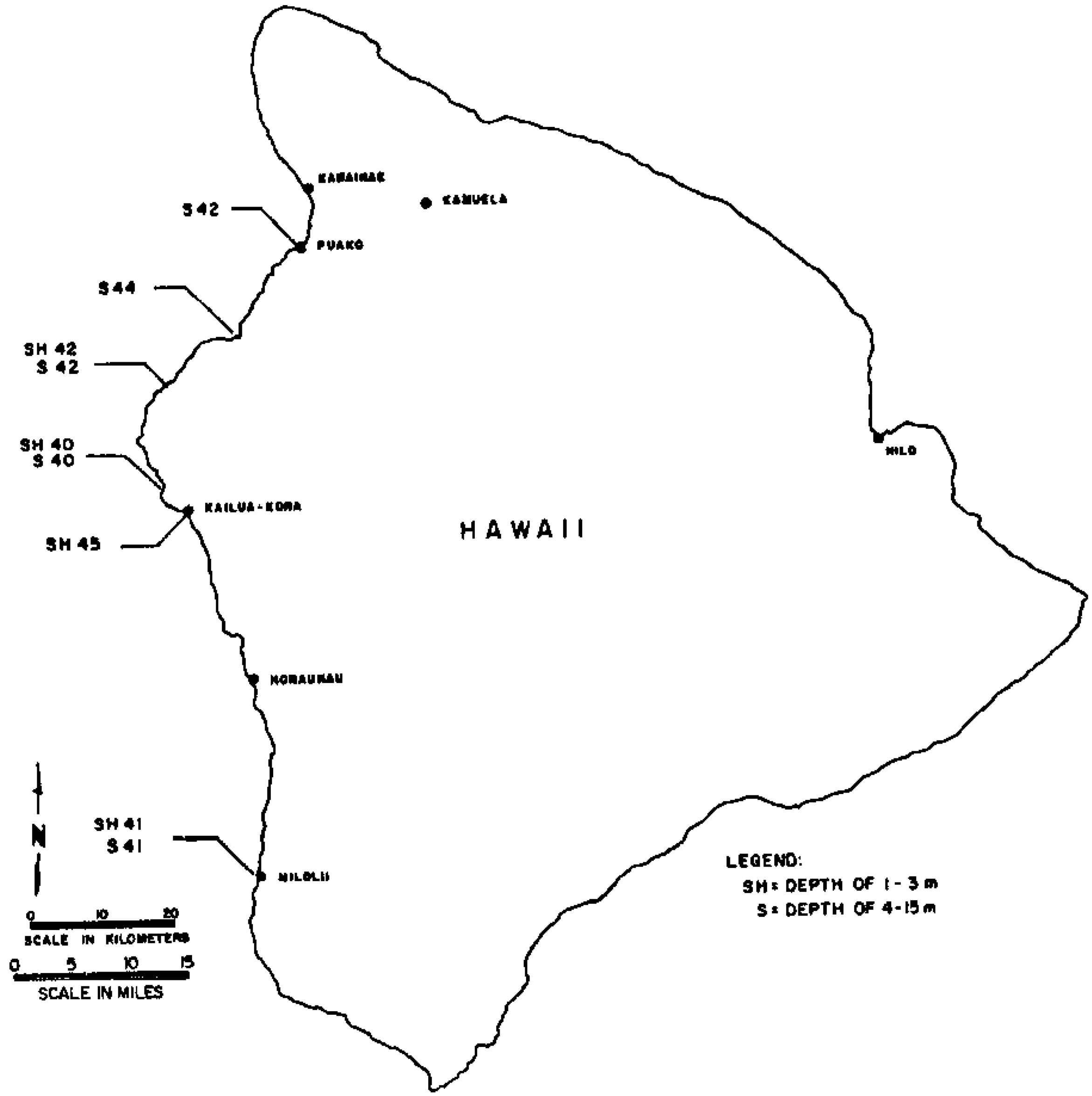


FIGURE 5.5. AREA AND STATION LOCALITIES FOR THE ISLAND OF HAWAII.

deposition of mud and silt: much of the fringing reef flat in the southern part of Kaneohe Bay, Oahu (Station R28), the reef flat of Maunalua Bay, Oahu (Station R25), and the reef flat fringing the southern section of Molokai near Kaunakakai (Station R60).

Subtidal waters around the Hawaiian Islands are characterized by a variety of bottom structures: coral cover may be on the order of 100 percent at depths less than 1 m to more than 50 m off the Kona coast of Hawaii; in other areas boulders, rubble, and dead coral are characteristic of the substrate; still other areas are predominantly sandy. Stations which represent the 1- to 3-meter depth interval in this study are in general in shallow bays which have a predominantly rubble-strewn substrate with occasional heads of the coral *Porites*. Except for the stations on the Kona coast where sediments include basalt, the sediments are primarily calcareous. One shallow water station included in this survey is man-made: the newly formed Honokohau Boat Harbor (SH40), excavated from the basalt coastline in 1969, on the Kona coast of Hawaii.

The subtidal stations at depths of 4 to 15 m also include a variety of types. Many of the stations are those off the steep frontal slope of fringing reefs, Stations S1 (Kilauea reef), S23 (off the Waikiki reef); and others are from subtidal coral communities where there is no fringing reef (Stations S2, S21, S27, etc.).

The deepest stations are located around the island of Oahu (Stations SD29, SD20, SD293, SD295, SD294) and include stations off Pearl Harbor and Honolulu Harbor.

Species Composition

The characteristics of the Hawaiian marine molluscan fauna have been outlined by Kay (1967). Gastropods comprise the predominant part of the molluscan fauna both in terms of species numbers and abundance. A gastropod:bivalve species ratio of 82:18 is characteristic. The gastropods are also characterized by a strong epifaunal tendency; and even among the bivalves, most species for which we have data tend to be epifaunal rather than infaunal.

Five gastropod families with micromolluscan representatives comprise the dominant components of all the assemblages analyzed. Relative abundance and relative frequency of occurrence of the representatives of these groups are shown in Figure 5.6 and detailed in Table 5.10.

The Phasianellidae are represented by a single species, *Tricolia variabilis*, which is associated with frondose algae such as *Sargassum* spp. and *Padina*. It is ubiquitous, occurring with an average relative abundance of 9 percent in all the habitats considered with a .88 relative frequency. *Tricolia* is assumed to feed on epiphytes growing on the larger frondose algae on which it is found.

The Rissoidae are represented by at least eight genera in Hawaiian waters, of which "*Cithna*", and *Rissoina* are the major representatives of

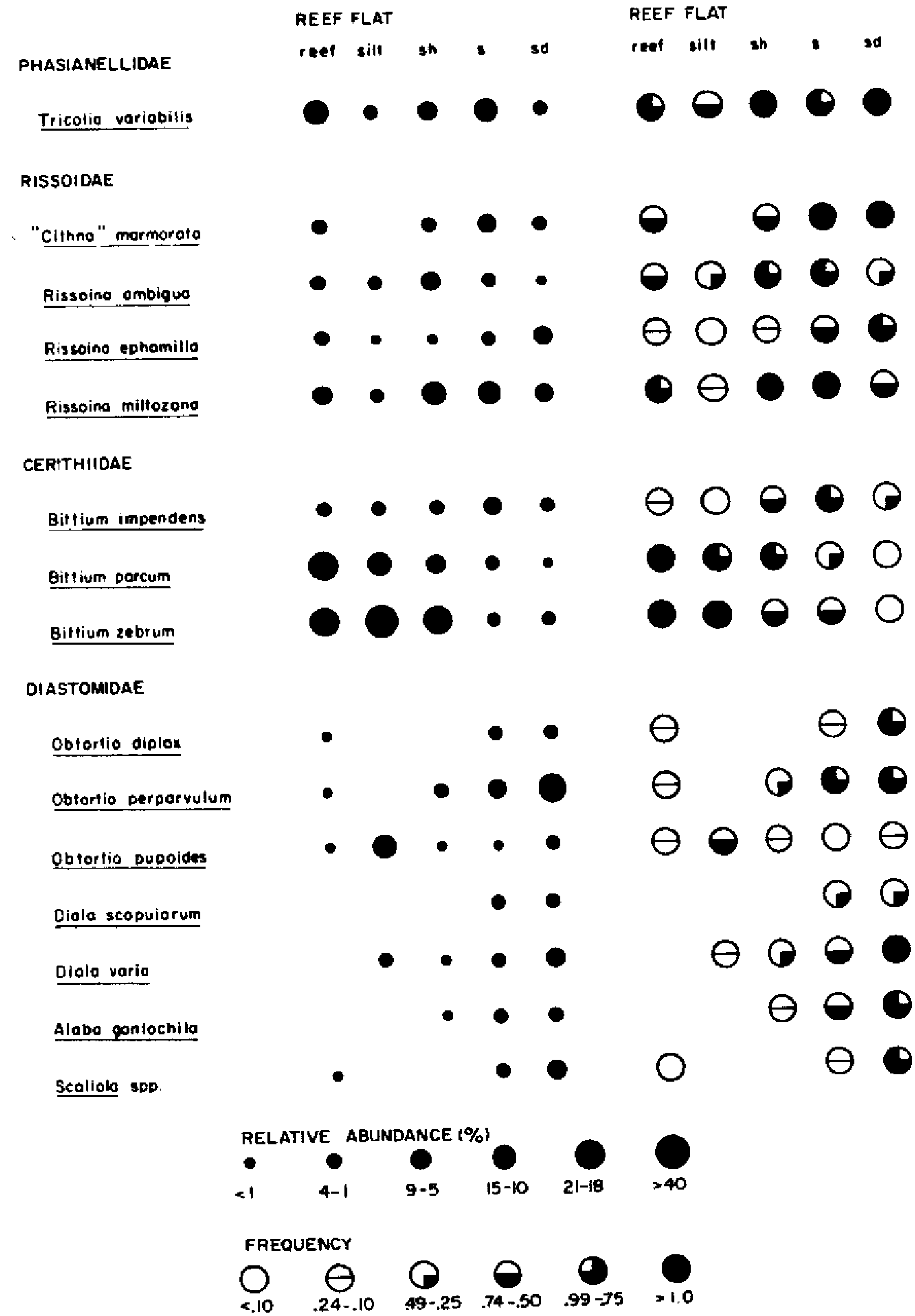


FIGURE 5.6. RELATIVE ABUNDANCE AND FREQUENCY OF MICROMOLLUSCS.

the family in these habitats. *Rissoina ambigua* and *R. miltozona*, are, like *Tricolia*, nearly ubiquitous, but are proportionately more characteristic of the shallow subtidal stations than the deeper, where they are replaced by *R. ephamilla*, "*Cithna*" (Fig. 5.6), and other small rissoids. *R. ambigua* and *R. miltozona* are detritus feeders and microherbivores associated with rubble. The habits of "*Cithna*" are not known, these rissoids are assumed to be associated predominantly with rubble and to be herbivores. The shells of the shallow water rissoids are larger (ca 7 mm long) and more coarsely sculptured than the shells of the small (ca 4 mm) *Rissoina ephamilla* and the smooth, vitreous "*Cithna*".

Of the four genera of Cerithiidae occurring in Hawaiian waters, only one, *Bittium*, is a predominant component of the assemblage on reef flats and in subtidal waters. *Bittium parcum* and *B. zebrum* are associated with reef flats and shallow, subtidal waters (Fig. 5.6); the former occurs on frondose algae such as *Sargassum* spp. and *Padina* with *Tricolia*. *B. zebrum* is rubble-associated and feeds on microalgae. *B. impendens* also appears to be rubble-associated, and is characteristic of mid-depths (that is, from 10 to 30 m). The shells of *B. impendens* and *B. zebrum* are about 10 mm in length, heavy and coarsely sculptured; the shells of *B. parcum* are smaller (8 mm in length), thinner in texture and only faintly sculptured.

The Diastomidae represent a family of small molluscs the habits of which are not known. One species, *Obtortio pupoides*, is frequently found in the sediments of reef flats and occasionally at depths of more than 15 m (Fig. 5.6). The other diastomids, *O. perparvulum*, *O. diplax*, *Alaba goniochila*, and *Scaliola* spp. are predominantly deep water species (Fig. 5.6). The shells of these latter diastomids are distinguished from those of *Obtortio pupoides* and *Bittium* spp. by their smaller size (3 mm), fragile texture, and lack of sculpture.

The habits of the Pyramidellidae are frequently recorded as those of ectoparasites on polychaetes, gastropods, oysters, and other sedentary invertebrates. Several species of pyramidellids are included in the assemblages; their specific habits and associations are not known but all are here presumed ectoparasitic on oysters and other sedentary invertebrates.

The molluscs cited above, except for the pyramidellids, are herbivores of one form or another--grazers or detritus feeders. Carnivores other than pyramidellids do not form conspicuous components of the assemblages; those that are represented are primarily faunal grazers, such as members of the Triphoridae and Marginellidae which feed on sponges and ascidians. Active predators, such as *Natica*, turrids, small miters, etc. are sparsely represented. Infaunal gastropods are also noticeably absent from the assemblages; when present they are represented by *Caecum* spp. and *Acteocina* sp. Nor do bivalves, either infaunal or epifaunal, comprise conspicuous components of the assemblages except in a few instances which will be noted subsequently. Attached gastropods, such as *Hipponix*, vermetids, and *Crepidula* are also restricted in occurrence to specific situations.

Species Groupings

FRINGING REEF FLATS. The gastropod:bivalve numerical ratio on the fringing reef flats averages 98:2. Of the gastropods which form the most conspicuous components of the assemblages on fringing reef flats, two patterns of family dominance are distinguishable: a Phasianellidae/Rissoidae pattern and a Cerithiidae pattern (Fig. 5.6). Two additional groups of molluscs, the Pyramidellidae and the Diastomidae, are also useful in distinguishing reef habitats.

The Phasianellidae/Rissoidae pattern is associated with reef flat areas where there is a predominantly calcareous algal substrate and clean, unsilted conditions: the eastern portion of the Kilauea reef; most stations on the Waikiki reef; the northern, unsilted stations and seaward stations of the Maunalua reef; and the north Kaneohe Bay station (Fig. 5.7 and Table 5.10). Despite the predominance in this assemblage of the rubble-associated *Rissoina ambigua* and *R. miltozona*, the assemblage is more accurately characterized by its association with frondose algae. The dominant component of the Cerithiidae at these stations is *Bittium parcum* (Fig. 5.8) and these small molluscs with *Tricolia* in fact comprise the greater proportion of the assemblages.

The Cerithiidae pattern is dominant on the sandy areas of the western part of the Kilauea reef flat, at all silted stations of the Maunalua reef and fringing reef in Kaneohe Bay, and on the Molokai reef flat. With few exceptions the dominant cerithioid is the rubble-associated *Bittium zebrum* (Fig. 5.8). At the Waikiki reef flat stations where the Cerithiidae are dominant, *Bittium parcum* comprises the greater proportion of the *Bittium* assemblage.

The Phasianellidae/Rissoidae and the Cerithiidae patterns of distribution are graphically demonstrated in Figure 5.7 by the north-south gradient of assemblages at stations in Kaneohe Bay and in transects across the reef flat from shore to sea in Maunalua Bay.

Pyramidellids form a conspicuous component of the reef flat assemblages only in the southern part of Kaneohe Bay (Fig. 5.7D). The diastomid *Obtortio pupoides*, although not a dominant component of any of the reef flat assemblages appears in greater relative abundance and more frequently on silted reef flats than at stations on nonsilted reef flats (Figs. 5.6 and 5.7).

DEPTHS OF 1 TO 3 m. The gastropod:bivalve numerical ratio is 97:3. The bivalves are predominantly epifaunal. The common feature of the majority of stations of this habitat type is the predominance of the rubble-associated Rissoidae, *Rissoina ambigua* and *R. miltozona* (Fig. 5.9: Stations SH1, SH27, and SH30), and the cerithioid *Bittium zebrum* (Fig. 5.9: Stations 44, SH40, SH40a). The species composition of the two stations at Honokohau Boat Harbor (SH40 and SH40a) is somewhat anomalous in the low proportions of the dominant family groups characteristic of these depths; the anomaly is accounted for by the fact that at these two stations the oyster *Ostrea sandvicensis* forms the greater part of the

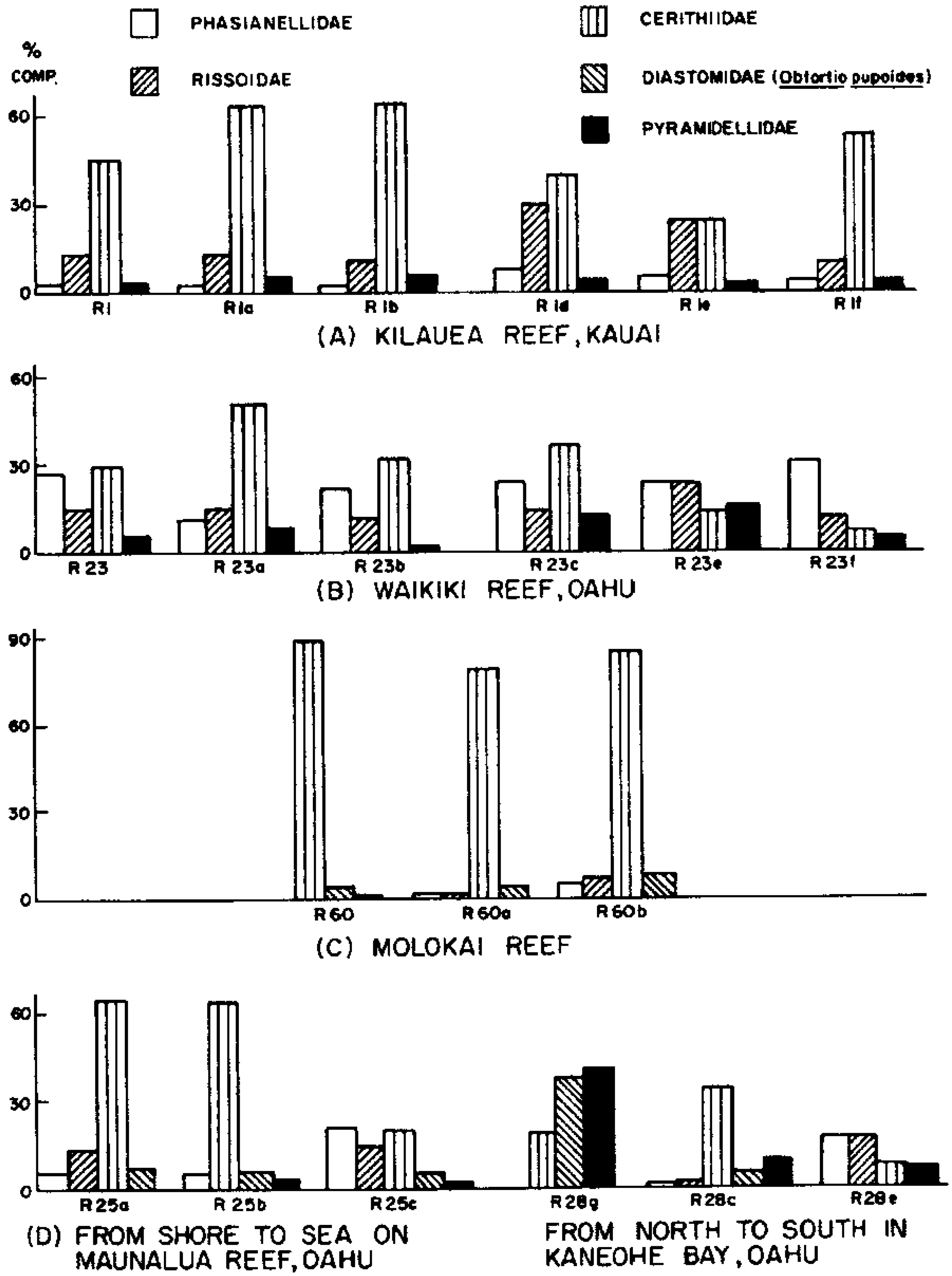


FIGURE 5.7. RELATIVE ABUNDANCE OF GASTROPOD FAMILIES ON FRINGING REEF FLATS.

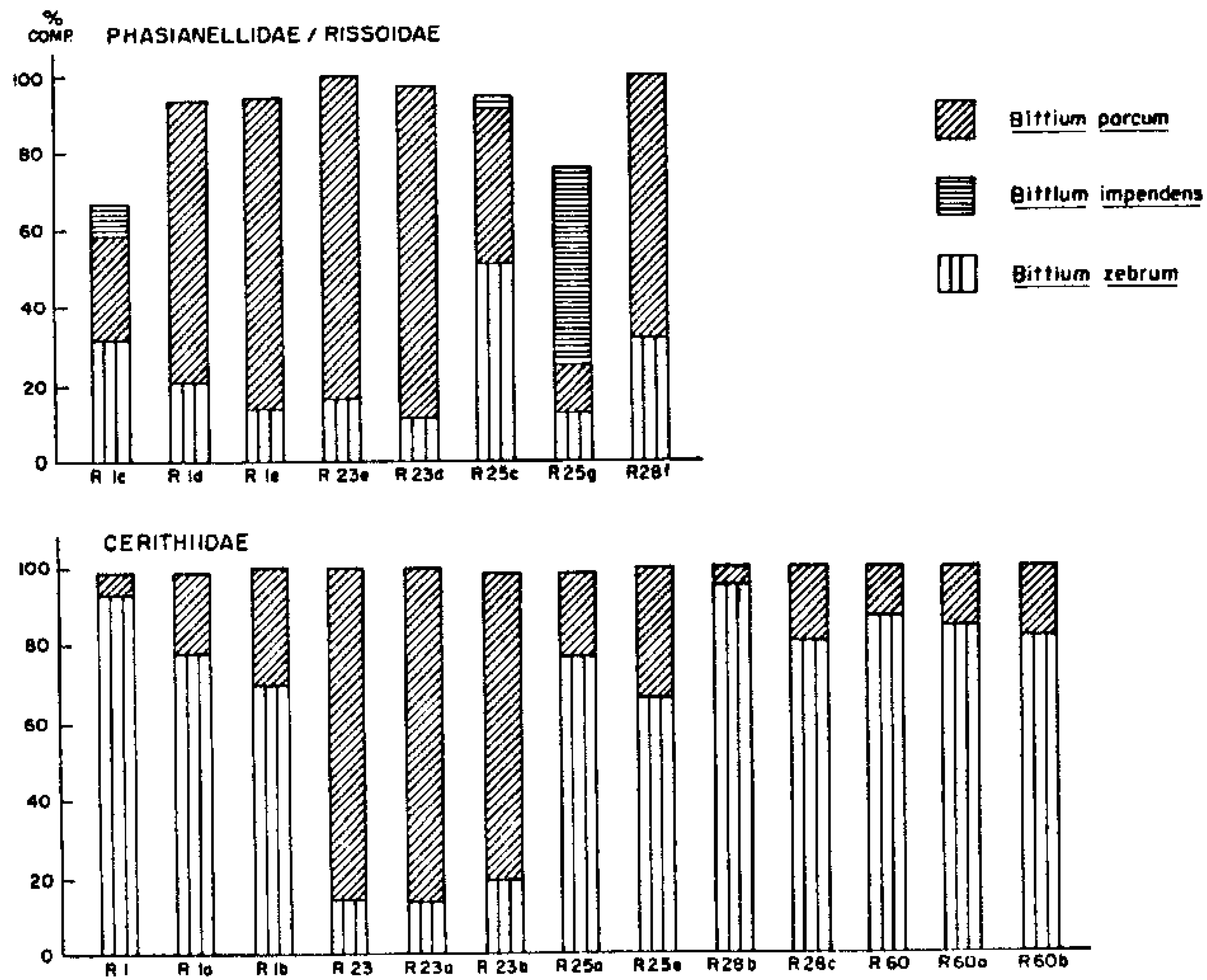


FIGURE 5.8. RELATIVE PROPORTIONS OF *BITTIUM* SPECIES IN THE PHASIANELLIDAE/RISSOIDAE AND CERITHIIDAE DOMINATED STATIONS.

TABLE 5.10. MICROMOLLUSCAN FAMILY COMPOSITION IN PERCENT OF ASSEMBLAGE.

AREA	STATION NUMBER	TRICOLIA	RISSOIDAE	CERITHIIDAE	DIASTOMIDAE	TRIPHORIDAE	PYRAMIDELLIDAE
		PERCENT					
TIDEPOOLS							
POIPU, KAUAI	T1	9	12	75	—	—	—
" "	T1a	.07	42	40	—	.04	.08
" "	T1b	.08	57	51	—	—	.04
KAENA POINT, OAHU	T20	.06	66	12	—	.06	—
" " "	T20a	.5	40	15	—	1.0	—
" " "	T20b	3.0	58	8	—	1.0	—
CAPE KINAU, MAUI	T30	.08	12	20	—	.08	—
" " "	T30a	—	4	37	—	.03	—
KEALAKEHA, HAWAII	T40	7.0	18	16	—	2.0	4.0
HONAUNAU, HAWAII	T41	3.0	9	64	—	.03	2.0
" "	T41a	7.0	31	12	—	—	1.0
FRINGING REEFS							
ANINI, KAUAI	R1	3.0	15	46	.07	5.0	3.0
" "	R1a	2.0	12	64	—	1.0	5.0
" "	R1b	2.0	10	65	—	.03	6.0
" "	R1c	—	39	33	—	9.0	5.0
" "	R1d	8.0	30	40	—	1.0	3.0
" "	R1e	5.0	25	25	—	9.0	1.0
" "	R1f	4.0	10	55	—	.07	90
" "	R1g	6.0	17	33	—	—	17
WAIKIKI, OAHU	R23	20	16	38	—	1.0	3.0
" "	R23a	11	13	57	.09	3.0	9.0
" "	R23b	31	11	32	.07	.04	1.0
" "	R23c	25	14	20	—	2.0	12.0
" "	R23d	36	9	22	—	3.0	8.0
" "	R23e	24	24	13	7.0	3.0	96.0
MAUNALUA BAY, OAHU	R25	3.0	1.0	65	11	2.0	.06
" " "	R25a	5.0	13	67	7	2.0	—
" " "	R25b	4.0	5	65	7	2.0	2.0
" " "	R25c	21.0	15	20	6	2.0	2.0
" " "	R25d	—	8	66	—	3.0	—
" " "	R25e	.05	2.0	84	1	2.0	.05
" " "	R25f	3.0	11	62	—	5.0	4.0
" " "	R25g	42.0	15	4.0	21	6.0	.35
" " "	R25h	—	4	48	—	—	1.0
" " "	R25i	1.1	5	68	—	4.0	5.0
KANEOHE BAY, OAHU	R20	—	1	40	13	—	41
" " "	R20a	—	1	31	11	3.0	30
" " "	R20b	.09	.06	46	14	6.0	19
" " "	R20c	1.0	2.0	34	5	.09	18
" " "	R20d	5.0	5.0	72	.04	9.0	19
" " "	R20e	19.0	19	18	—	4.0	7
" " "	R20f	13.0	15	21	—	7.0	3
" " "	R20g	—	—	19	29	--	33
KAUNAKAKAI, MOLOKAI	R60	—	—	90	4	—	.06
" "	R60a	.08	.08	80	5	—	—
" "	R60b	4.0	7.0	66	9	—	—
SUBTIDAL 1 TO 3 m							
KUHIO PARK, KAUAI	SH3	13.0	21.0	11	1.0	5.0	1.0
KAHANA BAY, OAHU	SH27	14.0	39.0	23	.06	8.0	2.0
" " "	SH27a	5.0	33.0	16	3.0	3.0	6.0
CAPE KINAU, MAUI	SH30	3.0	44	17	2	4.0	1.0
" " "	SH30a	.09	41	6	—	11	.07
" " "	SH30b	.09	49	17	—	8.0	.09
KIHOLO, HAWAII	SH44	3	34	41	.01	4.0	2.0
MILOLII, HAWAII	SH41	4	35	20	—	10	.03
MAKALAWENA, HAWAII	SH42	14	37	30	—	—	1.0
WAILUA, HAWAII	SH45	2	30	39	—	—	1.0
" "	SH45a	1	11	43	—	4.0	2.0
HONOKOHAU, HAWAII	SH40	—	6	16	—	.09	6.0
" "	SH40a	1	6	35	—	—	4.0
SUBTIDAL 5 TO 15 m							
KILAUEA, KAUAI	S1-7	4.0	27	9	11	18	5.0
" "	S1-9	6.0	22	20	7	6	5.0
" "	S1-15	—	27	17	25	—	2.0
McBRYDE PLT., KAUAI	S2-16	2.0	51	6.0	7.0	8.0	1.0
" " "	S2-17	4.0	40	4.0	10.0	10.0	9.0
" " "	S2-18	2.0	21	—	39.0	8.0	2.0
SUNSET BEACH, OAHU	S20	5.0	31	3.0	11.0	24.0	1.0
BARBER'S POINT, OAHU	S21	12.0	34	12.0	2.0	5.0	4.0
PEARL HARBOR, OAHU	S22	26.0	17	6.0	7.0	4.0	7.0
WAIKIKI, OAHU	S23	3.0					
" "	S23a	4.0	40	5.0	4.0	13.0	2.0
" "	S23b	5.0	33	6.0	11.0	12.0	2.0
" "	S23c	10.0	40	9.0	1.1	15.0	2.0
" "	S23d	21.0	20	2.0	11.0	5.0	1.0
" "	S23e	35.0	19	9.0	3.0	1.0	.05
HAWAII KAI, OAHU	S26	6.0	31	56	1.0	5.0	3.0
KAHANA, OAHU	S27	53.0	16	9.0	10.0	5.0	2.0
CAPE KINAU, MAUI	S30	—	30	12.0	12.0	3.0	3.0
" " "	S30a	—	27	7.0	12.0	1.0	4.0
HONOKOHAU, HAWAII	S40	9.0	34	15	—	5.0	—
MILOLII, HAWAII	S41	18.0	38	15	.08	8.0	—
MAKALAWENA, HAWAII	S42	22.0	37	15	.04	2	3.0
SUBTIDAL 16 TO 50 m							
WAIMEA, OAHU	S29	9.0	8.0	2.0	40.0	7.0	1.0
MAKAPUU, OAHU	S291	4.0	12.0	2.0	58.0	8.0	.08
PEARL HARBOR, OAHU	S22a	3.0	10.0	3.0	31.0	.08	5.0
HONOLULU HARBOR, OAHU	S292	7.0	10.0	—	52.0	3.0	1.0
SUNSET BEACH, OAHU	S20a	6.0	38	.04	8.0	22.0	2.0
WAIMEA, OAHU	S29a	6.0	29	3.0	37.0	8.0	2.0
SUNSET BEACH, OAHU	S20b	6.0	40	7.0	12.0	17.0	3.0
KANEOHE BAY, OAHU	S28	3.0	12	1.0	63.0	5.0	2.0
" " "	S28a	4.0	27	.08	50.0	2.0	—
KANE POINT, OAHU	S295	.09	18	2.0	19.0	16.0	3.0
HALEIWA, OAHU	S293	4.0	18	—	38.0	8.0	.04
" "	S293a	9.0	9	.02	45.0	3.0	
HONOLULU HARBOR, OAHU	S292a	4.0	11	1.0	45.0	—	11
WAIMANALO, OAHU	S294	3.0	10	.04	45.0	6.0	5.0
BARBER'S POINT, OAHU	S21a	2.0	35	2.0	29.0	8.0	4.0

assemblage (Fig. 5.10), thus reducing the numbers of epifaunal forms present.

DEPTHS OF 4 TO 15 m. The gastropod:bivalve numerical ratio is 96:4. The bivalves are predominantly epifaunal. Three patterns of gastropod species composition are distinguishable (Fig. 5.9): 1) a Rissoidae- and hence rubble-associated pattern occurring at stations where coral cover ranges from 50 to 100 percent; 2) a Phasianellidae-dominated assemblage where the substrate is sand and where no coral was reported suggesting a predominantly frondose algal habitat; and 3) a pyramidellid-dominated assemblage in Pearl Harbor (Station S22).

The rissoids of the rissoid and phasianellid assemblages differ from those in shallow waters in the increasing predominance of *Rissoina ephamilla* and "*Cithna*" *marmorata* both in terms of relative abundance and frequency (Fig. 5.6). *Bittium impendens* is the dominant cerithioid, in contrast to the *B. parcum*/*B. zebrum* assemblages at lesser depths (Fig. 5.6), except in Pearl Harbor where *Bittium zebrum* is the only cerithioid present.

Three stations sampled within this depth range do not fit the three patterns described: At Station S12 off the Kilauea Reef (Kauai) and Station S26 off the Maunalua Bay (Oahu) reef there are high proportions of Cerithiidae, *Bittium parcum* and *B. zebrum*, in the assemblages. The anomaly at the Kilauea Station stems from the fact that the station is at the bottom of a break in the reef crest and the assemblage represents an accumulation of reef-flat species. A similar situation appears to exist at the Hawaii Kai station which is a lagoon formed by excavation of the fringing reef. At the third station, Lawai (S18), on the McBryde coast of Kauai, there is a higher proportion of Diastomidae present than is apparently usual at 10-meter depths, and the assemblage more nearly resembles assemblages from greater depths as described below.

DEPTHS OF 16 TO 45 m. The gastropod:bivalve numerical ratio is 93:7. Several of the bivalves are infaunal (e.g. *Limopsis* and *Nucula*) in contrast to stations at lesser depths. The Diastomidae comprise the dominant component of the assemblages at most of the stations, but there is also a strong rissoid component. The assemblage is presumably rubble-associated. Its distinguishing features are several species *Rissoina ephamilla, Diala* spp., and *Obtortio* spp. (Fig. 5.6), which are found in greatest relative abundance at these depths. At three stations, Pearl Harbor, Barbers Point, and Honolulu Harbor, several specimens of *Obtortio pupoides* and *Bittium zebrum* were recorded in the sediments. The three stations are located at the entrance to harbors traversed by large ships.

TROPHIC STRUCTURE. Trophic structure in all the habitats sampled is predominantly herbivore (Fig. 5.10), with grazing herbivores comprising the greater proportions of the assemblages in all but three instances, Pearl Harbor, the southern part of Kaneohe Bay, and Honokohau Boat Harbor. In Pearl Harbor and Honokohau Boat Harbor the large numbers of sedentary bivalves which were counted indicate the dependence of the assemblages on the primary productivity of the water column. In the southern part of Kaneohe Bay, dependence of other communities on the

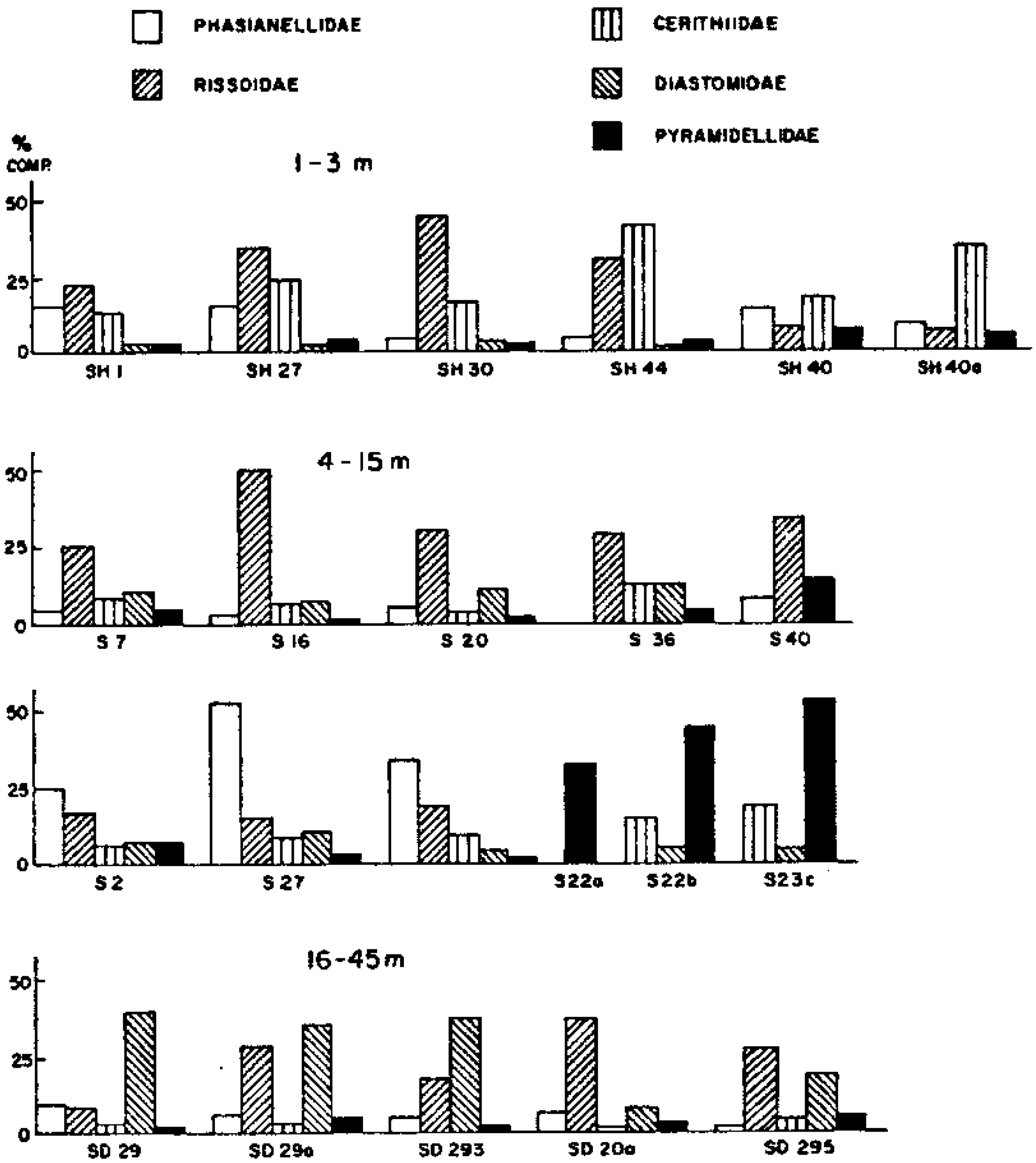


FIGURE 5.9. RELATIVE PROPORTIONS OF GASTROPOD FAMILIES IN SUBTIDAL WATERS.

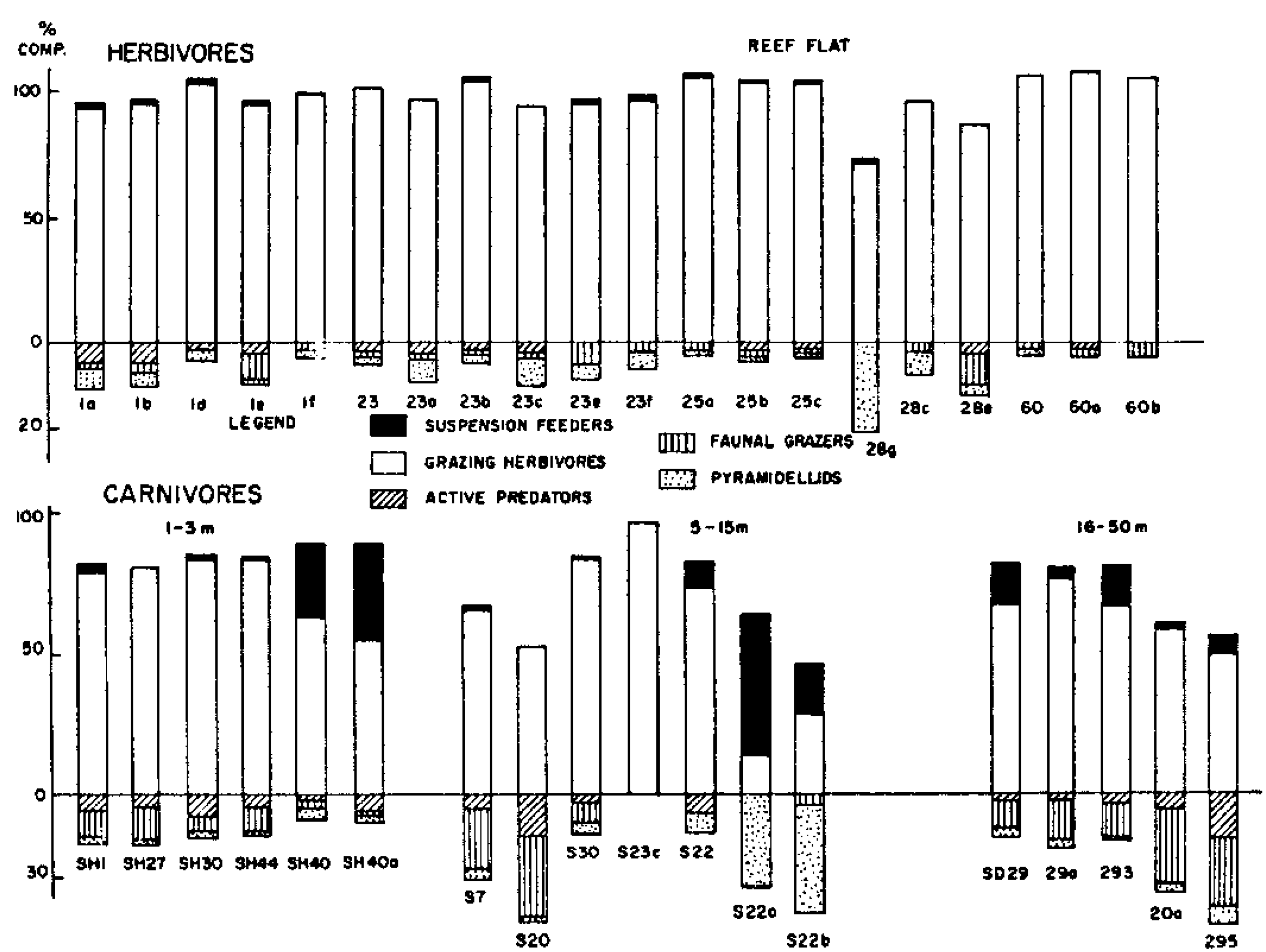


FIGURE 5.10. PERCENTAGES OF INDIVIDUALS REPRESENTING TROPHIC TYPES ON REEF FLATS AND AT SUBTIDAL STATIONS.

primary productivity of the water column is inferred from the numbers of pyramidellids which occur in the micromolluscan assemblages, the pyramidellids presumably occurring on sessile invertebrates in the area. The relatively higher proportion of pyramidellids at depths of 80 ft (24.38 m) off Honolulu Harbor suggests a similar situation. The proportionately greater number of bivalves at depths of more than 15 m tends to shift the trophic structure at these depths in the direction of suspension feeding although the molluscs with these habits by no means predominate in the assemblages. On reef flats affected by silting the predominance of the rubble-associated *Bittium zebrum* suggests a shift in the herbivore structure from forms which graze on epiphytes associated with frondose algae to those associated with rubble.

Among the carnivores, faunal grazers, which are assumed to reflect communities of sponges and ascidians, are predominant except where they are outnumbered by the ectoparasitic pyramidellids in Pearl Harbor and Kaneohe Bay. Faunal grazers are more conspicuous on nonsilted reef flat stations than on those affected by silting, and they are also more conspicuous at depths of 5 to 15 m and at greater depths than they are on reef flats or at depths of less than 3 m.

STANDING CROP. Standing crop as indicated by numbers of shells per cu cm is generally lower on reef flats than at the subtidal stations, and lowest on those reef flat stations with silt (Fig. 5.11). Standing crop is also generally lower at shallow subtidal stations than at those of depths of more than 3 m, but it is almost inordinately high (70 cu cm) at some of the deepest stations (Fig. 5.12). Kauai subtidal stations at depths of 3 to 15 m are generally lower in standing crop than are stations at similar depths off Oahu and Hawaii. On Oahu, two stations, one off the Waikiki reef and one in Kahana Bay, which have a predominantly herbivore trophic structure (i.e. Phasianellid-dominated) have the lowest standing crop.

DIVERSITY. There is a strong correlation between species diversity and the physical condition of reef flats: these reef flat stations which are silted have noticeably depressed Shannon-Weaver values which contrast with the higher values of reef flat stations which are not silted (Fig. 5.11). The relation between diversity and silting may be attributed to lesser availability of frondose algae and sponge- and ascidian-covered rubble on which microherbivores and faunal grazers live, the unstable mud substrate precluding growth of both algae and encrusting invertebrates. The availability of habitat for micromolluscs is thus decreased. If we assume that micromolluscan distributions are associated primarily with the diversity of available habitat, then low Shannon-Weaver values are not unexpected.

Among the subtidal stations, the lowest diversity values occur in Pearl Harbor where there is considerable evidence of eutrophication. In addition, two stations at Kahana Bay, Oahu (S27) also exhibit low diversity values. Both stations also show high proportions of algal-associated micromolluscs.

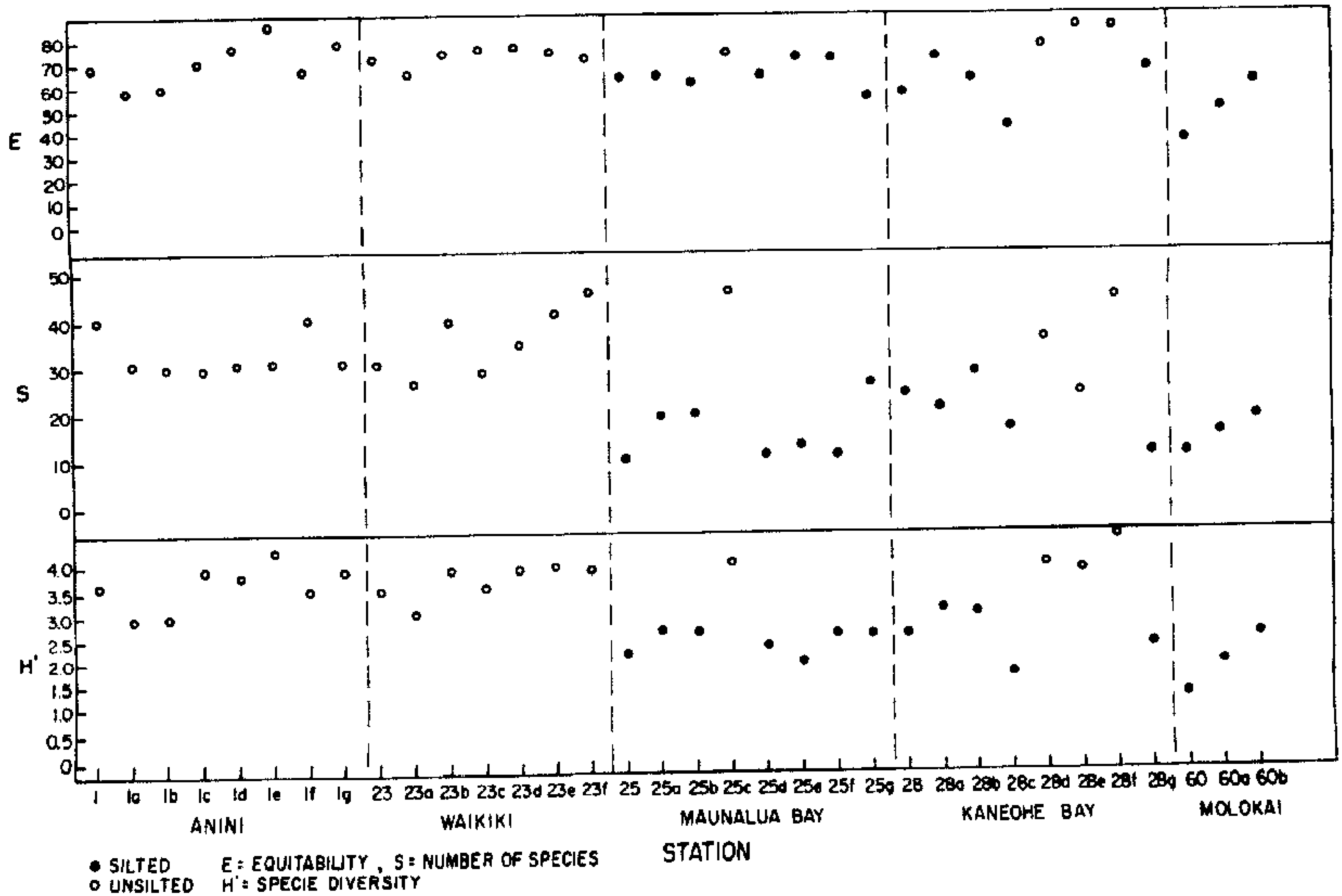
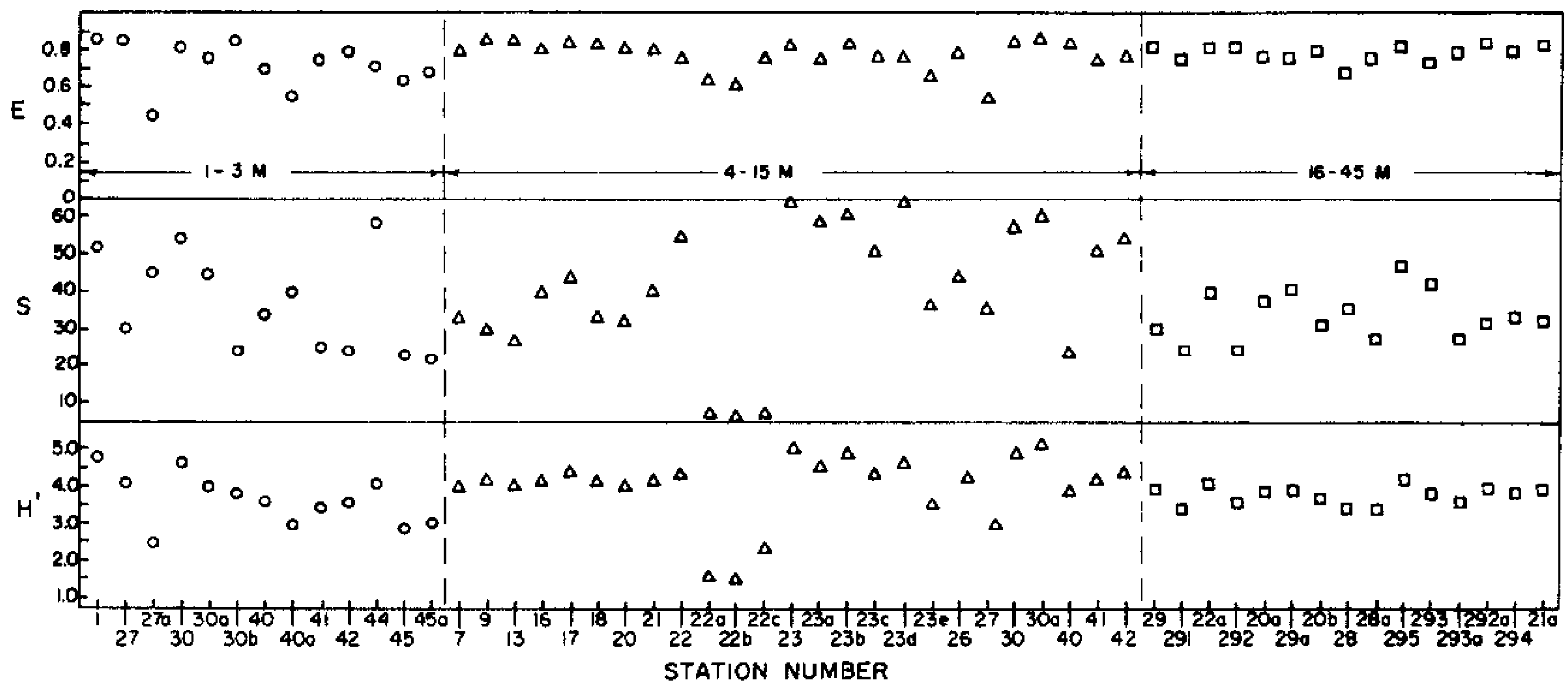


FIGURE 5.11. FRINGING REEF STATIONS.



E = EQUITABILITY , S = NUMBER OF SPECIES
H' = SPECIE DIVERSITY

FIGURE 5.12. SUBTIDAL AREAS.

Discussion

The present study of micromolluscan assemblages from the surficial sediments of more than 50 stations in the Hawaiian Islands attempts to explore the relationships among species composition habits and habitat type, and to ascertain what factors are important in controlling distribution and abundance.

The major assemblages described above exhibit several contrasting features for at least the dominant components of the assemblages. Reef flat assemblages are comprised of rather coarsely sculptured shells associated with either frondose algae or rubble. At shallow, subtidal depths rubble-associated species predominate; at greater depths there is an increase in the proportion of faunal grazers. At depths of more than 15 m the assemblage is comprised of many small, fragile shells, and faunal grazers and bivalves play a more conspicuous role in the trophic structure of the communities than they do at lesser depths.

Standing crop and diversity values are fairly consistent for most stations which have not been affected by pressures generated on land. However, there are noticeable differences among the ecosystems: the Kauai stations exhibit lower standing crops than do those from other islands. Diversity values for subtidal waters are consistently higher at depths of more than 5 m than for reef flats and shallow subtidal waters of less than 3 m, and lower at depths of +15 m.

When ecosystems are affected by pressures generated on land, there appear to be two responses, both involving changes in the structure of the community. On reef flats where algal-dominated and rubble-associated communities are affected by silting, the change appears to be one in which the rubble-associated species *Bittium zebrum* becomes the major component of the fauna. Standing crop and diversity values are conspicuously depressed by silting.

When the change involves input of nutrients, as in Kaneohe Bay and Pearl Harbor, the community changes toward one which is dominated by suspension feeding forms dependent upon the primary productivity of the water column. Both standing crop and diversity values are also conspicuously depressed as at Pearl Harbor.

Three groups of micromolluscs serve as indicators of environmental conditions: *Obtortio pupoides* which is associated primarily with silted reef flats, and, which also appears in deep harbor areas (ca 27.43 m in Pearl Harbor); pyramidellids which we take as indicative of large numbers of sedentary fauna; and *Bittium zebrum* which is the apparent surviving species in all areas under stress. It is perhaps of more than passing interest that *Obtortio pupoides* or a very close relative is also characteristic of anoxic environments in the Fanning Island lagoon, and that *Bittium zebrum* is one of the most ubiquitous species in the Indo-West-Pacific, occurring in a variety of color forms from the east coast of Africa to Hawaii.

If we can accept the assumption that micromolluscan species composition and diversity reflect the structure of the communities of which micromolluscs are a part, then the following set of conditions appear to exist in the coastal waters of the Hawaiian Islands:

1. Reef flats and shallow subtidal waters to depths of less than 3 m are somewhat less diverse than are subtidal waters of greater depths. If diversity is associated with stability, it follows that shallow coastal waters including reef flats and shallow bays represent somewhat less stable conditions than occur at greater depths in the Hawaiian Islands.
2. The response of ecosystems to land-generated pressures involves primarily changes in structure from a grazing herbivore environment with associated frondose algae to either a rubble-associated ecosystem with few species or to a eutrophic state with many suspension feeders and low diversity.

CHANGES IN INSTITUTIONAL ARRANGEMENTS

During the time period covered by this progress report several actions have been taken at both the federal and state level which either change the policy framework within which public decisions are made, or constrain the freedom of decision, or point the direction or the timetable of action programs. In addition, events beyond the immediate control of public agencies have distracted the citizen, reoriented societal objectives, or altered the priority of various goals. In neither of these categories is the ultimate impact fully predictable, nor is the effect of one upon the other at all clear.

The QCW project study year began with citizens strongly supporting environmental perfection in all aspects of life; concerned with the ecological consequences of all man's acts, and heedless about either costs, cost effectiveness, or the relative scale of environmental destruction and the measures necessary to preclude it. However, there was talk of taxpayer dissatisfaction, reduction in personal property taxes, and a general alarm at what at that moment seemed high prices. There was evidence that the time was near when the cost of society's objectives would have to be weighed against the benefits on the environmental scale; but in general the citizens still lived in an emotionally charged dream world and adhered to the illusion that industry could be made to foot the bill while lowering its prices.

The year ended with the citizen emotionally exhausted and politically polarized over Watergate, dismayed at the energy crisis, concerned lest his way of life might be unnecessarily circumscribed by the ecological attitudes to which he so recently subscribed, thoroughly alarmed at costs and shortages, and showing signs of a willingness to reconsider priorities, particularly if a scapegoat could be found for environmental disarray.

The effect of such changes in public attitudes or the point where they may again be stabilized will, of course, be a determinant of the development rate of systems and policies aimed at protecting the quality of coastal waters.

More definite in outline, although unclear as to future interpretations, are several institutional arrangements of recent origin. Some of these are outlined in the paragraphs which follow.

FEDERAL LEGISLATION

Perhaps the most significant of all recent happenings in the field of water quality control is the passage of Public Law 92-500, the Federal Water Pollution Control Act, Amendments of 1972. Not only does this Act change public policy, but its breadth and its vageness make it susceptible to a great many conflicting interpretations which will take a long time to resolve.

Of particular importance to the planner, decision maker, legislator, regulatory agency, waste producer, engineer, scientist, and technologist concerned with land-water quality relationships and pollution control are the following facts:

- The Act declares that it is the policy of the Federal government to discontinue all waste discharges to navigable waters of the United States by the year 1985.
- Although there is a growing debate over the feasibility of enforcing such a policy, the statement has generated broad proposals to dispose of all liquid (and other) wastes upon the land.

However, the Act further provides in Section 304(e) that (see EPA-600/4-73-010, July 1973):

> The Administration [of EPA]...shall issue...within one year the effective date of this subsection (and from time to time thereafter) information including (1) guidelines for identifying and evaluating the nature and extent of nonpoint sources of pollutants, and (2) processes, procedures, and methods to control pollution resulting from --
>
> (A) agricultural and silvicultural activities, including runoff from fields and crop and forest lands;
> (B) mining activities, including runoff and siltation from new, currently operating, and abandoned surface and underground mines;
> (C) all construction activity, including runoff from the facilities resulting from such construction;
> (D) the disposal of pollutants in wells or in subsurface excavations;
> (E) salt water intrusion resulting from reductions of fresh water flow from any cause, including extraction of groundwater, irrigation, obstruction, and diversion; and
> (F) changes in the movement, flow, or circulation of any navigable waters or groundwaters, including changes caused by the construction of dams, levees, channels, causeways, or flow diversion facilities...

Pursuant to the foregoing provisions the EPA is proceeding to prepare guidelines for the control and monitoring of surface and groundwaters which the states must implement.

The Act requires each state to develop standards and programs which concentrate upon the water pollution problem and seek to resolve it. To this end the EPA will provide guidelines which the state must meet, and will provide financial assistance to the state to carry out its program. Should any state fail to provide and implement a program acceptable to the EPA, the federal agency may move in and operate such a program in that state. Guidelines for Developing or Revising Water Quality Standards under the Public Law 92-500 provisions have already (January 1973) been compiled and distributed to the states.

The new law provides for establishing guidelines for proper operation of waste water treatment facilities, for training of plant personnel, maintaining and staffing qualified laboratories, and reporting of operational and monitoring results. For this purpose a Municipal Waste Water Systems Division was established in the EPA with the following mandated functions that it:

> "...will be responsible for developing the technical policies, regulations, and guidelines to articulate EPA strategies for implementing legislative mandates in the municipal waste water treatment field. These policies, regulations, and guidelines will provide national direction for interstate, state, and local authorities in the design, construction, operation, and maintenance of municipal waste water treatment systems. This technical direction will be consistent with federal fiscal policies and sound water quality planning principles."

The Division has four principal tasks:

- To set policies and to design, develop, and administer an effective program for the operation and maintenance of municipal waste treatment systems.
- To establish firm goals for the completion of the construction of municipal waste treatment systems and to monitor progress toward the accomplishment of this task.
- To set policies for and to ensure that new, improved, and effective designs and engineering techniques are employed in the facility's construction program, and to ensure that these systems constitute the most cost-effective designs and technologies available.
- To ascertain and report on the degree to which the construction program and available funding meet the needs of treatment in terms of population served and in degree of treatment for meeting water quality goals.

The federal law has both strengths and weaknesses in so far as it applies to the coastal water quality in Hawaii. Ensuring proper design and operations of waste water treatment plants is a major step forward. Such steps do, however, bear upon the degree of freedom of the state to utilize the results of land-water quality investigations in providing appropriate systems. This is especially true in that the federal law establishes secondary treatment as the minimum goal of all waste water treatment systems. The fallacy of such a provision is demonstrated clearly in Hawaii in the case of requiring secondary treatment for the proposed Sand Island waste water treatment facilities and ocean outfall. Intensive investigations have documented little environmentally detrimental effects of raw sewage discharge beyond aesthetics. Further, they have predicted even less effects resulting from the discharge of advanced primary treated effluent into a more suitable site in the ocean.

Among the weaknesses of the federal program are such problems as the following:

1. Ten regional offices often seem not to be a part of the same agency.
2. It tends to impose the same standards on all situations, which:
   a) may make no sense because of climatological, geographical, cultural, ecological, and other regional differences.
   b) requires the adoption of the rationale that "there is no such thing as overtreatment of waste water", and hence may require the investment of funds in virtually useless systems.
   c) assumes that the response of receiving water is predictable on the basis of quality as measured by laboratory analyses.
3. May afford apparent ease of policy enforcement at the eventual cost of credibility loss, and hence of effectivenss of the administering agency.

STATE LEGISLATION AND ACTIVITIES

Four Acts of the 1973 Regular Session, Seventh State Legislature of Hawaii are pertinent to the institutional changes of the past year which bear upon Coastal Water Quality. Summarized these are:

ACT 107

(S.B. No. 930, SD 1, HD 1) *SHORELINE AREAS; REMOVAL OF SAND AND OTHER MATERIALS; CLARIFICATION OF DEFINITION.* Prohibits the removal of sand, coral, rocks, soil, or other beach compositions within the shoreline area or 1000 ft (304.8 m) seaward of it or in ocean water 30 ft (9.144 m) deep or less. Permits the commercial mining of sand or other minerals, or taking of coral or rock in the territorial ocean 1000 or more ft ($\geq$304.8 m) from the shoreline or in ocean water 30 or more ft ($\geq$9.144 m) deep; if a commercial enterprise has the written permission of all governmental agencies having jurisdiction. Clarifies the meanings of shoreline, shoreline area, and shoreline setback line and deletes the term "shoreline setback area." Effective *May 17, 1973.* (SSCR 399; HSCR 741)

ACT 118

(H.B. No. 1089, HD 1, SD 1) *ENVIRONMENTAL QUALITY; CONFORMANCE WITH FEDERAL REGULATIONS.* Expands definition of "waste" to include excessive noise. Establishes procedures for issuance of permits to conform with federal regulations, including public notice of each application for a permit to control water pollution; provides for suspension or revocation of a permit if it is violated, obtained by misrepresentation, conditions change, or the public interest demands. Requires the director to act on a variance or permit within 180 days of the application. Increases the penalty for violations from $2500 to $10,000 for each separate offense. Sets the penalty for water pollution violations at between $2500 and $25,000 per day of violation or imprisonment up to one year or both. Effective *May 17, 1973.*

ACT 161

(S.B. No. 377, SD 2, HD 1) *ISSUANCE OF REVENUE BONDS FOR ANTI-POLLUTION PROJECTS.* Authorizes the Department of Budget and Finance with gubernatorial approval to issue in its own name revenue bonds, with final maturity not exceeding 40 years, to finance anti-pollution projects. Sets the conditions and procedures for issuance and for the use of the revenues, sales of the anti-pollution project bonds, and extension or renewals of project agreements. Exempts from state, county, and municipal taxation all revenues derived by the Department of Budget and Finance from any anti-pollution project and all interests of the state in any such project. Requires that anti-pollution projects be certified as necessary or desirable by the Department of Health and be undertaken with responsible parties. Requires the project party to pay the principal and interest on all revenue bonds issued, when due, and other expenses relating to such issuance. Provides for purchase by the county of anti-pollution facilities for the supply or distribution of water to or the collection or treatment of sewage and other waste disposal from a single or multi-family residential development.

Requires the attorney general to either intervene in a suit brought to determine the constitutionality of the Act or to bring a declaratory judgement action for a determination that revenue bonds issued under the Act can be excluded when determining the total constitutional indebtedness of the state. Effective *May 22, 1973.* (SSCR 126, 545; HSCR 775)

ACT 164

(S.B. No. 929, SD 1) *COASTAL ZONE MANAGEMENT PROGRAM; ESTABLISHED.* Authorizes the State Department of Planning and Economic Development to prepare a coastal zone management program establishing objectives, policies, and standards as guidelines for the Land Use Commission and other state and county agencies in the use of lands and waters in coastal zones of the state which conform with the State Comprehensive Outdoor Recreation Plan, as required by the Federal Coastal Zone Management Act of 1972, Public Law 92-583. Allows the Department of Planning and Economic Development to expend federal grants and matching state funds for the development and administration of the coastal zone management program. Effective *May 22, 1973.* (SSCR 397, 561; HSCR 804)

Evidence produced by the QCW project which showed that current Hawaiian standards regarding total nitrogen in Class AA cannot be met by nature was utilized by the State Department of Health in 1973 in actively seeking to revise Chapters 37 and 37A of the Public Health Chapters. To this end the state is actively seeking more realistic numerical values which are defensible under the provisions of Public Law 92-500.

PUBLIC INFORMATION ACTIVITIES

During the report year the QCW project continued its public information activities. A public technical seminar series of two meetings continued the program started during the first year of the project. Five issues of the Project Bulletin (hereinafter appended) were released and distributed to more than 500 public officials, technicians, scientists, organized groups, and individual citizens. These issues deal with: the QCW Summary Progress Report, Mercury Levels in Marine Biota, Bacterial Indicators of Water Quality, and Coastal Waste Disposal Practices in Hawaii.

Participating scientists from the QCW project group presented four papers before scholarly and technical groups, testified at public hearings in Hawaii, and responded to calls for assistance by legislators and public officials.

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REFERENCES

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APPENDICES

APPENDIX A: FISH SURVEY

Survey Methods

Data of fish abundance and species diversity were collected at Stations 1 to 6 (Fig. 3.11) using a technique modified from Brock (1954). At each station a 250-ft (76.20 m) long nylon line was placed on the bottom by SCUBA divers. While swimming along the line the divers recorded species, numbers, and sizes of all fish seen within 10 feet (3.05 m) of either side of the line (20 feet or 6.10 m total) and in the water column 10 feet (3.05 m) above the bottom.

Abundance of each species in pounds of fish was calculated by using the species constant values for weight-length relationships available from the State of Hawaii Division of Fish and Game. Weight is determined by applying the equation: $\text{length}^3 \times \text{constant} = \text{weight in pounds}$.

Results and Discussion

Species diversity indices were calculated by two separate techniques on an APL/360 computer at the University of Hawaii. In the Shannon, Weaver (1963) formula $H' = -\Sigma\, p_i \log_2 P_i$, where P_i is the fraction of the total number of individuals in each species. The diversity index, H', is an estimate of a random sample of a larger population.

In the Brilliouin (1960) formula, $H = \frac{1}{N} \log_2 \frac{N!}{N_1!\, N_2!\, \ldots N_s!}$, where N is the total number of individuals, N_s is the number of individuals in each species. The diversity index, H, is the true diversity of the collection treated as a separate population and not as a small sample of a larger unknown population (Pielou 1966).

The results of the fish transects run at Stations 1 to 6 are shown in Table A.1 to A.6. Each table also includes the date and time of day of the transect data collection. This information is important if repeat transects are run at these stations at some time in the future, since fish abundance is somewhat seasonal for some species. Daily feeding activity of different species also varies considerably.

A summary of the data and diversity indices of fish transects are shown in Table A.7.

A large school of goatfish was observed at Station 1 during the transect run. This is a wandering schooling species and should not be considered as a continuous resident of this station. For comparison with other stations, this species is excluded from the data.

The abundance of fish in pounds per acre at Station 2, adjacent to the present outfall site, is less than half of that at Station 1. Diversity is also lower at Station 2 than at Station 1. Characteristics of

TABLE A.1. SPECIES, SIZE AND WEIGHT OF FISH RECORDED AT STATION 1 IN KAILUA BAY, 23 JULY, 1973.

FAMILY-SPECIES	NUMBER OF INDIVIDUALS <6"	6-10"	>10"	CONSTANT	WEIGHT (POUNDS)
ACANTHURIDAE					
Acanthurus nigroris	6			.00068	0.88
Acanthurus nigrofuscus	12			.00095	2.46
Acanthurus sandvicensis	35(5)			.00132	5.78
Naso lituratus	6			.00092	1.19
BALISTIDAE					
Baslistes bursa	6			.00089	1.15
Rhinecanthus rectangulus	2			.00101	0.44
CANTHIGASTERIDAE					
Canthigaster jactator	3(3)			.00121	0.10
CARANGIDAE					
Caranx melampygus			4(15)	.00064	8.64
CHAETODONTIDAE					
Chaetodon quadrimaculatus	4(5)			.00095	0.48
Chaetodon multicinctus	2(5)			.00104	0.26
Chaetodon fremblii	1(5)			.00097	0.12
Forcipiger flavissimus	2				--
CIRRHITIDAE					
Paracirrhites cinctus	10(3)			.00074	0.20
Paracirrhites arcatus	6(5)			.00073	0.55
LABRIDAE					
Stethojulis axillaris	25(4)			.00054	0.86
Thalassoma duperreyi	52(5)			.00059	3.84
LUTJANIDAE					
Aprion virescens	.		1(15)	.00086	2.90
MULLIDAE					
Parupeneus multifasciatus	16	3		.00081	0.80
Parupeneus pleurostigma		2		.00045	0.90
Mulloidichthys auriflamma		(200+)*		.00044	33.00
MURAENIDAE					
Gymnothorax eurostris			1(36)	.00013	6.07
POMACENTRIDAE					
Chromis vanderbilti	30(4)			.00065	1.25
Pomacentrus jenkinsi	22(4)			.00101	1.42
Plectroglyphidodon johnstonianus	18(3)			.00066	0.32
SCARIDAE					
Scarus perspicillatus			3(15)	.00083	8.40
TOTAL	258	(205+)*	9		82.01

NOTE: NUMBERS IN PARENTHESES INDICATE ACTUAL LENGTH USED IN CALCULATING WEIGHT. TRANSECT RUN AT 1230 HOURS.

* SCHOOL OF GOATFISH OBSERVED SWIMMING THROUGH TRANSECT. WEIGHT FIGURES IN PARENTHESIS INCLUDE SCHOOL; SECOND WEIGHT EXCLUDES THEM.

TABLE A.2. SPECIES, SIZE, AND WEIGHT OF FISH RECORDED AT STATION 2 IN KAILUA BAY, 23 JULY 1973.

FAMILY	NUMBER OF INDIVIDUALS <6"	6-1"	>10"	CONSTANT	WEIGHT (POUNDS)
ACANTHURIDAE					
Acanthurus nigroris	19			.00068	2.79
Acanthurus nigrofuscus	4			.00095	0.82
Acanthurus leucopareius	22			.00074	3.52
Acanthurus sandvicensis	63(5)			.00132	0.83
BALISTIDAE					
Rhinecanthus rectangulus	2			.00073	0.32
CANTHIGASTERIDAE					
Canthigaster ambionensis	2(3)			.00097	0.05
CHAETODONTIDAE					
Chaetodon quadrimaculatus	2(5)			.00095	0.23
Chaetodon corallicola	3(5)			.00098	0.37
CIRRHITIDAE					
Paracirrhites cinctus	4(3)			.00074	0.08
LABRIDAE					
Stethojulus axillaris	25(4)			.00054	0.86
Thalassoma duperreyi	59(5)	1		.00059	4.35
Thalassoma umbrostigma	1			.00060	0.13
Thalassoma ballieui			1(11)	.00059	0.79
MONOCANTHIDAE					
Pervagor spilosoma	1(3)			.00082	0.02
MULLIDAE					
Parupeneus multifasciatus		3		.00081	2.43
POMACENTRIDAE					
Chromis vanderbilti	76(4)			.00065	3.16
Abudefduf abdominalis	12(5)			.00080	1.20
Abudefduf imparipennis	16(2)			.00063	0.08
Pomacentrus jenkinsi	15(4)			.00101	0.97
TOTAL	326	4	1		23.00

NOTE: NUMBERS IN PARENTHESES INDICATE ACTUAL LENGTH USED IN CALCULATING WEIGHT. TRANSECT RUN AT 1400 HOURS.

TABLE A.3. SPECIES, SIZE, AND WEIGHT OF FISH RECORDED AT STATION 3 IN KAILUA BAY. 23 JULY, 1973.

FAMILY-SPECIES	NUMBER OF INDIVIDUALS <6"	6-10"	>10"	CONSTANT	WEIGHT (POUNDS)
ACANTHURIDAE					
Acanthurus olivaceus	2			.00068	0.29
Acanthurus sandvicensis	41(5)			.00132	6.77
Acanthurus leucopareius	14			.00074	2.24
Ctenochaetus strigosus	4(4)			.00094	0.24
BLENNIDAE					
Cirripectus variolosus	4(2)			*	--
Istiblennius gibbifrons	1(2)			*	--
CHAETODONTIDAE					
Chaetodon lunula	1			.00124	0.27
CIRRHITIDAE					
Paracirrhites cinctus	4(3)			.00074	0.08
Paracirrhites forsteri	2			.00070	0.30
LABRIDAE					
Stethojulis axillaris	40(4)			.00054	1.38
Thalassoma duperreyi	56(5)			.00059	4.13
Thalassoma umbrostigma	21			.00060	2.72
MULLIDAE					
Parupeneus porphyreus		3(8)		.00084	1.29
POMACENTRIDAE					
Chromis vanderbilti	40(4)			.00065	1.66
Chromis leucurus	2(3)			.00098	0.08
Pomacentrus jenkinsi	12(4)			.00101	0.78
Plectroglyphidodon johnstonianus	20(3)			.00066	0.36
TOTAL	264	3			22.59

NOTE: NUMBER IN PARANTHESES INDICATE ACTUAL LENGTH USED IN CALCULATING WEIGHT. TRANSECT RUN AT 1600 HOURS.

* UNKNOWN.

TABLE A.4. SPECIES, SIZE, AND WEIGHT OF FISH RECORDED AT STATION 4 IN KAILUA BAY. 24 JULY, 1973.

FAMILY-SPECIES	NUMBERS OF INDIVIDUALS <6"	6-10"	>10"	CONSTANT	WEIGHT (POUNDS)
ACANTHURIDAE					
Acanthurus olivaceus	3			.00068	0.44
CANTHIGASTERIDAE					
Canthigaster jactator	1(3)			.00121	0.03
CHAETODONTIDAE					
Chaetodon corallicola	2(5)			.00098	0.25
CIRRHITIDAE					
Paracirrhites forsteri	6			.00070	0.91
Paracirrhites cinctus	4(3)			.00074	0.08
LABRIDAE					
Stethojulis axillaris	5(4)			.00054	0.17
Thalassoma duperreyi	10(5)			.00059	0.74
MULLIDAE					
Parupeneus pleurostigma	3			.00045	0.29
Parupeneus multifasciatus	4			.00081	0.70
TOTALS	38				3.61

NOTE: NUMBERS IN PARENTHESES INDICATE ACTUAL LENGTH USED IN CALCULATING WEIGHT. TRANSECT RUN AT 1230 HOURS.

TABLE A.5 SPECIES, SIZE, AND WEIGHT OF FISH RECORDED AT STATION 5 IN KAILUA BAY. 24 JULY, 1973.

FAMILY-SPECIES	NUMBER OF INDIVIDUALS <6"	6-1"	>10"	CONSTANT	WEIGHT (POUNDS)
ACANTHURIDAE					
Acanthurus olivaceus	2	2		.00068	1.65
Acanthurus nigroris	13			.00068	1.91
Ctenochaetus strigosus		2		.00094	1.88
Naso unicornis		2		.00064	1.28
BALISTIDAE					
Balistes bursa		11(8)		.00089	5.01
Melichthys vidua		2(8)		.00110	1.13
CANTHIGASTERIDAE					
Canthigaster jactator		4		.00121	4.84
CHAETODONTIDAE					
Chaetodon corallicola	5(5)			.00098	0.61
Chaetodon fremblii	2			.00097	0.42
CIRRHITIDAE					
Paracirrhites cinctus	2(3)			.00074	0.04
Paracirrhites arcatus	13(5)			.00073	1.19
HOLOCENTRIDAE					
Holocentrus xantherythrus	5(4)			.00066	0.21
LABRIDAE					
Bodianus bilunulatus		9(8)	3(12)	.00062	5.75
Stethojulis axillaris	2(4)			.00054	0.07
Thalassoma duperreyi	20(5)			.00059	0.37
Coris venusta	2			.00044	0.19
Labroides phthirophagus	1			.00041	0.09
Macropharyngodon goeffroyi	1			.00074	0.16
MALACANTHIDAE					
Malacanthus hoedtii	6			.00004	0.05
MULLIDAE					
Parupeneus multifasciatus	10			.00081	1.75
Parupeneus pleurostigma	3			.00045	0.29
POMACANTHIDAE					
Centropyge potteri	2(4)			.00111	0.14
POMACENTRIDAE					
Chromis leucurus	6(3)			.00098	0.16
Plectroglyphidodon johnstonianus	2(3)			.00066	0.05
SCARIDAE					
Scarus perspicillatus	3			.00079	0.51
SERRANIDAE					
Caesioperca thompsoni	54			.00047	3.17
TOTAL	154	32	3		32.92

NOTE: NUMBERS IN PARENTHESES INDICATE ACTUAL LENGTH USED IN CALCULATING WEIGHT. TRANSECT RUN AT 1500 HOURS.

TABLE A.6. SPECIES, SIZE, AND WEIGHT OF FISH RECORDED AT STATION 6 IN KAILUA BAY. 24 JULY, 1973.

FAMILY-SPECIES	NUMBER OF INDIVIDUALS <6"	6-10"	>10"	CONSTANT	WEIGHT (POUNDS)
ACANTHURIDAE					
Acanthurus nigrorus		10		.00068	6.80
Acanthurus nigrofuscus		2		.00095	1.90
Acanthurus sandvicensis	26	12		.00132	23.24
Acanthurus olivaceus		3		.00068	2.04
Ctenochaetus strigosus		1		.00094	0.94
Naso unicornis		5		.00064	3.20
BALISTIDAE					
Balistes bursa	1	11(8)		.00089	5.20
Rhinecanthus rectangulus		3		.00073	2.19
CANTHIGASTERIDAE					
Canthigaster jactator	3			.00121	0.78
CHAETODONTIDAE					
Chaetodon corallicola	2(5)			.00095	0.24
Chaetodon fremblii	1	1		.00097	1.18
Chaetodon quadrimaculatus	3(5)			.00095	0.36
Forcipiger flavissimus	1			*	--
CIRRHITIDAE					
Paracirrhites cinctus	5(3)			.00074	0.10
Paracirrhites forsteri	3	1		.00070	1.15
Cirrhitus alternatus		1		.00800	0.80
LABRIDAE					
Coris gaimardi	1(4)			.00044	0.03
Stethojulis axillaris	15(4)			.00054	0.52
Thalassoma duperreyi	14(5)			.00059	2.23
Bodianus bilunulatus			1(12)	.00062	1.07
Labroides phthirophagus	3			.00041	0.27
MULLIDAE					
Parupeneus multifasciatus	1	5		.00081	4.22
Parupeneus pleurostigma	4	1		.00045	0.84
POMACANTHIDAE					
Centropyge potteri	3(4)			.00111	0.21
POMACENTRIDAE					
Chromis ovalis	53(4)			.00095	3.22
ZANCLIDAE					
Zanclus canescens	1	2		.00102	2.26
TOTAL	140	58	1		64.99

NOTE: NUMBERS IN PARENTHESES INDICATE ACTUAL LENGTH USED IN CALCULATING WEIGHT. TRANSECT RUN AT 1330 HOURS.

* UNKNOWN.

TABLE A.7. SUMMARY OF ABUNDANCE, NUMBER OF SPECIES OF FISH, AND DIVERSITY INDICES AT SIX STATIONS IN KAILUA BAY. 23-24 JULY, 1973.

STATION	NUMBER FAMILIES	NUMBER SPECIES	NUMBER INDIVIDUALS IN SIZE CLASSES <6"	6-1"	>10"	TOTAL POUNDS	POUNDS/ACRE	DIVERSITY INDEX B*	SW**
1	12	25	258	(200+)	9	51.01(139.01)	444.4(1211.1)	3.591	3.804
2	9	19	311	4		23.00	200.4	3.099	3.242
3	7	17	264	3		22.59	196.8	3.107	3.265
4	6	9	38			3.61	31.5	2.501	2.935
5	13	26	154	32		32.91	286.7	3.464	3.830
6	10	26	140	66	1	64.99	566.2	3.391	3.672

NOTE: NUMBERS IN PARENTHESES INCLUDE A WANDERING SCHOOL OF GOATFISH COUNTED IN THE TRANSECT.

* B = BRILLIOUIN DIVERSITY INDEX.

** SW = SHANNON - WEAVER DIVERSITY INDEX.

these two stations are otherwise quite similar in depth, exposure to surge, bottom configuration, algae, and coral cover.

The extremely low abundance and diversity of fish at Station 4 can probably be attributed to its shallowness (10 ft or 3.05 m), exposure to strong surge, and its uniform bottom cover of sand and closely cropped algae, which all provide a relatively inhospitable environment for a large and varied fish population.

Abundance of fish in pounds per acre at Station 6 is about double that of Station 5; however, this difference is due largely to the presence of a great number of a single species of fish, *Acanthurus sandvicensis* at Station 6, and its complete absence at Station 5. Total number of species and diversity seen at these two stations are identical or very similar.

APPENDIX B: A SURVEY OF THE MICROMOLLUSCAN ASSEMBLAGES IN KAILUA BAY, OAHU

Micromolluscs, that is, molluscs with shells less than 10 mm in greatest dimension, were studied from sediment samples representing six stations in Kailua Bay, Oahu collected in June-July, 1973. This study is part of a general survey to provide a description of the benthic conditions and a quantitative account of the dominant benthic biota in Kailua Bay (pp. 125-33).

Sediments were obtained by hand retrieval from the six stations described by Reed (p. 125 and Fig. 3.11). The molluscs were studied by removing all shells from standard 25 cu cm volumes of sediments under a binocular dissecting microscope, and by analyzing the shells thus obtained for species composition, species diversity, trophic structure, and standing crop. Species diversity was calculated using the function $H' = -\Sigma p_i \log_2 p_i$, where p_i equals the fraction of the total number of individuals represented by each species (Pielou 1964). Diversity values were calculated on an APL/360 computer at the University of Hawaii. Standing crops were estimated by dividing the number of shells obtained from a station by the volume of sediment analyzed. Trophic structure was determined by calculating the number of individuals associated with a particular feeding habit and dividing by the total number of individuals in the sample.

Results

Eighty-two species of micromolluscs were recorded in the sediment samples (Table B.2). Species composition is shown graphically in Figure B.1 and registered in Table 3.30. Three families are dominant at all six stations: the Phasianellidae represented by one species, *Tricolia variabilis*; the Rissoidae by 16 species; and the Cerithiidae by six species. Two patterns are distinguishable in terms of species composition (Fig. B.1): Stations 2 and 4 dominated by *Tricolia* and the cerithid, *Bittium parcum*, both of which are associated with frondose algae, and Stations 1, 3, 5, and 6 dominated by the rubble-associated rissoids.

Stations 2 and 4, where algae are the dominant benthic organism, not only resemble each other in the high proportion of *Tricolia* and *Bittium parcum* relative to the other molluscs but, as would be expected, show a higher proportion of herbivorous forms than do the other four stations (Table B.1). Stations 2 and 4 also have a higher standing crop and lower species diversity (H') than do the other stations. Station 2 is distinguished from Station 4 by a higher species diversity, higher standing crop, and proportionately more representatives of the genus *Rissoina* than occur at Station 4. Station 4 is distinguished by a higher proportion of suspension feeders than occur at Station 2, the suspension feeders represented by the mat-forming mytilid *Brachidontes crebristriatus*, and by a higher proportion of representatives of the rissoinid genus *Merelina* than occurs at Station 2.

Stations 1, 3, 5, and 6, which are rissoid-dominated, have a higher proportion of carnivores relative to herbivores than occur at Stations 2 and 4, lower standing crop, and higher species diversity. Among the four

TABLE B.1. STANDING CROP, SPECIES DIVERSITY, SPECIES COMPOSITION, AND TROPHIC STRUCTURES OF MICROMOLLUSCAN ASSEMBLAGES IN KAILUA BAY.

	STATION					
	1	2	3	4	5	6
NUMBER OF SHELLS	239	542	290	398	180	69
NUMBER PER cm^2	9.6	21.7	11.6	15.2	7.2	2.8
NUMBER OF SPECIES	29	40	38	28	39	21
SPECIES DIVERSITY (H')	3.9	3.7	4.3	2.6	4.2	3.9
RELATIVE PROPORTIONS OF DOMINANTS						
Tricolia	11%	28%	17%	47%	20%	20%
CERITHIDAE	18%	14%	8%	26%	5%	10%
RISSOIDAE	40%	26%	20%	12%	40%	33%
MERELINA spp.*	11%	12%	12%	84%	9%	13%
RISSOINA spp.*	85%	60%	74%	4%	59%	52%
VITRICITHNA	1%	18%	12%	11%	7%	--
Hipponix spp.	--	--	11%	2%	1%	--
BIVALVES	--	1%	8%	4%	--	--
TROPHIC STRUCTURE						
HERBIVORES	81%	92%	87%	97%	75%	74%
GRAZING	81%	90%	83%	92%	75%	74%
SUSPENSION FEEDING	--	2%	4%	5%	--	--
CARNIVORES	18%	89%	13%	2%	25%	26%
ACTIVE PREDATORS	5%	1%	6%	--	10%	16%
FAUNAL GRAZERS	11%	4%	6%	1%	12%	10%
PARASITES	2%	3%	1%	1%	3%	--

* PERCENTAGES CALCULATED ON BASIS OF TOTAL NUMBER OF RISSOIDAE.

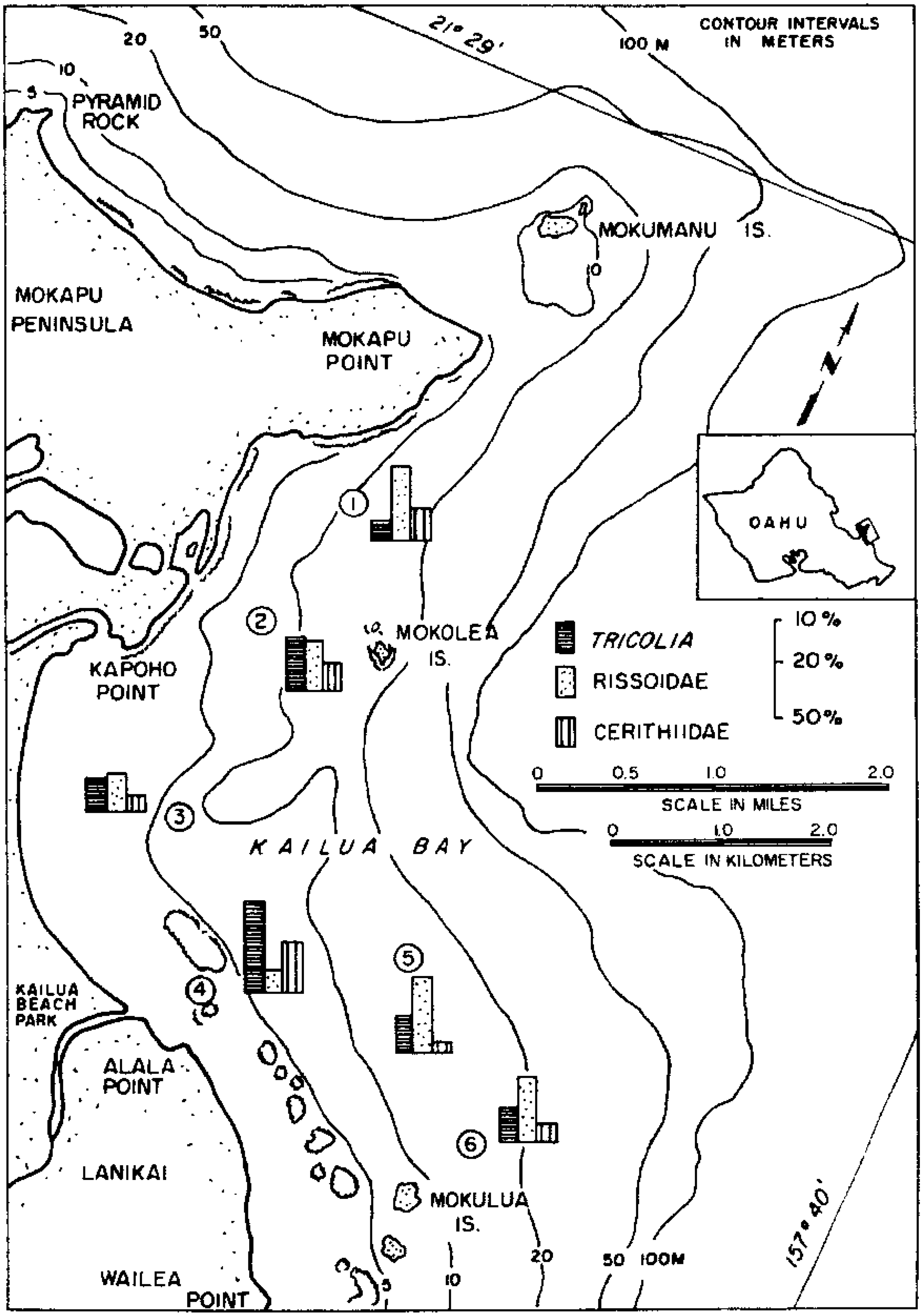

FIGURE B.1. STATIONS AND SPECIES COMPOSITION FOR MICROMOLLUSCS IN KAILUA BAY, OAHU.

TABLE B.2. MICROMOLLUSCS RECORDED FROM KAILUA BAY.

SPECIES	STATION NO.					
	1	2	3	4	5	6
Scissurella sp.			+			
Diodora granifera	+		+			
Alcyna rubra		+	+			
Alcyna subangulata		+		+		
Gibbula marmorea			+		+	
Euchelus gemmatus			+	+		
Synaptocochlea concinna			+	+		+
Letothyra candida	+				+	
Leptothyra rubricincta	+		+		+	
Leptothyra verruca	+			+		
Tricolia variabilis	+	+	+	+	+	+
Barleeia sp.	+					
Merelina granulosa	+	+		+	+	
Merelina sp.	+	+			+	+
Merelina sp.	+	+	+	+	+	+
Rissoina ambigua	+	+	+		+	+
Rissoina ephamilla		+			+	
Rissoina finokii					+	+
Rissoina gracilis		+		+		
Rissoina miltozona	+	+	+		+	+
Rissoina triticea	+	+	+		+	+
Rissoina turricula	+	+	+	+	+	
Vitricithna marmorata	+	+	+	+	+	
Parashiela beetsi		+			+	
Zebina tridentata					+	
Alvania sp.						+
Rissoid sp.		+		+	+	
Microdochus sp.					+	
Haplocochlias sp.	+					
Rissoella sp.		+				
Caecum sepimentum			+			
Planaxis labiosa		+	+			
Bittium hiloense			+			
Bittium parvum	+	+	+	+		
Bittium zebrum	+	+	+	+	+	+
Bittium impendens		+			+	+
Cerithium atromarginatum		+				
Plesiotrochus sp.			+			
Bittium perparvulum	+	+	+			
Bittium diplax		+				
Diala varia		+				+

TABLE B.2. MICROMOLLUSCS RECORDED FROM KAILUA BAY (CONTD).

SPECIES	STATION NO.					
	1	2	3	4	5	6
Alaba goniochila					+	+
Cerithiopsis sp.	+	+	+			
Triphora spp.	+	+		+	+	+
Balcis spp.		+	+			
Vanikoro sp.		+				
Hipponix foliaceus	+	+	+	+	+	
Hipponix grayanus			+			
Hipponix trigonus		+		+		
Kogomea sandwicensis	+			+	+	
Cysticus sp.			+		+	
Mitrella margarita					+	+
Seminella smithi					+	
Seminella varia	+	+	+		+	+
Pisania juv.			+			
Lovellona peasei	+					
Carinapex minutissimus	+	+			+	+
Iredalea sp.	+					+
Daphnella sp.					+	
Kermia pumila	+					+
Mitromorpha metula					+	
Conus sp.			+			
Mitra sp.					+	
Peristernia chlorostoma					+	+
Morula sp.	+		+			
Odostomia stearnsiella	+				+	
Odostomia scopulorum		+		+	+	
Odostomia paulbartschi	+	+		+		
Odostomia patricia		+	+		+	
Odostomia sp.				+	+	
Haminea crocata				+		
Atys semistriata				+	+	
Williamia radiata			+			
Anisodonta lutea				+		
Arcinella sp.			+			
Ctena bella					+	
Acar plicata	+	+				
Hemicardium mundum		+				
Barbatia nuttingi		+	+			
Brachidontes crebristriatus		+		+		
Septifer sp.		+		+		
Chlamys sp.			+			

stations, the two shallow water stations, 1 and 3 (18 ft and 20 ft or 5.49 and 6.10 m), have a higher standing crop than occurs at 5 and 6 (45 ft or 13.72 m), and they are distinguished from Stations 5 and6 by the presence of *Bittium parcum*, a characteristically shallow water species. Station 3 is distinguished from all the other stations in the occurrence of a higher proportion of the sedentary grazing prosobranch *Hipponix* spp. The shells from Stations 5 and 6, which are not only coral-dominated in terms of the substrate, but also subject to surge, are worn, and several are subfossil. The low numbers of *Rissoina triticea* and the absence of *Bittium parcum* at these stations are characteristic of the depths of these stations.

Conclusions

Species composition, species diversity, trophic structure, and standing crop of the micromolluscs of the six stations in Kailua Bay are comparable with the patterns which emerge at other areas of similar depth and substrate around Oahu. The patterns are shown in Figure B.2 with the Kailua stations included for purposes of comparison. *Tricolia/Bittium parcum*-dominated assemblages tend to exhibit higher standing crop, lower species diversity (H'), and a relatively greater abundance of grazing herbivores than do rissoinid-domianted assemblages. Three stations require comment. Station 1 which has an algal-dominated substrate is characterized by the rissoid assemblage rather than the *Tricolia/Bittium parcum* assemblage; this pattern may be accounted for by the fact that the algae at this station are primarily turf-formers. The highest standing crop was recorded at Station 2, which is the station nearest the present sewage outfall; it is tempting to speculate that the high standing crop reflects the high nutrient concentrations and hence higher productivity at this station. The very low standing crop at Station 6 may be due to the surge conditions present at this station which would preclude deposition *in situ* of micromolluscs.

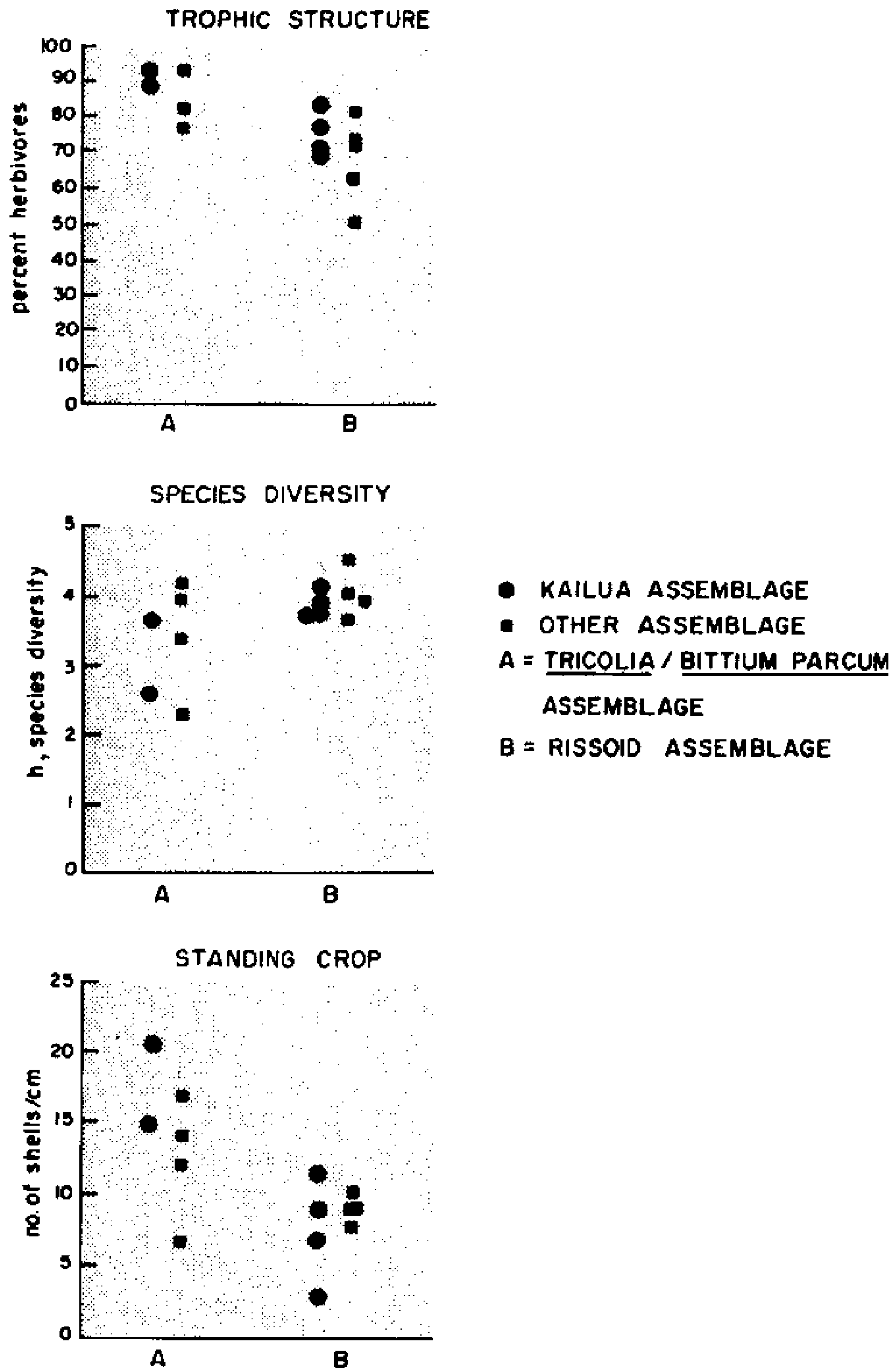

FIGURE B.2. PATTERNS IN STANDING CROP, SPECIES DIVERSITY, AND TROPHIC STRUCTURE IN *TRICOLIA/BITTIUM PARCUM* AND RISSOID ASSEMBLAGES AT 18 TO 45 FOOT DEPTHS, OAHU.

APPENDIX C: PROJECT BULLETINS ISSUED

a summary

QUALITY OF COASTAL WATERS PROGRESS REPORT

QUALITY of COASTAL WATERS

PROJECT BULLETIN

Project Bulletin No. 5/November 1972 L. S. Lau, Principal Investigator

NATURE OF REPORT

In conformity to the plan outlined in the proposal to the Sea Grant Program of the University of Hawaii for the Year 04, an Annual Report has been prepared by the Coastal Water Quality Project. The first Annual Report describes and summarizes the nature and results of the experimental and evaluative work of the Project to the period ending August 31, 1972. The project is a multi-disciplinary, multi-directional study directed to the general objective of identifying and evaluating the social, political, economic, institutional, educational, and scientific and technological factors which impede or expedite the protection and restoration of coastal water environments in Hawaii. Based on the results obtained from the wide-ranging study, the crucial scientific and rational parameters needed in formulating effective policies, institutions, and systems will be developed. The attainment of eight specific objectives is assigned to appropriate faculty specialists participating in 14 activities which comprise the Project. These specialists also assist the Principal Investigator in planning the activities which comprise the Project and in interpreting and evaluating the results in terms of the general and the specific objectives. The report is, therefore, a multi-disciplinary accounting of the progress made during 1971-72.

RATIONALE OF PROJECT

The report begins with a statement of the rationale on which the Project is based. Basically it emerges from a series of concepts and realities of environmental control. In no especial order of relative importance these include:

1. The quality of waters and sediments reaching coastal waters are a function of what man and nature do upon the land.
2. Isolation of specific types of land development (e.g., undeveloped, agricultural, urban, and industrial) is necessary if the water quality factors generated by man are to be identified and controlled at the source.
3. Traditional chemical, physical, and bacterial analyses may characterize water in terms of its components and their concentrations. In terms of the effect upon coastal and marine environments, they largely define what quality factors cross the interface between the land (area of origin) and the water (area of effect).
4. To evaluate water quality on an environmental scale a new parameter is needed, *i.e.*, the stress or lack of stress upon marine ecosystems resulting from constituents or concentrations of constituents in water and sediments.
5. It is important to measure coastal water quality by the response of living things because the food chain begins in the coastal zone where the linkage between nutrients and both diadromous[1] and pelagic[2] fisheries is most easily broken.
6. It is important to continue to analyze water and sediments chemically and physically because:
   a) Critical concentrations for living things require identification.
   b) Data are needed by regulatory

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[1]Diadromous: migrating between fresh and salt waters

[2]Pelagic: oceanic and being far from land

agencies in establishing effective controls at the source of generation and emission and in classifying coastal waters on a realistic basis.

NATURE OF RESULTS OF STUDIES

Pursuant to the foregoing concepts, the Project initiated studies designed to take advantage of situations in Hawaii where major land use and coastal water and environmental quality relationship was most readily identifiable.

Influence of Undeveloped Land

Kahana Bay, Oahu was selected as a coastal water influenced by 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 extended by a program of analysis of water and sediments of the system and of the biota of the Bay. As in all situations studied, especial attention was given to the pesticide, heavy metals, and nutrients in the water and sediments and to evidence of stress on the aquatic community.

Significant findings, which if substantiated with time, will be of value to regulatory agencies of the state were:

1. Only when diluted heavily with fresh water runoff did the dissolved oxygen content in estuarine waters of the Bay meet the Class AA Standards designated for Kahana Bay waters.
2. Phosphorus was mostly of a Class AA level (0.02 mg/1), but this value was exceeded seasonally.
3. Nitrogen and coliform organisms varied in pattern but generally responded similarly to phosphorus.

Thus during the report period, Kahana Bay tended to meet Class A Standards rather than Class AA Standards.

The pesticides, DDT and PCP (pentachlorophenol) in Kahana Bay waters and sediments appeared at levels which seem to be ubiquitous in nature. That is, at levels of about 1 to 3 or 4 parts per trillion is an exceedingly small amount, about one ounce in the total amount of water which is used in the entire United States in one day for all purposes, including irrigation.

Heavy metals, particularly lead, cadmium, zinc, chromium, and nickel appeared in the sediments of Kahana Bay although little or none were found in the waters entering the Bay. Concentrations in sediments followed no identifiable pattern but ranged from about 50 to 2000 times the amounts permitted to be discharged into receiving waters by current standards. Apparently the heavy metal content in coastal sediment in Hawaii is related to parent geologic formations from which the sediments were derived.

Biota in Kahana Bay were measured along several transects. A considerable variety of species were found in numbers ranging qualitatively from rare to very common. Some evidence from previous studies indicate that fresh water during heavy rains may damage the biota of the Bay. However, because Kahana Bay is intended as a baseline against which to compare coastal waters under the influence of other types of land development the data cannot be readily evaluated on any absolute scale. The possibility that the fact of embayment may yield data which cannot be compared with that obtained from more exposed coastal zones is not being overlooked as data from other areas become available.

Influence of Sugarcane Culture and Milling

The most comprehensive study made during the report period was related to coastal zones influenced by land in sugarcane culture. First priority was given this situation to monitor "before" and "after" conditions as the Kilauea Sugar Company on the north Kauai coast closed operations after 92 years of continuous activity. Untreated mill wastes were the major contributor of quality factors from the sugarcane industry. Soil, leaf trash, and bagasse from the milling operation created a daily visible plume and debris which washed ashore. Coliform organisms were also associated with the turbid mill waste. Sediments, rather than water, harbored most of the nutrients, heavy metals, and pesticide residues found in the ocean. DDT, although not used by the sugarcane industry, was present in wastewater and sediments in the same small amount reported for Kahana Bay. Herbicides used sugarcane culture did not appear in the coastal water.

Following the cessation of plantation operations in November 1971, the aesthetic aspects of the coastal water quickly improved. By March 1972, the debris was gone from beach areas and fish were back in the area in impressive numbers. Continued monitoring of the other aquatic biota is continuing to observe changes and to evaluate the initial observations made of aquatic life in relation to the sugar mill wastes.

Studies were initiated in south Kauai late in the report period to assess the effects of changed operational practices by the McBryde Sugar Company, used as a base of reference, data collected in 1968 by the Environmental Protection Agency. Operational practices and wastewater treatment facilities now employed quite clearly demonstrate that it is possible to operate without discharging mill waste into the ocean and to prevent irrigation tailwater overflows except when flooding occurs after intense rainfall. Monitoring of ocean water and sediments for comparison with the 1968 data is in progress. At the time of reporting, only very preliminary data was available. It was noted that the usual 1 part per trillion of DDT was also present in south Kauai.

Other studies at the Hamakua Coast, Hawaii show deposits of sugar mill waste to be usually limited to 1/4 mile on either side of the mill. Where sediments have accumulated, benthic invertebrates such as coral have been smothered.

Influence of Urbanization of Land

Aspects of the influence of urbanization which are considered in the Annual Report are:

1. The effect of domestic wastewater (sewage).
2. The effect of storm water runoff.

Prior to the initiation of the Coastal Water Quality Project, action to alleviate the largest sewage discharges at Sand Island, Pearl Harbor, and Kaneohe Bay has already been begun by the City and County of Honolulu and by state and federal agencies. Therefore, the contribution of the Project to these programs was largely a cooperative one in which data were freely exchanged and assistance rendered by project staff and associates in acquiring data on the "before" conditions in discharge areas. The aspect of the Project dealing with "after" conditions is, therefore, deferred until the appropriate time in the program.

Covering the contribution from urban runoff other than sewage, a program of observations of water, sediments, and biota in progress at Maunalua Bay (an area influenced by surface runoff from inhabited areas with marinas and ongoing construction), and Waikiki Beach, where cooperation with the Corps of Engineers affords an opportunity for extensive sediment and water analyses, is reported briefly.

Evaluative Studies

In addition to the foregoing studies involving experimental techniques as a basis for evaluation, Chapter 5 of the Report discusses the results of evaluative studies. Data were collected from a wide range of sources and disseminated by various members of the Project Staff at public hearings, testimony before legislative committees, and review of environmental impact statements. In addition, an informative public information medium entitled, *Project Bulletin*, was established and four issues distributed to a wide sector of the community. Its purpose was to bring to the attention of those responsible for decision-making the ongoing results of the experimental work and key concepts and rationale which should be given consideration in policy decisions but which might well be lost to the public in the larger context of the *Annual Report*.

SUMMARY OF FINDINGS

Throughout the *Annual Report* attention is called to results which support tentative conclusions. Cther results suggest that some effects of man's activities may be more apparent than real, especially, if categorically entertained. For example, the esthetic effects of sugar mill wastes at north Kauai disappeared once the discharge of mill wastewater was discontinued. Fish catch in the affected area likewise began rapidly to increase. In a more subtle and complex vein, a local situation may render some considerations to be far more critical than they would be elsewhere. For example, secondary sewage in Kaneohe Bay may be ecologically harmful on a long timespan although aesthetically acceptable, whereas at Sand Island raw sewage may do less permanent damage and only within a limited area although it is aesthetically unacceptable.

But in a less speculative vein, it seems evident that a period of observation will be necessary to assess the overall biological changes which may occur at north Kauai.

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 indusrry 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 is that DDT in samll 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 heavy metals such 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.

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MERCURY LEVELS IN MARINE BIOTA

QUALITY of COASTAL WATERS

PROJECT BULLETIN

Project Bulletin No. 6/January 1973 L. S. Lau, Principal Investigator

By Howard Klemmer and Samuel N. Luoma
(Editor's note: Dr. H. Klemmer is the Director of Community Pesticides Studies Hawaii, and Samuel N. Luoma is a graduate student in the Zoology Department.)

Mercury ranks as the sixteenth least common element in the crust of the earth and, yet, because of its chemical reactivity, is widely distributed in a variety of organic and inorganic forms. Worldwide commercial usage of the metal and its release from the burning of fossil fuel, estimated recently at some 23 million pounds annually, has created an extensive and continuing redistribution.

Increasing awareness of problems caused by the redistribution of mercury in both organic and inorganic forms has resulted from outbreaks of major acute and chronic poisonings in human, bird, animal, and fish populations. However, our understanding of this metal is still very incomplete as to the nature of its entry into specific biological systems: whether it accumulates through biological concentrations at different trophic levels and whether it reaches toxic levels in either inorganic or organic form at any trophic level.

As part of the Quality of Coastal Water Project, recent studies of mercury levels in a wide range of biota collected from a nearshore area on Kauai indicate that benthic feeders show a greater ability to accumulate mercury than animals feeding above the sediment-water interface (Fig. 1). Of the organisms feeding on benthic organic material 53 percent show detectable mercury concentrations (>0.05 ppm) while only 15 percent of the organisms classed as browsing epiphytic herbivores or midwater and higher trophic level carnivores contain mercury at reliably detectable levels. QCW studies have already shown that mercury concentrations in related sediments far exceed those in the water column in most areas (Project Bulletin No. 5), so the disparate mercury level found in benthic and non-benthic biota may not be too surprising and actually makes sense. What is intriguing, however, is that the study suggests, contrary to traditional assumption, the most effective pathway of mercury transport may not be through a linear food-chain from plankton to herbivore to carnivore, but that greater concentrations of mercury may be found in organisms associated with short food chains linked directly to the benthos.

In deeper Hawaiian waters, the pelagic carnivores, marlin, tuna, and mahimahi, appears to contain appreciably higher levels of total mercury than five nearshore species of fish, as indicated by measurements made recently and summarized in Table 1. Mean levels of total mercury in tuna are near the 0.5 ppm level established by the Food & Drug Administration as the maximum permissible level for mercury in edible fish. Total mercury levels in marlin far exceed this tolerance limit and, consequently, the local sale of marlin for human consumption has been banned by the Hawaii State Department of Health.

As shown in Table 1, organic mercury levels measured tended to equal total mercury levels in all species analyzed except marlin, indicating that most of the mercury stored in edible muscle tissues is organic. In marlin muscle tissue, organic mercury levels are much lower than those for total mercury, a finding that has been confirmed through independent measurements made by Dr. Westoo's group in Sweden, who also identified the organic fraction as methyl mercury. Prior to this finding, it has been assumed that 90 percent or more of all mercury in fish tissue was in organic form. Why mercury in marlin tissue differs so drastically is not known. Perhaps a biotransformation occurs from the organic to the more oxidized inorganic form, or alternatively, marlin may absorb and store greater levels of inorganic mercury from sea water.

Controlled laboratory experiments are needed to properly study the fate of mercuric ions in marine ecosystems. A series of such experiments will shortly get underway within the QCW project. Proposed is a simplified food chain featuring marine annelids and one or more predator fish that can be maintained in the laboratory.

The objectives of the study are threefold: 1) to study the biotic

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transport of mercury in a simplified, short food-chain ecosystem characteristic of stressed environments; 2) to study the role sediment-dwelling annelids may play in cycling mercury from the sediments to the upper trophic levels of the ecosystem; and 3) to provide information useful in selecting organisms which can be used in monitoring mercury in Hawaii's marine water.

GLOSSARY

benthos-description of organisms on or within sediments

epiphytic herbivores-plant-eating organisms which feed on multicellular plants extending above the surface of the substrate (They do not take in sediment.)

carnivores-animal-flesh eating or predatory animals

pelagic-mobile organisms living within the water column

annelids-marine worms

trophic levels-nutritional levels in which organisms obtain their food from the same types of sources

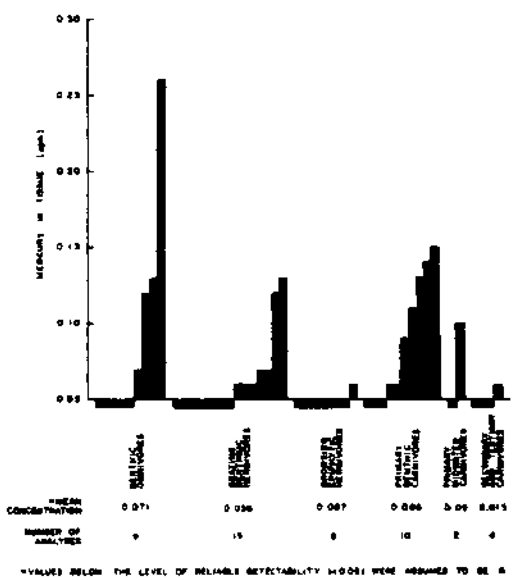

FIGURE 1. MERCURY LEVELS IN ORGANISMS FROM NEAR SHORE WATERS OFF KAUAI. EACH LINE REPRESENTS AN INDIVIDUAL ANIMAL. DASHES BELOW X AXIS REPRESENT MERCURY LEVELS OF <0.05 PARTS PER MILLION.

TABLE 1. TOTAL AND ORGANIC MERCURY FOUND IN MUSCLE TISSUE OF FISH CAUGHT IN HAWAIIAN WATERS. FROM RIVERS, J.B., J.E. PEARSON, AND C.D. SHULTZ. 1972. "TOTAL AND ORGANIC MERCURY IN MARINE FISH." *BULL. ENVIRON. CONTAM. & TOXICOL.* 8(5) PP. 257–66.

COMMON (LOCAL) SCIENTIFIC NAME	NO. OF FISH ANALYZED	ORGANIC MERCURY PPM		TOTAL MERCURY* PPM	
		AVERAGE	RANGE	AVERAGE	RANGE
PELAGIC SPECIES:					
Pacific Blue Marlin (A'u) *Makaira ampla*	29	0.93	0.23-1.79	4.78	0.35-14.0
Yellow Fin Tuna (Ahi) *Neothunnus macropterus*	24	0.48	0.25-1.00	0.54	0.24-1.32
Skip Jack Tuna (Aku) *Katsuwonus pelamis*	20	0.41	0.20-0.57	0.58	0.27-0.52
Dolphin (Mahimahi) *Coryphaena hippurus*	10	0.25	0.15-0.30	0.25	0.17-0.31
INSHORE SPECIES:					
Squirrel Fish (Uu, Menpachi) *Myripristis argyromus*	14	0.21	0.10-0.40	0.21	0.10-0.43
Bigeyed Scad (Akule) *Trachurops crumenophthalmus*	10	0.10	0.07-0.11	0.09	0.07-0.11
Red Goat Fish (Weke-ula) *Mulloidichthys auriflamma*	10	<0.05	---	<0.05	---
Mullet (Amaama) *Mugil cephalus*	10	<0.05	---	<0.05	---
Parrot Fish (Panuhunuhu) *Scaridae*	10	0.05	<0.05-0.10	0.05	<0.05-0.08

BACTERIAL INDICATORS OF WATER QUALITY

QUALITY of COASTAL WATERS

PROJECT BULLETIN

Project Bulletin No. 7/December 1972 L. S. Lau, Principal Investigator

By Reginald H.F. Young

(Editor's note: Dr. Young is Associate Professor of Civil Engineering and Associate Sanitary Engineer of Water Resources Research Center.)

Bacteriological densities are an integral part of any water quality standard to protect such uses as the drinking water supply, recreation, and propagation of fish and shellfish. The objective of these involves the detection of fecal contamination from all warm-blooded animals, since this is the natural link to the occurence of pathogenic (disease causing) organisms in polluted water. Methods for the direct detection of pathogenic organisms are generally too complicated and expensive for use in field determinations. To circumvent this difficulty an organism or group of organisms is utilized to identify pathogenic organisms in water. The coliform organism group was selected as an indicator because these bacteria are always present in large numbers in fecal wastes of humans and other warm-blooded animals and are relatively easy to detect, isolate, and enumerate.

Standard Methods[1] defines the coliform bacteria group as "all of the aerobic and facultative anaerobic, Gram-negative, non-sporeforming, rod-shaped bacteria which ferment lactose with gas formation within 48 hours at 35°C." This definition is considered general and includes a heterogeneous group of bacterial species, most of which have little health significance. The ability to ferment lactose, however, led to the development of simple techniques for identifying the presence of the coliform organisms.

The coliform group includes not only organisms that have fecal origin, such as *Escherichia coli* but also organisms that live on dead matter in the soil, such as, *Aerobacteria aerogenes* which is commonly found in runoff, even from virgin watershed areas, and would be expected to thrive and even multiply in some cases in polluted waters.

Water quality standards typically express maximum allowable bacterial concentrations statistically most probably number (MPN) by the multiple tube fermentation test or the actual count per unit volume as determined by the newer membrane filter technique. Other indicator bacteria systems have been proposed in the past but for reasons that have been considered unsatisfactory in comparison with the coliform bacteria with the exception of the fecal streptococci group which are normal inhabitants of the intestines of humans and other warm-blooded animals. Recent developments in methodology, including high temperature incubation, differential media, and membrane filter techniques have focused attention on the fecal coliform and fecal streptococci groups of bacteria as pollution indicators. It has long been known that coliform bacteria from the gut of warm-blooded animals would produce gas from lactose broth at 45°C while the coliforms from non-fecal sources would fail to grow. This trait of the fecal coliform has been adapted to a standardized procedure now involv-

[1] *Standard Methods for the Examination of Water and Wastewater*, 13th Edition, 1971, American Public Health Assoc.

ing a multiple tube dilution technique with a lactose broth media or a membrane filter technique, both with incubations at near 45°C.

COLIFORM STREPTOCOCCUS RELATIONSHIP

The density relationship between fecal coliforms (FC) and fecal streptococci (FS) can be used to effectively distinguish between the contribution of human and non-human warm-blooded animal wastes. Geldreich has reported that the ratio between FC and FS density exceeds 4:1 (FC:FS) in human fecal material and in domestic wastes. This relationship was reversed in studies of packing house and dairy farm effluents, representative of livestock and poultry fecal contamination, with a FC:FS ratio generally less than 0.7:1. Studies of stormwater and fecal material from cats, dogs, and rodents yielded the same low FC:FS relationship. Similar relationships has been developed with the density between fecal coliforms and total coliforms (TC).

STATE WATER QUALITY STANDARDS

The state of Hawaii standards for water quality list specific levels for coliform bacteria for each water classification. For Class AA coastal waters (waters designated for oceanographic research, shellfish and marinelife propagation, coral reef and wilderness area conservation, and esthetic enjoyment), there is a median total coliforms limit of 70 organisms/100 ml. For Class A coastal waters (recreational uses and esthetic enjoyment) and the fresh waters Classes 1 (potable supplies) and 2 (all other waters) there is a median limit on total coliforms of 1000/100 ml. Fecal coliforms should not exceed an arithmetic average of 200/100 ml for Classes A and 2 and 20/100 ml for Classes 1 in any 30-day period. For Class B coastal waters (small boat harbors, commercial, shipping, and industrial use, bait fishing, and esthetic enjoyment), there is only a limit on fecal coliforms with an arithmetic average of less than 400/100 ml during any 30-day period.

It was on the basis of these standards that both Keehi Lagoon and Manoa Stream were classified as polluted and posted by the State Department of Health in events much publicized by the local news media two to three years ago. Since sources of direct sewage discharge into these water bodies, particularly Manoa Stream have not been publicly identified, it is appropriate to examine the indicator bacteria relationships for these waters to differentiate between human waste contamination and that contamination that might "naturally" occur in a watershed. This is significant for all watershed areas in the state, for if undeveloped areas show levels of coliform densities in excess of the State Water Quality Standards, then some modification or changes should be made in the Standards or their enforcement. It is also important that the effects of the waste water treatment plants discharge and non-point sources of contamination be distinguished for coastal waters.

WRRC WATERSHED STUDIES

Several watersheds have been studied by the Water Resources Research Center since 1970 on a seasonal basis to ascertain their water quality characteristics in both wet and dry weather conditions. This work includes the Manoa, Kapalama, and Kalihi watershed areas. Total coliform, fecal coliform, and fecal streptococci densities were obtained for all three watersheds. The watersheds represent undeveloped residential, urbanized-industrialized, and undeveloped -residential-industrialized, drainage areas, respectively.

At all stations on Manoa Stream, the state Standards for both total and fecal coliform densities were exceeded in both dry and wet weather conditions. However, the range in FC:TC was 0.01 to 0.09 for dry weather and 0.03 to 0.14 for wet weather conditions while the range in FC:FS was 0.14 to 0.59 for dry weather and 0.31 to 1.06 for wet weather conditions. The physical and chemical data for Manoa Stream were indicative of an excellent quality, in relation to The U.S. Public Health Service Drinking Water Standards. The bacterial density relationships show that the fecal organisms are predominantly of wild animal origin with a possible contribution from some human source during wet weather conditions.

Reported results of surveys of two high-mountain watersheds in Montana show a similar low density of coliforms and streptococci in closed undeveloped regions similar to Manoa Valley. The closed watershed actually yielded water with higher total and fecal coliform counts than the watershed open to recreational activities. The cause of this was considered to be due to a higher wild animal population in the closed area which is relatively free of human activity.

In Kapalama Canal, bacterial densities at all stations, over a one-year study period, exceeded the state standards. Average FC:TC for the Canal was 0.25:1 in Class 2 waters. The FC:FS relationship varied from 1.5:1 in the upper reaches of Class 2 waters to 6.0-9.0:1 in lower reaches of Class 2 waters to less than 0.5:1 in Class A waters. These results give indications of definite human sewage contamination from cesspools or sewers in the Class 2 water upstream of the tidal barrier which is located between Class A and Class 2 waters. Downstream of the barrier, there may be both a dilution effect and a natural die-off of the coliforms in the saline waters leading to the alteration in FC:FS ratio. Since the Canal waters discharge into Honolulu Harbor and probably into the Kalihi ship channel they may be a source of contamination for Keehi Lagoon. The chemical data for the Canal is of much poorer quality than those for Manoa Stream.

Varied results were obtained for Kalihi Stream, however, the total and fecal coliform levels were again in excess if the state Standards on most surveys. The FC:TC relationship ranged from 0.026 to less than 0.001 from the forest reserve to the reach under tidal influences. The FC:FS relationship had a higher level of variability but was less than 0.7 for 3 of 4 stations in dry-weather conditions and ranged from 0.9 to 1.4 in wet-weather conditions. Thus, there is probably some fecal contamination from cesspool overflows, street washings or sewer mains under high runoff conditions.

KANEOHE BAY DRAINAGE BASINS

A number of the streams in the Kaneohe Bay drainage basin were surveyed in 1968-69 and the results show a similar pattern of excessive total coliform levels, but with FC:FS relationships indicative of extremely low orders of fecal contamination and the latter of mostly wild animal origin.

HEALTH DEPARTMENT MONITORING

Indicator bacteria densities in coastal waters are the subject of continuous and regular monitoring by the State Health Department. Their results have been compiled for ready access and retrievability in a computer-based system developed by Jackie Miller of the Water Resources Research Center staff. However, the total results are too voluminous to review in this brief document. In areas that are under study in the Quality of Coastal Waters project available data does show that coliform densities are in general conformance with the state Standards. At Sandy Beach, for example, all reported results since 1963 are less than the Class A standard for that area. At Waikiki, a similar situation exists with only 4.5 percent of the 1285 individual samples between 1969 and 1971 having a MPN index greater than 1000/100 ml. Coastal areas on Kauai near the Kilauea and McBryde plantations have similar low coliform levels. Observations at 6 stations in the Hawaii-Kai Marina have yielded high densities at only two sites, but all results are within the Class A levels for that area. Corollary results obtained in the Oahu Water Quality Program study between June 1970 to February 1971 show median total coliform levels in coastal and offshore waters in most areas around the island to well within the state standards Median and maximum levels in excess of the Standards are generally related to high runoff and stream discharge or obvious wastewater discharge such as at the Sand Island outfall.

SUMMARY

Overall results obtained to date from watershed areas on Oahu indicate that coliform densities alone are not indicative of bacterial quality and sources of contamination of surface waters. The fecal coliform/fecal streptococcus and, possibly, the fecal coliform/total coliform relationship are direct indicators of type and kind of fecal pollution. Thus, their adoption as indices for water quality standards would provide a direct and immediate assessment of fecal contamination of nonpoint sources of pollution and the distinction between the impact of such sources and that of direct waste discharges into the coastal water environment.

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COASTAL WASTE DISPOSAL PRACTICES IN HAWAII

QUALITY of COASTAL WATERS

PROJECT BULLETIN

Project Bulletin No. 8/June 1973 L.S. Lau, Principal Investigator

By Gordon L. Dugan and Reginald H.F. Young

(Editor's note: Dr. Dugan is Associate Professor of Civil Engineering and Dr. Young is Associate Professor of Civil Engineering and Associate Sanitary Engineer of Water Resources Research Center.)

Waste disposal practices in Hawaii, as in most other locations of the U.S., in the past have been mainly governed by utilizing the most economically convenient method of disposal--which in Hawaii, with relatively small land areas surrounded by ocean, means that regardless of method of disposal, the ocean essentially serves as the ultimate sink for most land generated wastes.

In compliance with the Federal Water Quality Act of 1965 Hawaii established (1) Water Quality Standards based on receiving water quality; (2) Determined the use and assigned water quality criteria to be made for each given body of water; and (3) Established a plan to achieve and maintain those criteria.

The standards that were established and adopted in 1968 were very stringent with the result that most treated waste water effluents will not meet the rigid established water quality receiving standards. The discharger may, however, apply for a variance or zone of mixing within a certain area to allow for assimilation of waste water if the discharge has received the best practicable treatment and if it does not unreasonably interfere with the actual use of the water areas for which it is classified. No zones of mixing are permitted in Class AA coastal waters.

From September 1968, when waste water discharge applications were first solicited, until July 1972, there have been 186 waste discharge permits issued by the State Department of Health. Several more permit applications are presently under review. The nearly 200 present or pending waste discharge permits include not only municipal discharges but also 21 sugar processing plants, 3 pineapple canneries, 2 oil refineries, and 5 electric power producing plants. Only four of these situations will be briefly reviewed herein: Sand Island Outfall, Kaneohe Bay, Kahe power plant, and sugar mill wastes.

Sand Island Outfall

The Sand Island Outfall presently discharges approximately 55 mgd of untreated sewage through a 3600 ft ocean outfall at a depth of approximately 40 ft. Besides domestic sewage the discharge includes light industrial waste water and wastes from two pineapple canneries. Exclusive of infiltration, which is estimated to be over 40 percent, the outfall discharges approximately one-half the domestic sewage generated on the island of Oahu.

The untreated sewage produces a very distinctive and visible plume which can be generally observed from aircraft, boats, and at higher elevations in Honolulu. There is general public agreement that this condition which has been in existence for nearly 30 years is environmentally unsatisfactory and should be eliminated as soon as possible.

Investigation of the outfall plume confirmed the conjecture that the receiving waters could not possibly approach its Class A classification under State standards. Floatable material, settleable solids, coliforms, and nutrients are all exceeded. In a recent study it was found that approximately 300 acres around the outfall were characterized by lower diversity and density of benthic organisms and that approximately 300 acres around the outfall were characterized by lower diversity and density of benthic organisms and that approximately 10 acres were characterized a high level of settleables with corresponding high densities of typical sludge organisms. Analyses of heavy metals and pesticides in sediments in the vicinity of the outfall indicate a dispersion of such materials in the direction downwind of the prevailing northeast trades (away from Honolulu).

Plans have been completed for a 85 mgd advanced primary sewage treatment plant with provisions for expansion to 106 mgd. The effluent is planned to be discharged through an 84 in outfall line, 9000 ft in length, that terminates in a 3350 ft diffuser which is located in a water depth of 220 to 240 ft. A 3000 x 3400 ft zone of mixing, extending from the ocean floor to the surface, has already been granted for the future outfall.

Kaneohe Bay

Kaneohe Bay, located in the northeastern coast of Oahu, is a popular recreational area for boating, fishing, and water contact sports. The entire Bay of approximately 14 sq mi, which receives the drainage from a 21 sq mi area, is presently classified as Class AA, except for two small harbor areas that are Class B. The aquatic environment of Kaneohe Bay has been the subject of considerable study primarily because of the presence of the University of Hawaii's--Hawaii Institute of Marine Biology on Coconut Island (located within Kaneohe Bay).

Reported effects of water quality during the last decade include coral kill, disappearance of clams, overgrowth of green-bubble algae, and increases in phosphorus and nitrogen in Bay waters, with a consequent increase in primary productivity. Fecal coliform and nitrogen values exceed the water quality standards near the outfall of the Kaneohe sewage treatment plant. The Bay also receives the discharge of Kaneohe Marine Corps Air Station sewage treatment plant.

Plans are presently being formulated to construct an interceptor sewer to conduct the two existing outfalls into the Bay, in addition to collecting two other nearby sewage treatment plant discharges, and transport them to deeper waters beyond the influence of the Bay.

Kahe Electric Power Plant Thermal Waste Water

The Kahe Power Station, newest of three Hawaiian Electric Company power generating stations that serve the island of Oahu, is located on the leeward coastline approximately four miles north of Barbers Point. The three units in operation in 1970 supplied an estimated 36 percent of the total electrical power for Oahu's Hawaiian Electric system, with this total expected to increase to about 53 percent in 1973. A fourth unit was put on line in July 1972.

Oceanwater is used for cooling water at Kahe with both intake and discharge points located at the shoreline, separated by a distance of about 600 ft with the intake lying north of the discharge. The required cooling water flow at Kahe is 72,000 gpm for the two older units (1964) and 74,000 gpm for the two newer ones (1972). The heat transfer that results in the cooling process is about 370 million Btu/hr with a cooling water temperature rise of about 10°F.

Prior to construction of the Kahe plant an investigation of the marine conditions found a seasonal variation in ocean surface temperatures of from 76°F in March to 82°F in September, with about 20°F diurnal variation. Under normal trade wind conditions at Kahe the discharge plume is directed seaward with the surface temperature rise not expected to be greater than 1.5°F beyond a radius of 4000 ft from the discharge structure with all four units in operation. However, under severe southerly or southwesterly wind conditions due to cyclonic storms bringing the plume northward to the intake, the discharge is recirculated with a temperature rise of as much as 23°F above ambient.

Sugar Mill Wastes

The technique of sugarcane harvesting since World War II has transformed from hand harvesting methods to mechanical methods. Mechanical methods involve burning the cane in the field, and the use of machinery that rakes the sugarcane into piles that are picked up by cranes, loaded onto trucks, and hauled to the mill. Large volumes of water are needed for washing the cane. Waste products, besides soil particles which amount to approximately 5 percent of the dry weight, include bagasse, the fibrous residue left over from sugarcane processing, and a small quantity of unprocessed sugarcane stalks. Various studies have concluded that turbidity resulting from soil and bagasse create the greatest problem in ocean disposal.

Treatment efforts to alleviate coastal waste disposal include bagasse burning for electric power production, hydroseparators, tube settlers, and sedimentation basins to significantly reduce the waste water sediment load, in addition to experiments with mechanical cane cutters and dry cane-cleaning methods.

Concluding Remarks

The aforementioned situations reflect point source discharges and their efforts on coastal waters. Main factors in coastal water quality that have received little attention are non-point sources of pollution resulting mainly from urban and agricultural runoff which can only be effectively controlled by land use regulations as opposed to receiving water quality standards. Hawaii was the first state (1961) to apply statewide land zoning to all State lands. The original intent of the zoning however, was not necessarily for coastal water quality protection, but the relationship of land use to coastal water quality must be delineated for effective environmental management. The Quality of Coastal Waters project represent the first such coordinated effort to establish the effects of land use practice on coastal water quality in the State of Hawaii.

P, N : P STANDARDS FOR HAWAIIAN STREAMS

QUALITY of COASTAL WATERS

PROJECT BULLETIN

Project Bulletin No. 9/November 1973 L.S. Lau, Principal Investigator

by HENRY K. GEE

(Editor's note: Henry K. Gee is Research Associate in Sanitary Engineering of Water Resources Research Center, University of Hawaii.)

One of the program objectives for the Hawaii State Water Strategy for 1974 is to revise the present Water Quality Standards to a more realistic set of standards in view of recent data obtained on the background conditions of coastal waters. Since the adoption of the current standards in 1968, many inconsistencies have been pointed out where the existing quality of natural waters could not meet the standards. However, nutrient levels for fresh waters were omitted from the original standards and little concern was given to phosphorus and nitrogen levels in Hawaiian streams.

With the enactment of the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500), guidelines for developing or revising water quality standards were established. Phosphorus limitations were specified for surface waters under the general water quality criteria and in a subsequent memorandum to regional administrators explaining the position of EPA on phosphorus and eutrophication.

Under the provisions of (Sections 46-13 and 46-16, Revised Laws of Hawaii, 1955) Chapter 342, Hawaii Revised Statutes, and the Federal Water Pollution Control Act Amendments, 1972 (PL 92-500), Chapter 37-A of the Public Health Regulations is to be amended to be consistent with the new Federal requirements and to include the necessary changes as recommended by the EPA.

A proposed draft of amendments by the Department of Health to the Water Quality Standards, Public Health Regulations Chapter 37-A, contains a proposed standard of 0.050 mg/l for total phosphorus in waters of Classes 1 and 2, the waters of streams, lakes and reservoirs (subsec. 6.b.3, p. 21). It also contains a proposed requirement that the natural ratio of nitrate-nitrogen to phosphate-phosphorus be maintained in waters of the same classes. The information presented here is to illustrate that neither of these proposed standards is suitable for fresh surface waters in Hawaii.

PHOSPHORUS CONCENTRATION

The proposed numerical standard for the concentration of total phosphorus appears to be based on guidelines issued by the Environmental Protection Agency (Guidelines for Developing or Revising Water Quality Standards, 1973). However, it is inappropriate for Hawaiian streams generally because (1) it is exceeded in nature, and (2) the usual concerns with high nutrient levels are generally inapplicable in Hawaii. The EPA guidelines actually suggest two significant levels of total phosphorus in fresh waters: 0.050 mg/l to prevent eutrophication in lakes and 0.100 mg/l to prevent nuisance plant growth in streams. However, no Hawaiian streams enter lakes, and although the low water flows of many streams are directed into reservoirs, the flood flows of all streams and the low water flows of many directly reach coastal waters, in which, for the most part, dispersal is very effective. Hawaiian streams are characteristically steep and fast flowing, particularly during wet weather when phosphorus concentrations are highest, and plants cause very little nuisance because of limited growth due to the high velocity flow.

Ching (1972) studied the water quality of Manoa Stream which drains a basin of 4200 acres consisting of forested and residential areas with very light commercial activities. During dry weather conditions the mean phosphorus concentration of 5 sampling stations was 0.101 mg/l with a mean wet weather concentration of 0.196 mg/l with values ranging from 0.175 to 0.204 mg/l. These values are 3 to 4 times higher than the suggested standard of 0.050 mg/l.

Kalihi Stream drains a basin of 6.7 square miles consisting of forest reserve watershed, residential and commercial and light industrial area. During 1970 and 1971 a study by a consortium consisting of Engineering Science, Inc., Sunn, Low, Tom and Hara, Inc. and Dillingham Environmental Co. (1972), working on the Oahu Water Quality Program for the City and County of Honolulu, found total phosphorus to range from 0.022 to 0.030 mg/l. A more recent study by Matsushita (1973) found the mean total phosphorus concentration dry weather flow to be 0.18 mg/l with a range of 0.11 to 0.34 mg/l and during wet weather the mean concentration to be 0.26 mg/l with a range of 0.03 and 0.27 mg/l. From a subbasin of an undeveloped (forest reserve) area of 354 acres, the dry weather flow was found to have a mean total phosphorus concentration of 0.11 mg/l.

A water quality study of Kaneohe Basin streams by Young, et al.(1969) at eleven sampling stations showed that the maximum phosphorus concentration occurred during the rainy winter months of December and January with a mean value of 0.267 mg/l and a range of 0.096 to 0.724 mg/l as P. A total of 9 streams were studied in this survey.

Four streams entering Pearl Harbor were studied by the Water Resources Research Center (Tenorio, Young, and Whitehead, 1969). Samples taken over a 3-year period resulted in the following mean concentrations of PO_4-P:

Waiawa Stream = 0.598 mg/l;
Waimalu Stream = 0.048 mg/l;
Waikele Stream = 0.345 mg/l;
Kalauao Stream = 0.095 mg/l.

Thus fresh water streams should be exempted from the EPA criteria because of two factors listed in the memo to regional administrators regarding phosphorus in the guidelines (April 1973). (1) The streams of Hawaii contain naturally occurring phosphorus exceeding the 100 μg/l limit, (2) The steep banks, high velocity flows, and high and natural concentrations of silt constitute natural conditions in Hawaiian streams limiting plant growth nuisances.

These factors would fit into the EPA's two criteria allowing exceptions:

1. GENERAL GUIDANCE: *"Some waters, because of naturally occurring poor quality, man-made pollution or technological limitations may qualify for an excepted classification. This determination, however, must be made on a case-by-case basis following an analysis of each such area. The analysis should be based on presently available information and must contain sufficient data to support the request for exception based on natural condition of the water or on technological limitations prohibiting improvement of water quality to the degree necessary..."*

2. UNIQUE PHOSPHORUS SITUATION: *"An exception may be granted if natural phenomena or conditions would be expected to limit biological plant nuisances. Examples would include those waters highly laden with natural silts or colors where less than 1 percent of the incident light would penetrate beyond depths of 0.5 meter during at least 50 percent of the growing season, or those waters whose morphometric features of steep banks, great depth, and substantial flows and mixing contribute to a history of no aquatic point problems, or those lakes in which the volume of water beneath the thermocline exceeds that of the water above the thermocline, or those waters that are managed primarily for waterfowl of other wildlife..."*

NITROGEN TO PHOSPHORUS RATIO

The atomic ratio of NO_3-N to PO_4-P in natural streams can be a fairly constant value or it can vary from one to two orders of magnitude. The variations may result from change in biological uptake, which in turn is dependent upon temperature, amount of solar radiation, stream flow, and turbidity. They may also result from changes in phosphorus concentration associated with changes in physical-chemical factors such as alkalinity, hardness, pH, and sediment concentration. The following tables show that the ratio varies greatly not only in four streams that discharge into Pearl Harbor but also in Kahana Stream which drains an undeveloped area on Windward Oahu.

The variation in the ratio even in natural conditions confirms the inadequacy, already pointed out by the Envirommental Center (Cox, 1973), of allowing no change in the ratio of NO_3-N to PO_4-P from natural conditions. It also indicates that no absolute ratio can be set as a standard, especially when this ratio can vary a hundredfold or more as shown by the Kahana Stream data.

ATOMIC RATIO OF NO_3-N TO PO_4-P IN PEARL HARBOR STREAMS (TENORIO, *et al.*, 1969).

DATE	STREAMS			
	WAIAWA	WAIKELE	KALAUAO	WAIMALU
08-17-67	3.85	9.55	0	0
10-03-67	3.18	8.00	51.07	2.94
11-21-67	5.02	5.75	4.71	27.04
11-26-67	21.54	8.34	30.64	18.26
02-20-68	4.16	1.41	35.75	21.07
04-04-68	5.04	5.97	0	0
06-27-68	5.81	6.34	37.61	0
08-27-68	5.15	7.52	45.06	53.62
11-04-68	8.93	9.20	51.43	214.5
01-31-69	1.06	6.96	0	10.21
03-13-69	4.20	4.97	7.80	0.42

ATOMIC RATIO OF NO_3-N TO PO_4-P IN KAHANA STREAM (QCW PROJECT DATA, UNPUBLISHED).

DATE	KAHANA	DATE	KAHANA
05-14-72	4.33	01-17-73	22.04
07-17-72	18.59	02-28-73	168.04
10-31-72	4.42	04-24-73	10.21
12-20-72	5.04	06-20-73	1.61

a summary

QUALITY OF COASTAL WATERS SECOND PROGRESS REPORT

QUALITY *of* COASTAL WATERS

PROJECT BULLETIN

Project Bulletin No. 10/July 1974 L.S. Lau, Principal Investigator

by L. Stephen Lau

(Editor's Note: Dr. L. Stephen Lau is Director of the Water Resources Research Center, Prof. of Civil Engineering, University of Hawaii, and Principal Investigator of the Quality of Coastal Waters project.)

OBJECTIVES OF PROJECT

This report summarizes the results of the second year of investigative and evaluative work of the University of Hawaii's Sea Grant Program project, "Quality of Coastal Waters." The general objectives of this multidisciplinary project are to identify, develop, and evaluate the critical physical, biological, and rational parameters needed in formulating effective policies, institutions, and systems for protecting the quality of coastal waters in Hawaii. Specific objectives are: to show the relationship between water quality standards and the quality of associated ecological environments; to assess the use of biota response in coastal waters as a determinant of control measures for protecting marine resources; to investigate the mechanism and significance of buildup of heavy metals and pesticides in sediments; to recommend the measures and institutional changes to protect coastal waters; to assess the social, economic, and political impacts of such recommendations; and to provide an informational and educational service to all sectors of the community.

NATURE OF RESULTS OF STUDIES

Research activities for the project year consisted principally of field and laboratory studies of coastal waters initiated in the first project year but with increased emphasis on biota and sediment with work concentrated as follows: enlarging the scope of study for the Hawaii Kai and Kahana areas and reducing the scope of study for the Kilauea and McBryde areas on Kauai; completing cooperative studies for Waikiki Beach, Kailua Bay, and Mokapu Outfall site; and terminating the observations for Sandy Beach. Assistance was rendered to the State Department of Health in the revision and updating of the State Water Quality Standards.

Influence of Undeveloped Land

Kahana Bay was selected for study as a coastal water area under the influence of relatively undeveloped land. Land contribution of nutrients to the bay via Kahana Stream and all nonpoint routes was found to be small despite the perennial nature of the surface and subsurface discharges. However, the nitrogen and phosphorus levels measured for Kahana Bay waters exceeded the levels allowed under its state Class AA water classification. In the contiguous open ocean water the nitrogen and phosphorus levels also exceeded the Class AA standards. Coliform organism concentrations met the Class A rather than Class AA standards. Thus, the Kahana Bay water quality tends to satisfy the Class A standard rather than the Class AA standard.

Heavy metals, especially lead, copper, zinc, chromium, and nickel appeared consistently and in a generally comparable range (a few to a few hundred ppm[1]) in the bay sediments, stream sediments, and watershed soils. The ubiquitous nature of their presence has been found to depend on the parent geologic formations from which the soils and sediment are derived. However, mercury and cadmium were only occasionally detected in the sediments and when detected, occurred at only a fraction of or a few parts per million. DDT was detected in the range of a few parts per trillion in the Kahana Bay sediment together with only periodically detected and very low levels of dieldrin, DDE, α and γ chlordane. In the Kahana Bay water both heavy metals and DDT were detected but only at levels similar to open ocean water, i.e., a fraction of, or a few parts per billion for the heavy metals, and only a few parts per trillion range for DDT.

Influence of Urbanized Land

The project's approach to studying the effects of urban land development is fractionalized, i.e., selection of single predominant type of urbanization of land to reveal the cause-effect relation. Recreational use of coastal land and water in Waikiki and domestic urban use of water and the abutting land in Hawaii Kai Marina and east Maunalua Bay furnish such situations. Domestic sewage is collected and removed from the areas.

Investigative results for the Hawaii Kai area and Maunalua Bay showed a general trend of improvement in water quality from the marina to the near-ocean bay waters. Nitrogen levels in the bay and only the near-ocean station were within the Class A state standard by which the water bodies are classified but phosphorus levels exceeded the standard elsewhere. All heavy metals were consistently present in the coastal sediments in the parts per million level. The levels of the ubiquitous pesticides analyzed, DDT, dieldrin, and PCP, (the latter is used primarily for termite control in house construction), were at least one order of magnitude higher than in the Kahana Bay sediments, thus reflecting intensive urban activities associated with a relatively new and growing residential development.

In the Hawaii Kai Marina and coastal waters, heavy metals were detected in the usual minimal parts per billion level as in open ocean water, and DDT, dieldrin and PCP were in the usual parts per trillion range. A turbid water plume in the Maunalua Bay was occasionally identified and apparently was related to currents and roiling bottom sediments rather than any liquid discharge. A biota study of the bay waters was completed and detailed.

Limited water quality data obtained for the Mamala Bay waters of Waikiki in support of a conjuctive study by Chave for the Corps of Engineers and coliform monitoring by the Department of Health are reported. In general the data satisfied state requirements for Class A waters except for phosphorus. Coral abundance was generally less toward Diamond Head than toward Ala Wai Canal, which is the only major drainage canal intercepting the surface runoff from the valleys and discharging into Waikiki coastal waters. From the findings, there is little evidence which would attribute any specific water quality effect solely to the presence of intense recreational activity at Waikiki.

Sandy Beach represents a rather complex situation: the open ocean coast beach being popular, the land use changing from rural and undeveloped to residential urban development, and above all, the coastal water receiving treated domestic effluent. The Project study was dovetailed to complement the studies undertaken by the consulting firm of Sunn, Low, Tom, and Hara, and the rou-

[1]Quality parameters in water are reported on weight per volume basis in the main report but for convenience on weight ratio basis in this summary:
- milligram per liter=parts per million
- microgram per liter=parts per billion
- nanogram per liter=parts per trillion

Quality parameters in sediment are reported on weight ratio basis:
- milligram per kilogram=parts per million
- microgram per kilogram=parts per billion
- nanogram per kilogram=parts per trillion

tine monitoring by the State Health Department. Results for the project area showed clear shoreline water similar to Waikiki but with higher nutrients than Kahana Bay water and the state Class A standard levels. However, the study by the consulting engineers of the offshore condition adjacent to the Hawaii Kai sewer outfall substantiated the supposition that there is little significant detriment to the coastal water and benthos from the discharge of treated wastewater off Sandy Beach.

A baseline survey of benthic biota, particularly coral and micromollusc abundance and diversity, and fish was performed for Kailua Bay, the proposed Mokapu outfall site, and the existing Kailua sewer outfall. While the greatest abundance and specific diversity of the fish were not near the outfall, the highest standing crop of micromolluscs is near the outfall. The occurrence of micromolluscs is comparable with the patterns in other areas of similar depth and substrate.

Influence of Sugarcane Culture And Milling

Nonpoint discharge studies of sugarcane production and milling wastes were continued but at a reduced scale 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 in 1971. Untreated mill wastes were found to be the major contributing factor to the presence of coliforms, sediments, trash, and bagasse. The effect was largely an extensive visible plume in the coastal waters and debris in both the water and on the beach. 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 wastes and sediments. Herbicides used in sugarcane culture did not appear in coastal waters. A striking aesthetic improvement of the coastal water and the beach quickly followed the cessation of mill waste discharge. Coastal water qualities continued to improve: phosphorus decreased to better than Class AA waters, DDT and PCP were detectable only at parts per trillion level. The rapid improvement is attributed to both the cessation of mill waste discharge and the heavy sea. Beach and ocean sediments continue to harbor about the same decreased amount of nutrients. Fish have reappeared rapidly since 1973. No apparent changes in micromolluscs have been observed since the cessation of mill operation. Tentative conclusions of the continued Kilauea investigative studies are: no evidence of eutrophication[2] in coastal water, adverse effects of discharge mostly transitory, and epibenthic[3] communities more influenced by waves, currents, and coastal topography than by mill waste discharge.

Studies were continued in south Kauai 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, the coastal water of Wahiawa Bay showed an anomalously high nitrogen content while no pesticide residues were found in the offshore water except for the one to two parts per trillion DDT which seems to be present everywhere.

EVALUATIVE SUMMARIES

Evaluative summaries were detailed for several key quality parameters in water and sediment. Heavy metals were ubiquitous and in parts per million range in coastal sediment in Hawaii. This suggests that if standards for the level of heavy metals in dredge spoil were to be set, care should be taken not to fix unrealistic levels that cannot possibly be attained. In the coastal waters, heavy metals also occur but only in the parts per billion range, a level

[2]Eutrophication: increased algal production due to excess nutrients

[3]Epibenthic community: plants and animals living on sea bottom between low tide level and 100 fathoms

quite comparable to the level in ocean water. Conjuctive studies of mercury uptake in an aquatic food chain from the water and sediment were continued and detailed.

Of the insecticides, the presence of DDT in sediments is ubiquitous. In Maunalua Bay and Hawaii Kai sediments, dieldrin, α and γ chlordane are found frequently and with highest concentration in the low parts per billion range. Their occurrence may be attributed to prior and current continuous use of these chemicals in the abutting land area and the poor sediment circulation within the Hawaii Kai Marina. In coastal waters insecticides were generally undetectable or at only a few parts per trillion. PCP, like DDT, seems to occur ubiquitously.

Herbicide residues in West Loch of Pearl Harbor and Kaiaka Bay were studied. Atrazine and ametryne do not appear to be a problem, however, because of its persistence in soils, diuron can be found in coastal sediments because eroded agricultural soils are transported with storm runoff.

Kahana Bay water contains about the lowest amounts of nutrients in coastal waters. The state standards for nitrogen and phosphorus were exceeded in all areas except for Kilauea, in the case of nitrogen, and McBryde, in the case of phosphorus.

The use of micromolluscs as an indicator organism was reported with a differentiation noted in species between coastal areas affected primarily by silting compared to areas affected primarily by nutrient input. In the former situation *Bittium zebrum*[4] becomes the major fauna component and standing crops and diversity values are conspicuously depressed. In the latter case, the community changes towards dominance by suspension feeding forms which depend on primary productivity[5] of the water columns. Also associated strongly with silted reef flats is *Obtortio pupoides*[6]. The response of an ecosystem to land-generated effects are changes in structure from a grazing herbivore[7] environment with associated frondose algae[8] to either a rubble associated ecosystem with few species or to a eutrophic[9] state with many suspension feeders and low diversity.

The principal changes in institutional arrangements noted in the project year are those resulting from the passage of the Federal Water Pollution Control Act Amendments PL 92-500. The effects of this legislation will be far-reaching and result in changes which include: new discharge permit requirements, reporting of operating and monitoring results for wastewater treatment facilities, a minimum requirement level of secondary treatment for municipal wastewaters, and industrial waste treatment effluent guidelines. The full impact of these and other changes is not yet apparent although some delays have incurred in regulatory actions and attempts to implement legislation.

[4]*Bittium zebrum:* micromollusc species of the Cerithiidae family

[5]Primary productivity: Photosynthetic and chemosynthetic conversion of solar energy to organic substances by producer organisms (primarily green plants) to be used as food materials

[6]*Obtortio pupoides:* Mollusc species of the Diastomidae family

[7]Herbivore: organism eating living plants

[8]Frondose algae: algae with leaf structures

[9]Eutrophic: rich in plant nutrients

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NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
ENVIRONMENTAL DATA SERVICE

DATA SHEET—DAILY VALUES

Station, Manoa (Beaumont) (State Key No. 712.1) Elevation 650 ft

Data, Precipitation -- Time of Observation: 8 a.m. (in inches)

1972	January	February	March	April	May	June	July	August	September	October	November	December	
1													
2													
3													
4													
5													
6	0												
7	0.41												
8	0.72												
9	0.09												
10	0.05												
11	0.02												
12	0												
13	0*												
14	0.02												
15													
16													
17													
18									0				
19									0.20				
20									0.23				
21									0.08				
22									0.09				
23									0.01				
24			0.10						0.16				
25			0						0*				
26			T ‡						0				
27			0						0.04				
28			0										
29			0*										
30			0										
31			0										
Sums													
Means													

* Sampling day. ‡ Trace.

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NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
ENVIRONMENTAL DATA SERVICE

DATA SHEET—DAILY VALUES

Station, Manoa (Beaumont) (State Key No. 712.2) Elevation 650 ft

Data, Precipitation -- Time of Observation: 8 a.m.
(in inches)

1973	January	February	March	April	May	June	July	August	September	October	November	December	
1													
2													
3													
4													
5													
6			0.20										
7			0.21										
8			0.23										
9			0.17										
10			0.13										
11			0.42										
12			1.70										
13			0.10*										
14													
15													
16													
17													
18													
19													
20													
21													
22													
23													
24													
25													
26													
27													
28													
29													
30													
31													
Sums													
Means													

* Sampling day.

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ENVIRONMENTAL DATA SERVICE

DATA SHEET—DAILY VALUES

Station, University of Hawaii (State Key No. 713) Elevation 80 ft

Data, Precipitation (in inches)

1972	January	February	March	April	May	June	July	August	September	October	November	December
1												
2												
3												
4	0											
5	0											
6	0											
7	0.05											
8	†											
9	†											
10	0.35											
11	0											
12	0											
13	0*											
14	0											
15	†								0			
16	†								†			
17	0.13								†			
18									0.03			
19									T ‡			
20									0.02			
21									T ‡			
22									0			
23									0			
24			0.08						0			
25			0						0*			
26			0						0			
27			0						T ‡			
28			T ‡									
29			T* ‡									
30			T ‡									
31			0									
Sums												
Means												

* Sampling day. † No data recorded since last rainfall. ‡ Trace.

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ENVIRONMENTAL DATA SERVICE

DATA SHEET—DAILY VALUES

Station, Manoa Tunnel (State Key No. 716) Elevation 650 ft

Data, Precipitation (in inches)

1972	January	February	March	April	May	June	July	August	September	October	November	December
1												
2												
3												
4												
5	0.36											
6	0											
7	0.68											
8	0.52											
9	0.06											
10	0.10											
11	0.08											
12	0.04											
13	0*											
14	0.04											
15	0.06								0			
16									0			
17									0.08			
18									0.18			
19									0.12			
20									0.02			
21									0.32			
22									0.26			
23									0.06			
24			0.02						0.20			
25			0						0*			
26			0						0			
27			0.12						0.28			
28			0									
29			0*									
30			0									
31			0									
Sums												
Means												

* Sampling day

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ENVIRONMENTAL DATA SERVICE

DATA SHEET—DAILY VALUES

Station, Waikiki Shell (State Key No. 717.2) Elevation 10 ft

Data, Precipitation -- Time of Observation: 8 a.m.
(in inches)

1972	January	February	March	April	May	June	July	August	September	October	November	December
1												
2												
3												
4												
5	0											
6	0											
7	0											
8	0											
9	0											
10	0											
11	0											
12	0											
13	0*											
14	T‡											
15	0.05											
16												
17												
18												
19									T‡			
20									T‡			
21									0			
22									0			
23									0			
24			0.01						0			
25			T‡						0*			
26			0						0			
27			0.01						T‡			
28			0									
29			T*‡									
30			0.01									
31			0									
Sums												
Means												

* Sampling day. ‡ Trace.

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ENVIRONMENTAL DATA SERVICE

DATA SHEET—DAILY VALUES

Station, Waikiki Shell (State Key No. 717.2) Elevation 10 ft

Data, Precipitation -- Time of Observation: 8 a.m.
(in inches)

1973	January	February	March	April	May	June	July	August	September	October	November	December	
1													
2													
3													
4													
5													
6			0.02										
7			T‡										
8			0										
9			0										
10			0										
11			T‡										
12			0										
13			0*										
14													
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19													
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21													
22													
23													
24													
25													
26													
27													
28													
29													
30													
31													
Sums													
Means													

* Sampling day. ‡ Trace.

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NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
ENVIRONMENTAL DATA SERVICE

DATA SHEET—DAILY VALUES

Station, Palolo Valley (State Key No. 718) Elevation 995 ft

Data, Precipitation (in inches)

19	January	February	March	April	May	June	July	August	September	October	November	December	
1													
2													
3													
4													
5	0.42												
6	0.02												
7	0.48												
8	0.28												
9	0.04												
10	0.04												
11	0												
12	0												
13	0*												
14	0												
15	0.02												
16									0				
17									0.04				
18									0.08				
19									†				
20									†				
21									†				
22									†				
23									†				
24			0						†				
25			0						*†				
26			0						0.33				
27			0.06						0.10				
28			0.02										
29			0*										
30			0										
31			0										
Sums													
Means													

* Sampling day. † No data recorded since last rainfall.

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NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
ENVIRONMENTAL DATA SERVICE

DATA SHEET—DAILY VALUES

Station, Palolo Valley (State Key No. 718) Elevation 995 ft

Data, Precipitation (in inches)

19 73	January	February	March	April	May	June	July	August	September	October	November	December	
1													
2													
3													
4													
5													
6			0.04										
7			0.34										
8			0.52										
9			0.02										
10			0.30										
11			1.86										
12			0.78										
13			0.52*										
14													
15													
16													
17													
18													
19													
20													
21													
22													
23													
24													
25													
26													
27													
28													
29													
30													
31													
Sums													
Means													

* Sampling day.

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NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
ENVIRONMENTAL DATA SERVICE

DATA SHEET—DAILY VALUES

Station, Paiko Drive (State Key No. 723.4) Elevation 10 ft

Data, Precipitation -- Time of Observation: 6 p.m.
(in inches)

19 72	January	February	March	April	May	June	July	August	September	October	November	December
1					0.02							
2					0							0.15
3					0							0.02
4					0							0.03
5					0	0						0
6					0.02*	0						0
7					0	0						0*
8						0.06						0.22
9						0			0			
10						0*			0			
11						0.10			0			
12									0		0	
13									0		0.02	
14							0		0*		0	
15							0		0		0.02	
16							0				0	
17							0.01				0*	
18							0				0	
19							0*					
20							0.03			0		
21								0		0.04		
22	0.72							0		0		
23	1.75							0		0		
24	3.60			0.02				0.03		0		
25	0.01			0				0.07		0*		
26	0			0				0.25*		0		
27	0.26			0				0.01				
28	0			0.03								
29				0.05*								
30				0.18								
31												
Sums												
Means												

* Sampling day.

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NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
ENVIRONMENTAL DATA SERVICE

DATA SHEET—DAILY VALUES

Station, Portlock Road (State Key No. 724.4) Elevation 6 ft

Data, Precipitation -- Time of Observation: 5 p.m. (in inches)

1972	January	February	March	April	May	June	July	August	September	October	November	December	
1					0							0.21	
2					0							0.04	
3					0							0.01	
4					0							0	
5					0	0						T‡	
6					0*	0						T‡	
7					0	0						T*‡	
8						0						0.15	
9						0			0				
10						0.02*			0		†		
11						0			0		†		
12									0		†		
13									0		†		
14							0.01		0*		†		
15							0		T‡		†		
16							0				†		
17							0				*†		
18							0				†		
19							0*				†		
20							0			0	0.05		
21								0.03		0			
22	†							0		0			
23	2.55							0		0			
24	6.31			0				0		0			
25	0			0				0		0*			
26	T‡			0				0.23*		0			
27	0.16			0				0					
28	0.01			0									
29				0.08*									
30				0.13									
31													
Sums													
Means													

* Sampling day. † No data recorded since last rainfall. ‡ Trace.

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DATA SHEET—DAILY VALUES

Station, Portlock Road (State Key No. 724.4) Elevation 6 ft

Data, Precipitation -- Time of Observation: 5 p.m.
(in inches)

19 73	January	February	March	April	May	June	July	August	September	October	November	December	
1													
2													
3													
4													
5													
6													
7													
8													
9													
10													
11													
12		0.03											
13		0											
14		T‡											
15		0											
16		0											
17		T‡		0.08									
18		0		0									
19	*			0									
20				0									
21			0.01	0									
22			0	0									
23			0.15	0					0.02				
24			0	0*			T ‡		0				
25			0	0.03			0		0				
26			0.03				0.06		0				
27			0.01				†		0.05				
28			T‡				0.03		0				
29					*		0		0.36*				
30							0		0				
31							0*						
Sums													
Means													

* Sampling day. † No data recorded since last rainfall. ‡ Trace.

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DATA SHEET—DAILY VALUES

Station, Kaalakei (State Key no. 724.6) Elevation 10 ft

Data, Precipitation -- Time of Observation: 6 a.m. (in inches)

19 72	January	February	March	April	May	June	July	August	September	October	November	December	
1					0								
2					0							0	
3					0							0	
4					0							0	
5					0	0						0	
6					0*	0						0	
7					0	T‡						0*	
8						0						0	
9						0			0				
10						0*			0				
11						0			0				
12									0		0		
13									0		0		
14							0		0*		0		
15							0		0		0		
16							0				0		
17							0				0*		
18							0				0		
19							0*						
20							.10			0			
21								0		0			
22	.60							0		0			
23	.95							0		0			
24	4.35			0				0		0			
25	0			0				0		0*			
26	0			0				.20*		0			
27	0			0				0					
28	.20			0									
29				T* ‡									
30				.25									
31													
Sums													
Means													

* Sampling day. ‡ Trace.

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DATA SHEET—DAILY VALUES

Station, Hawaii Kai (Kii Place) (State Key No. 724.11) Elevation 100 ft

Data, Precipitation -- Time of Observation: 6 p.m.
(in inches)

19 72	January	February	March	April	May	June	July	August	September	October	November	December
1					0							
2					0							.09
3					0							0
4					0							0
5					0	0						0
6					0*	0						.03
7					0	T ‡						.20*
8						.04						.20
9						T ‡			0			
10						T* ‡			0			
11						.05			0			
12									0		T ‡	
13									0		.04	
14							0		.11*		.05	
15							T ‡		0		.02	
16							.08				0	
17							0				0*	
18							0				0	
19							0*					
20							.12			0		
21								0		0		
22	.40							0		0		
23	2.60							0		0		
24	4.84			0				.02		0		
25	0			0				0		0*		
26	T ‡			0				.40*		T ‡		
27	.28		*	0				T ‡				
28	0			0								
29				0.07*								
30				.26								
31												
Sums												
Means												

* Sampling day. ‡ Trace.

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ENVIRONMENTAL DATA SERVICE

DATA SHEET—DAILY VALUES

Station, Hawaii Kai (Kii Place) (State Key No. 724.11) Elevation 100 ft

Data, Precipitation -- Time of Observation: 6 p.m.
(in inches)

1973	January	February	March	April	May	June	July	August	September	October	November	December	
1													
2													
3													
4													
5													
6													
7													
8	0.10												
9	0												
10	0												
11	0	0.02											
12	0	0											
13	0	0											
14	0	0											
15	0	0											
16	0	0											
17	0	0*		0.02									
18	0.02	0.04		0									
19	0*	0.03		0									
20				0.06									
21			0	0	0.33								
22			0.30	0	0								
23			0.12	0.04	0				0				
24			0	0*	0.10		0.10		0				
25			0	0	0		0		0				
26			0		0.07		0		0.03				
27			0*		0.86		0		0				
28			0.02		0.20		0.10		0				
29					0*		0		0.45*				
30					0		0		0				
31							0*						
Sums													
Means													

* Sampling day.

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DATA SHEET—DAILY VALUES

Station, Kahana (State Key No. 883) Elevation 800 ft.

Data, Precipitation (in inches)

1972	January	February	March	April	May	June	July	August	September	October	November	December	
1													
2													
3													
4													
5													
6													
7													
8					1.40							0.46	
9					†		†					†	
10				18.60	†		1.54					†	
11				†	†		†		0.21			†	
12				†	†		†		†			†	
13			0.22	†	†		†		†		6.08	†	
14			†	†	*,†		†		†		†	†	
15			†	†	7.42		†		†		†	0.81	
16			†	†			†		†		†	†	
17			†	10.50			6.40*		†		†	†	
18			*,†	†			†		0.34		†	†	
19			†	†			†		†		†	†	
20			0.68	*,†			†		†		2.60	*,†	
21				†			†		†		†	6.20	
22				†			†		†		*,†		
23				†			†		*,†		†		
24				9.30			0.86		†		†		
25									6.70		†		
26											†		
27											0.94		
28													
29													
30													
31													
Sums													
Means													

* Sampling day. † No data recorded since last rainfall.

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DATA SHEET—DAILY VALUES

Station, Kahana (State Key No. 883) Elevation 800 ft

Data, Precipitation (in inches)

19 73	January	February	March	April	May	June	July	August	September	October	November	December
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												
13												
14						†						
15						†						
16				10.20		†						
17				†		†						
18				†		4.80						
19				†		†						
20				†		*,†						
21				†		†						
22		†		†								
23		†		1.92								
24		†	0	*,†						†		
25		†	0	†						†		
26		5.98	0.01							†		
27		†	0.02							†		
28		*,†	0.03							†		
29			0.02*							1.16		
30			0.01							*,†		
31										†		
Sums												
Means												

* Sampling day. † No data recorded since last rainfall.

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NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
ENVIRONMENTAL DATA SERVICE

DATA SHEET—DAILY VALUES

Station, Kilauea (State Key No. 1134) Elevation 315 ft

Data, Precipitation (in inches)

1971	January	February	March	April	May	June	July	August	September	October	November	December
1												
2												
3												
4				1.87				0.25				
5								0.15				
6				1.19				0				
7				7.06				0.07				
8								0.56				
9								0.12		0.05	0.23	
10							0.69	0*		0.07	0.57	
11							0	0.08		0	0.10	
12							0			0.03	0.10	
13							0.02			0.03	0	
14							0			0*	1.79	
15							0			0	0.04*	
16						0.75	0			0	0.06	
17						0.02	0					
18						0	0.04					
19						0.21	0*					
20						0	0					6.37
21						0	0					
22			1.12			0.02						
23				1.13		0.03						
24			1.70	3.95		0.25						
25			2.75			0*						
26						0.04						
27												
28												
29												
30												
31												
Sums												
Means												

* Sampling day.

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U.S. DEPARTMENT OF COMMERCE
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ENVIRONMENTAL DATA SERVICE

DATA SHEET—DAILY VALUES

Station, Kilauea (State Key No. 1134) Elevation 315 ft

Data, Precipitation (in inches)

1972	January	February	March	April	May	June	July	August	September	October	November	December
1												
2			1.13	1.56								
3												
4												
5												
6												
7	0.11											
8	0.04											
9	0.02											
10	0.06											
11	0											
12	0											
13	0*						0.02					
14	0			2.15			0.77					
15	0.04			2.40		0	0.20					
16					0	0.03	0.05					
17					0	0.03	0.30					
18					0.02	0.19	0.16					
19					0.01	0.05	0.17					
20					0.13	0.10	0.17					
21		1.60			0.31	0.30	0.05					
22	2.64				0.05*	0	0.03*					
23	2.28				0.05	0.02	0					
24					0	0.01	0					
25						0.07						
26						0.05						
27						0.02*						
28						0.23						
29									1.87			
30												
31												
Sums												
Means												

* Sampling day.

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U.S. DEPARTMENT OF COMMERCE
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ENVIRONMENTAL DATA SERVICE

DATA SHEET—DAILY VALUES

Station, Kilauea (State Key No. 1134) Elevation 315 ft

Data, Precipitation (in inches)

1973	January	February	March	April	May	June	July	August	September	October	November	December	
1													
2													
3													
4													
5													
6													
7													
8													
9													
10													
11													
12													
13													
14													
15							0.07						
16							0.13						
17							0.10						
18							0						
19							0						
20							0						
21							0						
22							0						
23							0.03						
24							0						
25							0.11						
26							0						
27							0.06*						
28							0						
29							0						
30							0						
31							0						
Sums													
Means													

* Sampling day.

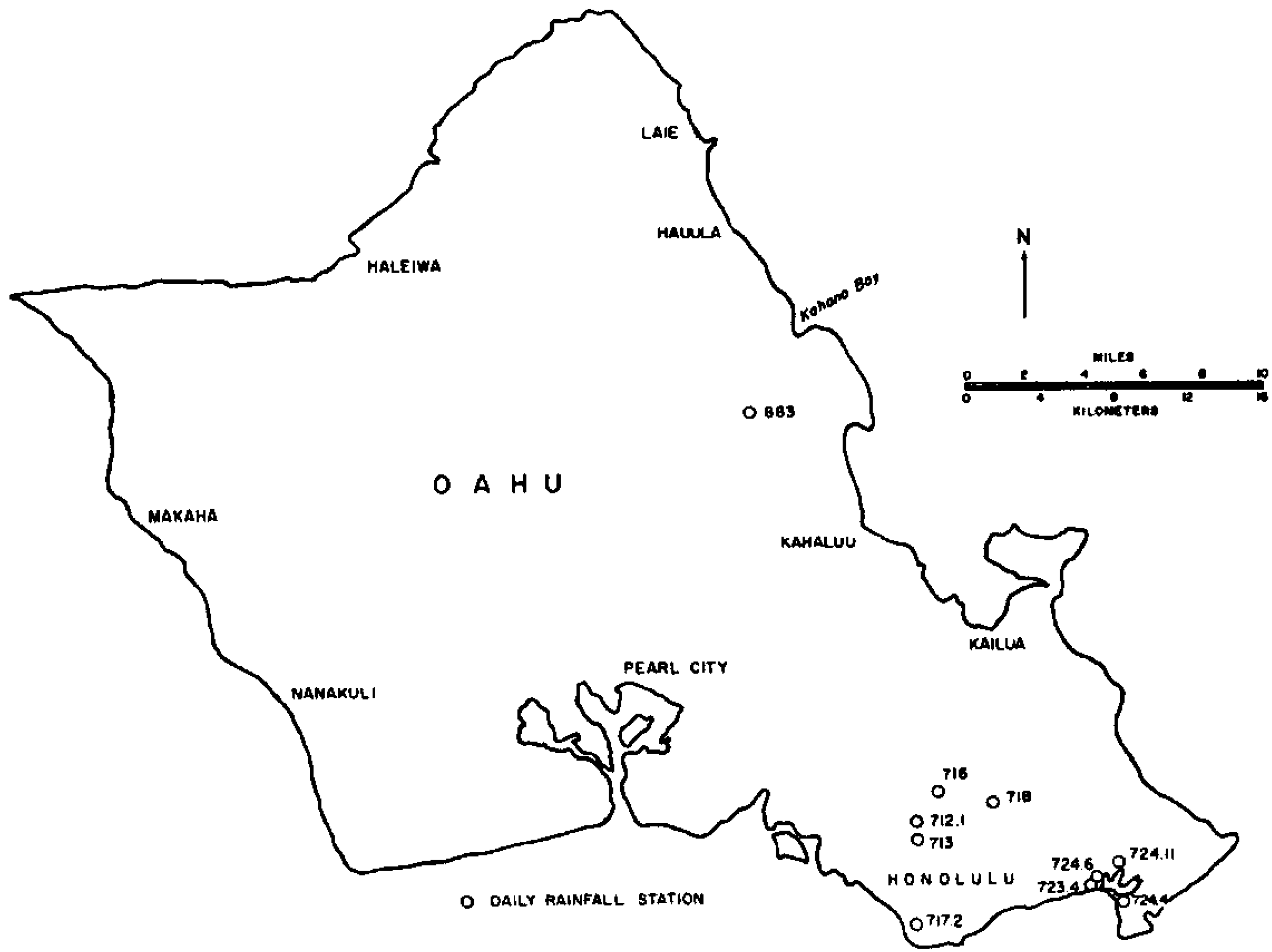

FIGURE D.1. DAILY RAINFALL STATIONS, ISLAND OF OAHU.

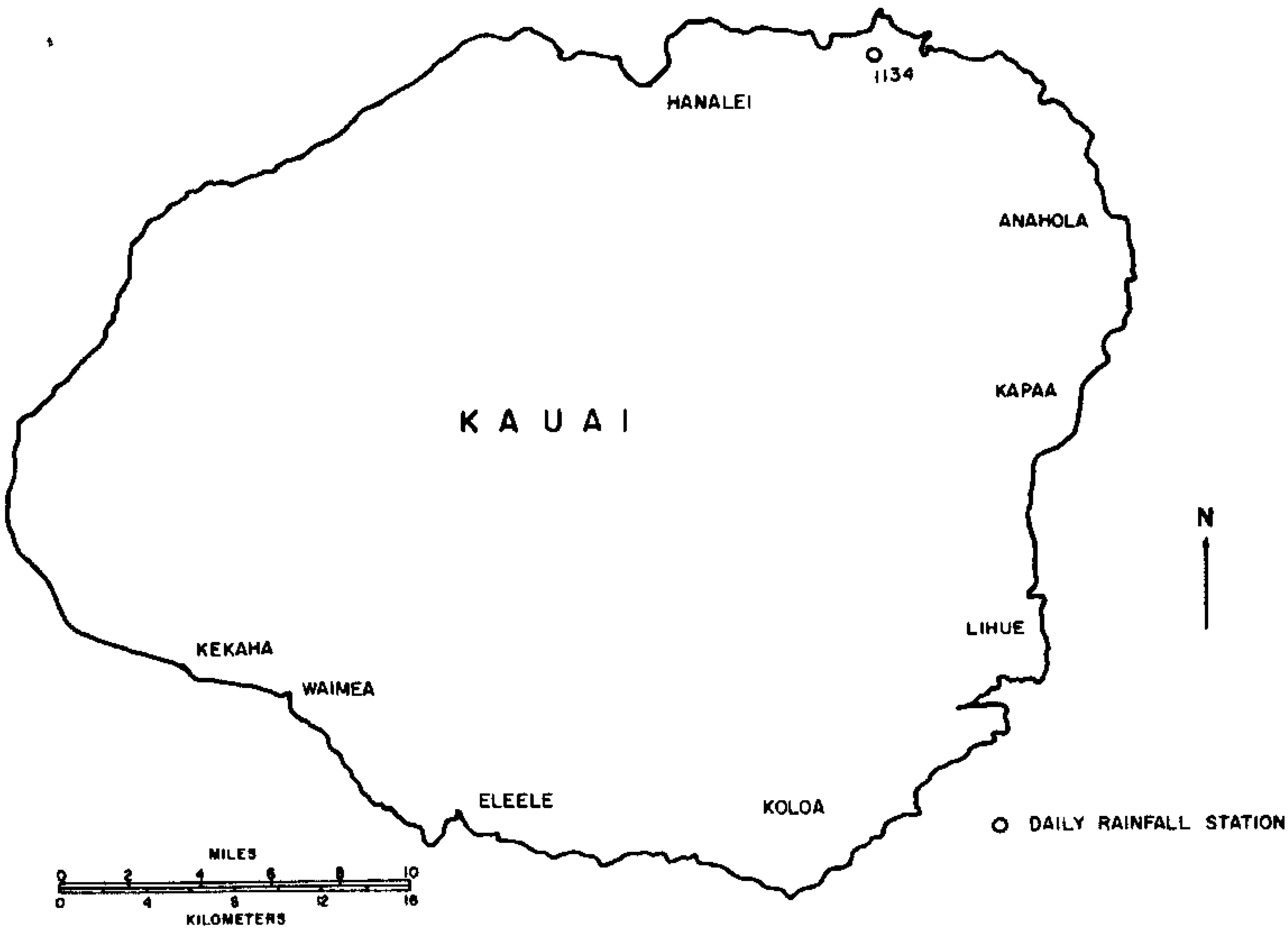

FIGURE D.2. DAILY RAINFALL STATION, ISLAND OF KAUAI.

APPENDIX E

Conversion of Units

English Unit	Multiplier	Metric Unit
acre	0.405	hectare, ha
acre-ft	1,233.5	cu meter, cu m
cu ft/min, cfm	0.028	cu m/min, m^3/min
cu ft/sec, cfs	1.7	cu m/min, m^3/min
cu ft	0.028	cu m
cu ft	28.32	liter, ℓ
cu in.	16.39	cu cm
cu yd	0.75	cu m
°F	0.555 (°F-32)	°Celcius, C
fathom	1.8	meter, m
ft	0.3048	m
gal	0.003785	cu m
gal	3.785	ℓ
gpd/acre	0.00935	cu m/day/ha
gpd/ft	0.0124	cu m/day/m
gpm	0.0631	liter/sec
inch, in.	25.40	millimeter, mm
in.	2.54	centimeter, cm
in.	0.0254	m
lb	0.454	kilogram, kg
lb/acre	1.121	kg/ha
lb/day/acre	11.2	kg/day/ha
mgd	3785	cu m/day
mgd/acre	9360	cu m/day/ha
mile	1.609	km
pcf	16.02	kg/cu m
psf	4.88	kg/sq m
psi	0.0703	kg/sq cm
sq mi	2.590	sq km
sq ft	0.0929	sq m
sq in.	6.452	sq cm
tons (short)	907	kg
tons (short)	0.907	metric tons
ton/acre	2.242	ton/ha

CONCENTRATION: LIQUID MEDIUM

ppm (parts per million) equiv. to milligram per liter at 4°C
ppb (parts per billion) equiv. to microgram per liter at 4°C
ppt (parts per trillion) equiv. to nanogram per liter at 4°C

CONCENTRATION: SOLIDS

ppm (parts per million) equiv. to milligram per kilogram
ppb (parts per billion) equiv. to microgram per kilogram
ppt (parts per trillion) equiv. to nanogram per kilogram