Hawaii Coastal Zone Management Program

technical supplement 2

Technical Considerations in Developing a Coastal Zone Management Program for Hawaii

HAWAII COASTAL ZONE MANAGEMENT PROGRAM

Technical Supplement No. 2

Management of Hawaii's Coastal Zone for Water Quality Objectives

by

Dr. Stephen Lau

This document was commissioned for the
State of Hawaii Department of Planning and Economic Development
by the
Pacific Urban Studies and Planning Program, University of Hawaii

The preparation of this report was financed in part
through a Coastal Zone Management Program Development Grant
from the United States Department of Commerce

August, 1975

MANAGEMENT OF HAWAII'S COASTAL ZONE

FOR

WATER QUALITY OBJECTIVES

P.H. McGAUHEY

L.S. Lau

WRRC Cooperative Report No. 4

Technical Supplement C to
Document 1:
Technical Considerations in Developing a Coastal Zone Management
Program for Hawaii
Pacific Urban Studies and Planning Program,
University of Hawaii

November 1975

WATER RESOURCES RESEARCH CENTER
University of Hawaii
Honolulu, Hawaii

PREFACE

This paper presents an overview of wastewater management as related to the quality of Hawaii's coastal waters. It is meant to be indicative, rather than exhaustive, in nature for planners and interested lay readers. It examines concepts for establishing an inland boundary of the coastal zone, and reflects some of the results of studies made during the course of the "Quality of Coastal Waters" project supported principally by the University of Hawaii Sea Grant Program during the years 1971 to 1975.

This report is a posthumous publication of the senior author. The first three chapters were completed in detail and the last three chapters up to the final draft form by both authors. The junior author undertook the responsibility for the completion of the manuscript in its entirety.

CONTENTS

FIGURES

TABLES

CHAPTER I

ENVIRONMENTAL AND INSTITUTIONAL ASPECTS OF HAWAII'S COASTAL WATER QUALITY

The Hawaiian Islands are small in size yet rise rapidly from sea level to high elevations. These facts in combination create an intrinsically intimate interaction between the land and adjoining coastal waters. The distance from the coast to the most remote inland point is 10.6 miles (17.1 km) for Oahu, 10.8 (17.4 km) for Kauai, 10.6 (17.1 km) for Maui, 3.9 (6.3 km) for Molokai, 5.2 (8.4 km) for Lanai, and 28.4 (45.7 km) for Hawaii. For the entire State, the percentage of land areas with elevation exceeding 2,000 ft (609.6 m) is 50.9%, and the percentage of area with slope exceeding 20% is 17.0 (Department of Planning and Economic Development 1969).

Influencing Coastal Features

Several major coastal features of the Hawaiian Islands which influence coastal zone management and coastal water quality considerations are: reef communities, varying shoreline characteristics, deep ocean water, low nutrient content in the ocean waters, and high circulation and energy levels of the coastal waters.

Offshore coral reefs (mostly fringing type) occur in the older islands such as Kauai, Oahu, and Maui. Reef building, by coral and algae, is one of the littoral processes that help shape terraces near sea level, thus creating shallow waters in the otherwise steeply cropping submarine topography that characterizes Hawaii. The reefs together with the shallow waters they confine, provide: a protective habitat for marine biota, supply of shell and coral detritus for beach buildup, and the marine resources for recreation. A few miles out from the shoreline, there is a steep submarine dropoff down to approximately 18,000 ft (5486.4 m) to the ocean floor which does not provide a biological substrate and opportunity for the accumulation of high nutrients in the ocean water as does the continental shelf of the mainland U.S. coasts.

Surface ocean currents, tides, and the dominant waves generated by the northeast trade wind affect Hawaii's open type shoreline configurations. Local thermo- and density-stratification of ocean water exists in Hawaii's coastal waters, close enough to the coast to permit utilization of the submerged field concept for sewage discharge from sewer outfalls.

Hawaii's white sandy beaches, formed of shell and coral detrital marine deposits from the reefs and reef platform, are world-known and provide a playground for Hawaii's people and tourists. Of the total 934.4 miles (1503.4 km) of tidal shoreline of the 6 major islands, 184.9 miles (297.5 km) are classified as sandy, with 24.4 miles (39.3 km) considered safe, clean, accessible, and generally suitable for swimming (DPED 1969, Table 8). Sea cliffs of varying heights constitute a part of Hawaii's coastline and provide some of the most spectacular sights, as well as sites for recreational shoreline fishing.

STREAM REGIME. Many streams, generally those on the windward side of the mountains and especially those portions originating in the high rainfall watershed, are rendered perennial by high level groundwater discharge and provide a habitat for aquatic biota. Perennial streams in Hawaii invite and, indeed, have been subjected to substantial diversion for various types of uses. Kahana Stream on Oahu, which drains an otherwise relatively undeveloped watershed, is an example.

Storm runoff draining into the Hawaiian coastal water is distinguished by its intensity and abruptness of occurrence. Its color and turbidity also set it off visibly from the clear blue ocean water. A unique flood hydrology arises from the intensity of storms, short stream courses, and the small size, and steepness of the drainage basin slopes (Wu 1969; Fok and Lau 1973). Thus, periodic land cleansings occur and exert a significant impact on the quality of coastal water and its ecosystems. The quality parameters discharged into the water include sediment, nutrients, toxic and other dissolved chemicals, and a salinity different from that of the coastal water (Chun, Young, and Anderson 1972; Matsushita and Young 1973). The impact of these quality parameters is accentuated in marinas and bays where the water circulation is weak and mixing is consequently poor.

Downstream Equivalent: Hawaii's Coastline. From a water quality standpoint, the conventional concept of "upstream sewage-today, downstream-drinking water-tomorrow" finds no application in Hawaii. Storm water in any specific situation, together with the water quality parameters it transports, reaches the coastline in a matter of hours, disperses in the coastal water, and exerts its influence over a certain specific reach of the shoreline. The population distribution in Hawaii parallels the coastline--the Hawaiian downstream equivalent--rather than being strung out along the course of the river, as is generally the case for mainland river basins. For that matter, Hawaii's navigable waters are, with only few exceptions, coastal rather than inland waters.

Groundwater Relation to Coastal Water Quality. Interchange between the ocean water and groundwater in the Hawaiian Islands manifests itself in such exchange phenomena as:

1. Salinity encroachment of the fresh groundwater (Ghyben-Herzberg lens) by the underlying salt water, both permeating the subsurface (Lau 1967)

2. Incursion of fresh or brackish groundwater, and the nutrients contained therein, into the ocean

Both exchange phenomena affect water quality, the second phenomenon affecting coastal water quality directly and marine biota indirectly.

Wastewater Management Practices

Coastal waters surrounding the islands of Hawaii traditionally served, and will continue to serve, as the ultimate sink for wastewater, either directly or indirectly. Point sources of wastewater discharge are the more obvious contributors of pollution. There are presently 142 points sources of the following types (Dept. of Health 1975):

1. Municipal sewage, both treated and untreated

2. Agricultural and industrial sources including irrigation tailwater, wash water, trash wash water, process water for sugarcane; thermal water and wash water for pineapple; thermal water from electrical power generation; and miscellaneous

3. Military installations, including both industrial and domestic wastewater

Most point sources discharge directly into open coastal water but some discharge into bays and harbors by way of open channels or by way of perennial or intermittent streams which empty quickly into the coastal water.

Nonpoint sources of discharges are also major contributors of wastewater into the Hawaiian environment. Unlike point discharges, their manner of discharge into the receiving water is diffused over an area. Examples of nonpoint sources in Hawaii are sediments eroded by heavy rain, storm runoff water from urbanized and construction areas, and cesspool seepage from unsewered homes.

In vogue since about 1970 is wastewater injection into the coastal subsurface groundwater by means of "effluent" injection wells (Takasaki 1974). As a rule, the natural groundwater flux in the subsurface moves towards the ocean. The injected water and quality parameters undergo dilution, dispersion, and chemical and biological reactions with the groundwater and the rock. Despite these processes, some of which are attritional and others contributional, some quality parameters will eventually be discharged into the coastal water. Knowledge defining these processes is presently meager for both the Hawaii basaltic rock and Ghyben-Herzberg lens (Peterson and Lau 1974).

Land disposal of treated effluent via irrigation water presents a possible alternative to ocean disposal in Hawaii. Irrigating sugarcane with effluent has been demonstrated to be promising in terms of the protection of groundwater and sugar qualities, and the maintenance of sugar and cane yields by a recently completed pilot field study on Oahu (Lau et al. 1975).

Concepts of Water Quality Criteria for Wastewater Disposal

A comparison of spectrum and concentration of physical, chemical, and microbiological quality parameters present in wastewaters with data on the same quality parameters in the receiving water may serve as a starting point for evaluating the impact of quality changes on the biota. From this premise evolved the "effluent standard" concept of water quality control, i.e., reducing the concentrations and eliminating certain quality parameters from wastewater, as guided by health and environmental criteria or standards, prior to disposal. However, it is generally recognized that natural processes in the receiving water can and do lessen or alter certain impacts of the discharge. This premise provides the primary basis for a "receiving water standards" concept, i.e., specifying the limits of concentration of various quality parameter standards not to be exceeded in the receiving water (McGauhey 1968). The State of Hawaii has adopted both types of standards.

Chapter 38 of the *Public Health Regulations* stipulates the effluent standards, and Chapter 37A the receiving water standards (State of Hawaii, Department of Health 1974).

As a general rule, the effects on biota of physical processes, such as dilution and dispersion of conservative (unchanging and nondissipating) physical and chemical parameters in the receiving water, are considerably simpler to determine than are those of biological processes leading to effects such as biostimulation and sublethal toxicity. The basic difference between physio-chemical and biological processes is reflected in the different level of the present understanding of the effects of these processes and poses a major difficulty in defining biological impact of any wastewater discharge today.

Present Institutional Arrangement

The State of Hawaii Department of Health (DOH) is the regulatory agency empowered by both the State of Hawaii and the federal government to exercise authority over water pollution control and wastewater discharges in the State of Hawaii. In matters where the federal government has primary authority, it serves as the intermediate agency between the principal federal water pollution control agency, Environmental Protection Agency (EPA), and the waste dischargers, which include municipalities, military installations, industries, and private entities. In matters where the State has full freedom of decision, it is the primary control agency. Its principal authority is set forth in detail in the State *Public Health Regulations*, (DOH 1974, chaps. 37, 37A, and 38). The regulation mode of the Department is essentially that of a permit and variance system. The original state permit system has been recently changed to NPDES (National Pollution Discharge Elimination System) permits to conform with federal regulations. Full exposition of the institutional framework for water quality control is being prepared by the DOH as a part of its overall environmental planning as well as the Hawaii Water Resources Regional Study (HWRRS) as a part of the nationwide level-B planning program under the Federal Water Resources Council.

The federal Coastal Zone Management Act (PL 92-583) enacted in 1972 is intended to develop a national program for the management, beneficial use, protection, and development of the land and water resources of the coastal zones. Coastal zone, as defined in the Act, means coastal waters and adjacent shorelands strongly influenced by each other and includes transitional and intertidal areas, salt marshes, wetlands and beaches. Furthermore, the coastal zone extends seaward to the limit of U.S. territorial seas and inland only to the extent necessary to control shorelands, uses of which have a direct and significant impact on coastal waters. Under the Act, state governments are the focal point for coastal zone management. The federal assistance enters by way of grants for development of a management program and for administration of the program. The National Oceanic and Atmospheric Administration (NOAA), U.S. Department of Commerce is the federal designated administrative agency.

The State of Hawaii has designated its Department of Planning and Economic Development (DPED) to administer the Federal Coastal Zone Management Act of 1972. This implies that its role in management of the coastal zone involves both coastal water and land. As is hereinafter demonstrated, wastewater generation and discharge into coastal water are intimately tied to land use and management practices. Hence, there exists a potential institutional overlap in jurisdiction between the DOH and the DPED as well as other agencies having authority over land uses, planning, and management.

CHAPTER II

REASONS FOR CONCERN REGARDING HAWAII'S COASTAL WATER QUALITY

Hawaii's coastal water environment provides a unique natural resource for year-round recreational activities which enhance island living, such as surfing, water skiing, sailing, swimming, snorkeling, scuba diving, and sport fishing. In addition, the scenic beauty of Hawaii's coastal and ocean environment attracts many visitors from all over the world. Thus, a very significant fraction of the State's economy derives from recreation, which in turn depends upon the safeguarding and enhancing of Hawaii's coastal resources and of its traditional island life style.

Because of its dependence on the quality of the coastal environment to maintain and propagate their species, the biota of Hawaiian waters constitutes another major reason for coastal water quality protection. The well being of aquatic life enhances both recreational and commercial activities, e.g., sport and commercial fishing, fishery research, etc. Many of Hawaii's residents have always enjoyed fishing both as a pastime and as a source of food for the family.

Some measure of the value of clean coastal water comes from contrasting Hawaiian coastal water and, hence, its quality, with those of two other places in the world: Piraeus, near Athens, Greece and Kaohsiung, in Taiwan, must be rated among the important shipping harbors in the world and are exceedingly valuable to commerce and industry for both countries; however, an inordinately low priority is placed on the quality of the marine ecosystem. Both harbors suffer from extremely weak circulation and receive apparently unlimited discharges of waste. The water environment is repulsive, the odor bad, and aquatic life virtually absent. In total, the water serves as nothing more than a shipping pathway and a waste receptacle.

CHAPTER III

CONCEPTS OF HAWAII'S COASTAL ZONE BOUNDARIES AND MANAGEMENT

One extreme concept holds that there are essentially no noncoastal areas in Hawaii because of the small land mass. The fact that the major islands of Hawaii are topographically high-rise islands is of no major consequence because it can be argued that there is nothing done by man upon these heights that does not directly affect the coastal land area and the adjoining coastal water and, therefore, that the entire island may be considered as a coastal zone and managed by a single coastal zone agency.

In the purest sense, the designation of coastal zone land hinges on whether the results of man's activities are so directly identifiable in detail that they can be controlled by coastal management techniques. Under this rationale, it is possible to consider that the high elevation of the central zones of the islands of Hawaii makes them noncoastal zones by the mere absence of human activity, except in a few instances, such as the astronomy observatory of Mauna Kea and the scattered homes on Tantalus. Moreover, at intermediate elevations, such as Schofield Barracks and the nearby pineapple plantations on the central plain of Oahu, the need for and nature of control of domestic wastewaters and agricultural practices could not be identified at the shoreline with such accuracy that a coastal management agency alone could replace the DOH and the Department of Agriculture (DOA), etc., in controlling the quality of wastewater released in these areas. Thus, in Hawaii the absence of man's activities is not the only measure by which to identify noncoastal lands. This point becomes obvious if one considers situations in the U.S. mainland, such as the zone between the Alleghanies and the Sierras. By no stretch of the imagination could one envision that water quality measurements and observations at the New Orleans delta area would enable the regulatory agency to manage intelligently the wastewaters from the cities, farms, and industries of America'a heartland. There, a number of agencies are responsible for controlling the quality of wastewater discharges and coastal zone management must be built around the realities of what legally enters the coastal zone. Thus, the noncoastal zones produce one of the factors a coastal zone agency must evaluate and recognize in management of the coastal zone.

From such considerations as the foregoing, we might distill a basic criterion that can be applied to Hawaii in relation to identifying a number of sectors of coastal land which should properly be designated as coastal zone land and, hence, subject to management by the coastal zone agency. For example, if one assumes that only high central land is noncoastal, the question of coastal zone limits lies in answering the question: Beyond what inland limits or boundaries, in any specific sector of the state under consideration, is it impossible to relate the quality of the land, water, and life of human or other living things, to what man does?

Under this assumption, the coastal zone agency would of necessity represent a super-agency which the DOH, DOA, the Board of Water Supply (BWS), etc., would serve by providing input data and enforcing requirements set by the super-agency. Obviously, neither the federal authorizing statute nor the legislature of Hawaii had anything of this sort in mind in establishing the Coastal Zone Authority.

It is therefore necessary to adopt a less all-embracing assumption and to answer instead the question: Beyond what identified line can coastal zone management techniques manage the land area of Hawaii only by disrupting other zonal considerations which may be equally, or more, important than those within the coastal zone?

The concept of a coastal zone by which land management protects coastal water quality involves inputs from noncoastal zones having other appropriate objectives postulates dividing the shoreline, with its adjacent 3-mile marine zone, into a series of sectors based on geography, public land use, recreation, value of aquatic life, and other factors. Each of these sectors would be a part of the coastal land zone comprising a Seaward Sector and a Landward Sector. But each might have a separate inland boundary based upon man's occupancy and activity on the land. This would mean that land management by agencies outside the boundary line would proceed as usual but inputs from the coastal zone management agency would be one of their considerations in controlling water quality discharges. Similarly, management of the given sector of a coastal zone would involve utilization of inputs from other land management entities, but the coastal zone agency would manage the particular sector for the optimal protection of the environment within that, and adjacent, sectors. For example, the DOH would supply most of the standards and other objectives which the coastal management agency seeks to achieve in the coastal zone; and the cooperation of inland management agencies would also be necessary to minimize objectionable water quality parameters flowing from noncoastal zones into coastal zones. Conversely, the coastal zone agency would have to accept agricultural and domestic wastewater effluents, as well as discharges from uninhabited land, in whatever condition proferred by inland management agencies (and nature). Similarly, the coastal zone agency would utilize as inputs to management, the regulations of the DOH and other state and federal agencies. Coastal zone management experience would most certainly feed back information to regulatory agencies which would aid in refining their water quality requirements.

In each sector, the management procedure would involve a realistic evaluation of the environmental factors to be considered as objectives in operating the management function: recreation, quality of human life, protection of aquatic life, development of economic enterprise, etc.

Characteristics and Management of Coastal and Noncoastal Land: A Conceptual Summary

Figure 1 illustrates that the coastal zone may be divided into two sectors: the Seaward Section and the Landward Section. The Seaward Section is envisioned as being primarily the indicator, or alarm zone, for the Landward Section, although it has resource materials in itself which are manageable without regard to the Landward Section. It involves the coastal habitat of diadromous fish, pelagic fish, benthic dwellers, as well as reefs and marine ferromanganese deposits of economic interest. It also involves areas suitable for aesthetic enjoyment only, beaches and parks, and marinas, each with its requirements for land management.

The Landward Section is intended to depict both intensive and nonintensive human development at various levels of sanitation, each of which produces point and nonpoint sources of wastes that may require special management in order to achieve the requirements and the objectives of the indicator (seaward) section of the zone.

A rough summary of the characteristics and management problems is included and stresses: (1) the interdependence of land management and water management agencies in some cases, and their essential independence in other situations; (2) the monitoring or indicating sector's health will call for the services of knowledgeable persons both inside and outside the responsible agencies, and for the maximum cooperation between all agencies; (3) the need for the information attained from, and the personnel who participated in, the "Quality of Coastal Waters" (QCW) project. One may say that the water and the ecology are among the objective functions without which the concept of Coastal Zone Management is reduced to the mere social problems of facilitating the getting along together of a lot of people in close quarters, while subscribing to a variety of sanitation standards.

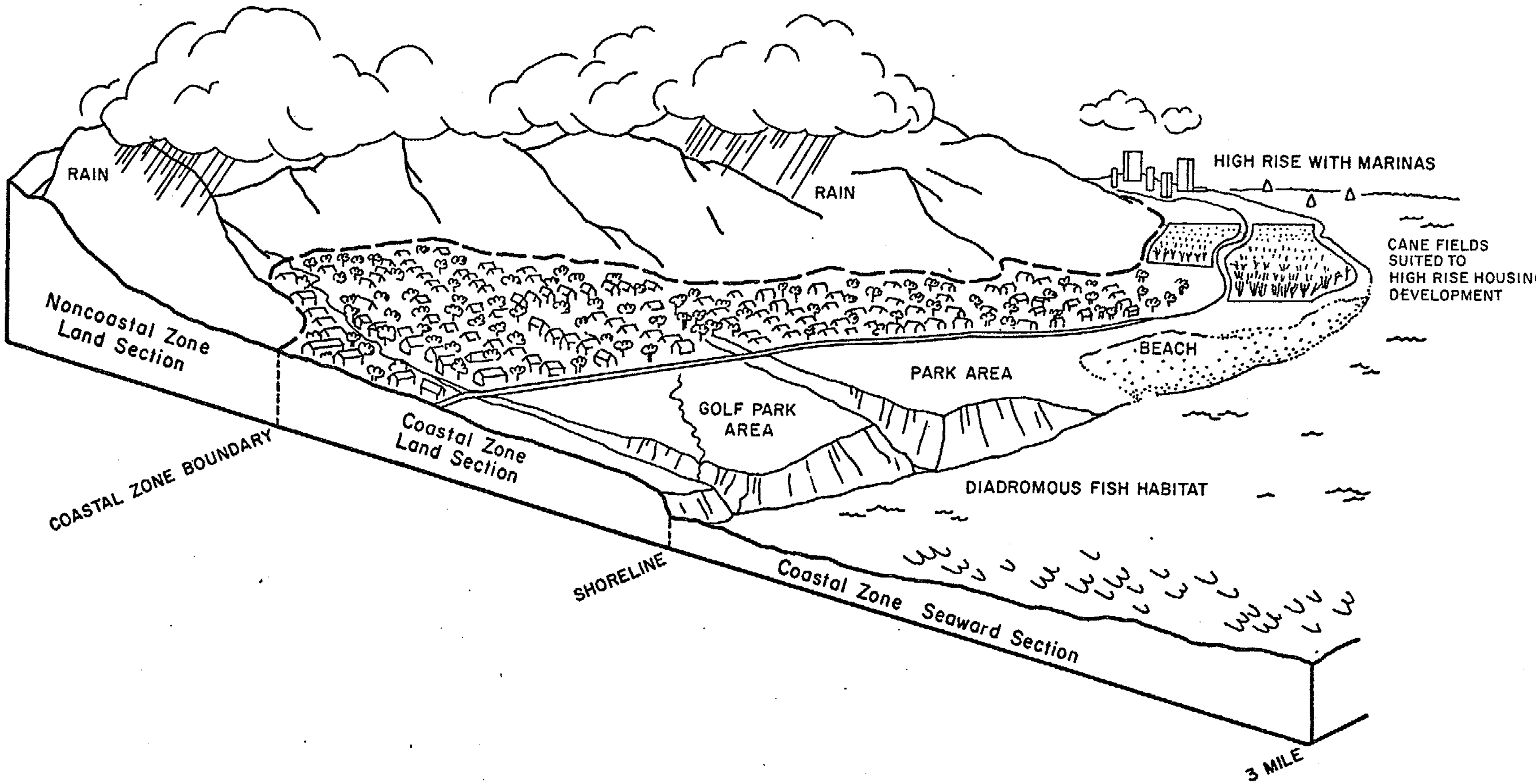


FIGURE 1. CONCEPTUAL COASTAL ZONE AND MANAGEMENT SCHEMATIC

LEGEND: FIGURE 1 COASTAL ZONE AND MANAGEMENT SCHEMATIC

NONCOASTAL ZONE

Characterized by:

1. Land little used by humans for agriculture, industry, or even recreation
2. Land dedicated to agriculture
3. Land occupied by subdivisions and towns
4. Large areas of nonpoint source infiltration of water which may reach the Seaward Section of the Coastal Zone either by surface runoff or underground seepage
5. Point source industrial and domestic wastes that are subject to release only after treatment. Degree of treatment and requirements not a function of the Coastal Zone Management objectives since in the matter of wastewater discharge the responsibility for water quality lies with a state agency other than the Coastal Zone Land Management agency.
6. Nonpoint sources, principally in the control of agricultural pests and forest management requirements for pesticides, which may or may not ever reach, or be detectable in, the coastal zone land or waters (and most likely not)

COASTAL ZONE

Landward Section

Characterized by:

1. Human occupancy in intense groups such as high-rise dwellings and associated services
2. Variable width from shoreline to zonal boundary; possibility in some instances of being essentially discontinuous except for a narrow roadway access and parking strip
3. Greatest area of population density of each island both in numbers of dwellings and occupants, variety of human activity, and, consequently, of pollutants which may:
   a. Damage the environment for human living
   b. Generate the greatest amount and variety of point-source pollutants
   c. Generate the greatest amount and variety of materials from nonpoint sources
   d. Seep into the Seaward Section waters and, if considered harmful, present the most difficult task of locating and controlling waste at its source

Major Significance:

1. The principal reason for dividing island into different types of zones for land management
2. Area in which greatest disagree-

Seaward Section

Characterized by:

1. Extend from shoreline to 3-mile (4.8 km) limit
2. Series of sectors of varying utility:
   Sand and coral materials
   Habitat for diadromous and pelagic fish
   Habitat for commercial food fishes
   Habitat for food chain organisms
   Recreational activities

Major Significance:

1. Resource materials characteristic of coastal waters
2. Sensor or indicator of pollution or contamination by:
   a. Seepage from waters entering ground in noncoastal area passing through cultivated or natural existing land areas containing soluble chemicals, i.e., seepage from nonpoint sources in noncoastal zone
   b. Seepage from waters entering ground in Landward Section of Coastal Zone and passing through refuse on surface of soil, buried refuse, fertilized land areas, gardens subjected to pesticides, etc.
   c. Surface runoff from nonpoint sources on noncoastal land
   d. Surface runoff from nonpoint

Management Problems:
Generally, the management of noncoastal land is directed to objectives beyond that of the Coastal Zone agency and, hence, is not readily assigned or resolved by any single land management agency which might be envisioned for all types of land within the State of Hawaii

This means that there is some point where the hazy boundary between coastal and noncoastal land is an inescapable fact, hence, there must be information feedback across this line both of a factual and a scientific nature.

In some instances, such as depicted in Figure 1, agricultural land may lie indisputably within the Coastal Zone. In this case, it is assumed that the Coastal Zone management agency will be the one with major jurisdiction, but that its decisions and guidance of an expert nature will have to come from outside the agency itself in creating a system of management that will not be destructive of agricultural economy, yet consistent with the water quality objectives of the Seaward Section of the Coastal Zone.

ment between people arises because of conflicting economic and societal reasons

3. Represents the critical zone as far as water pollution is concerned and, thus, is the zone in which greatest effort and most intelligent management must be obtained if the quality of coastal waters is to be maintained
4. Difficult to define absolutely because of population pressures which tend to force development of higher elevation lands, typically into the noncoastal zone least affected by nature and man
5. Imposes problems of land management for water quality and aesthetic purposes upon previously existing problems of health, zoning, and planning, thereby requiring either:
   a. A splitting of the responsibility of health and other existing agencies at the coastal zone boundary; or
   b. Creating a new agency or board with special duties and understanding of Coastal Zone land problems, which must work in harmony with existing agencies
6. Requires greater use than in the past of specialized knowledge of the effects of pollutants (from nonpoint as well as point sources) on the indicator area--the seaward section of the zone

sources on Landward Section of Coastal Zone

e. Direct discharges of debris into marinas
f. Refuse discarded on land at beach sites
g. Treated or untreated discharge from point sources on noncoastal land
h. Treated or untreated discharges from point sources in Landward Section of Coastal Zone
i. Debris or residues resulting from commercial development of mineral or biological resources within Seaward Section itself

Management Possibilities:
1. Subject to management to control results of direct exploitation or use of Seaward Section itself including, marinas and fresh water (and saline water) intrusions into Landward Section)
2. Serves principally as indicator of need for management of Landward Section or of noncoastal activities, and as a monitor of the effectiveness of land management measures in zones which affect it

Significance:
1. Represents the critical sector of the state, i.e., the principal objective of management of coastal and noncoastal land areas in Hawaii is the protection of the waters surrounding the island. Other societal ob-

7. Would seem to require that the state avoid any single approach to the coastal zone problem, i.e., the coastal zone should be divided into sectors for management purposes if the Seaward Section is to be more uniformly protected. (See accompanying discussion of the rationale.)

Management Possibilities:
The coastal zone management requires both maximum cooperation between all regulatory agencies in the state, plus greater use of consultant committees of water quality experts. Very careful definition and hard-nosed adherence to principles is needed.

jectives, such as visual harmony, and the results of overcrowding in terms of crime, lower quality of life, problems in high-rise living, etc., including public health, are important but are not the major reasons for a Coastal Zone Management Act per se

2. Because of the significance of the quality of water in the Seaward Section of the Coastal Zone, with which economic and other values of the aquatic environment are associated, the major management instrument of the Coastal Zone is the proper interpretation and implementation of the findings of the health, engineering, and biological team which assembled the QCW project

Coastal Water Quality Management through Coastal Zone Management: An Example for Identifying the Limit of Coastal Zones

Assuming that the State has established a Coastal Zone Authority for reasons of land use control and planning, and other appropriate functions, it becomes necessary to establish on rational grounds the appropriate landward limits of such an authority. To this end, and to the end of identifying the hinges in the water use system where such an authority might look with the purpose of protecting coastal water quality, Figures 2, 3, 4, and 5 have been prepared.

Figure 2 represents graphically a roughly isometric section through a hypothetical land area extending from the summit of a mountain range, and demarks the inland boundary of a drainage area, to the offshore 3-mile limit of the ocean receiving drainage from surface runoff and groundwater movement generated by precipitation on the entire area. It is not assumed that no other water quality pathways occur, but for planning and management purposes the concept is presumed to be adequate.

Note that Figure 2 depicts undeveloped mountain land, open space utilized as a park, agriculturally developed land (both at higher elevations and in the coastal plain), inland urban areas, coastal urban areas with an industrial center, urban park, swampy areas, airstrips, golf course, beaches, marinas, and commercial and recreational use of the seaward extension. Figures 3, 4, and 5, are detailed sections of Figure 2 and delineate land use by numbers.

Figure 3 represents the section of Figure 2 which does not properly belong within the purview of a Coastal Authority. Figure 4 then represents the landward sector of the coastal zone, while Figure 5 depicts the seaward extension of the coastal zone. Obviously, the zone line between the seaward extension and the land sector of the coastal zone is the water line.[1] The landward extent of the coastal zone, however, is determined less easily. It is established herein by the following criterion based on water quality: The Coastal Zone terminates at the line where the quality of water, or the degradation of the quality of water, is primarily the result of the activities of urban dwellers on the coastal plain which includes the valley flats.

There are other ways in which this criterion might be stated: for example, The landward limit of the Coastal Zone is that point beyond which water quality is the proper function of the State whose application of criteria and enforcement measures is general in application, rather than specific, to a particular geographic feature or a specific population concentration.

[1] According to the Environmental Shoreline Protection Act 176, SB No. 42 (State of Hawaii Eighth Legislature 1975), the "coastal zone" is defined as "...all waters subject to tidal influences extending seaward to the outer limit of state jurisdiction, and the land, water, and other resources therein and thereunder, and the adjoining lands extending inland to such boundary as determined by the state commission under this chapter."

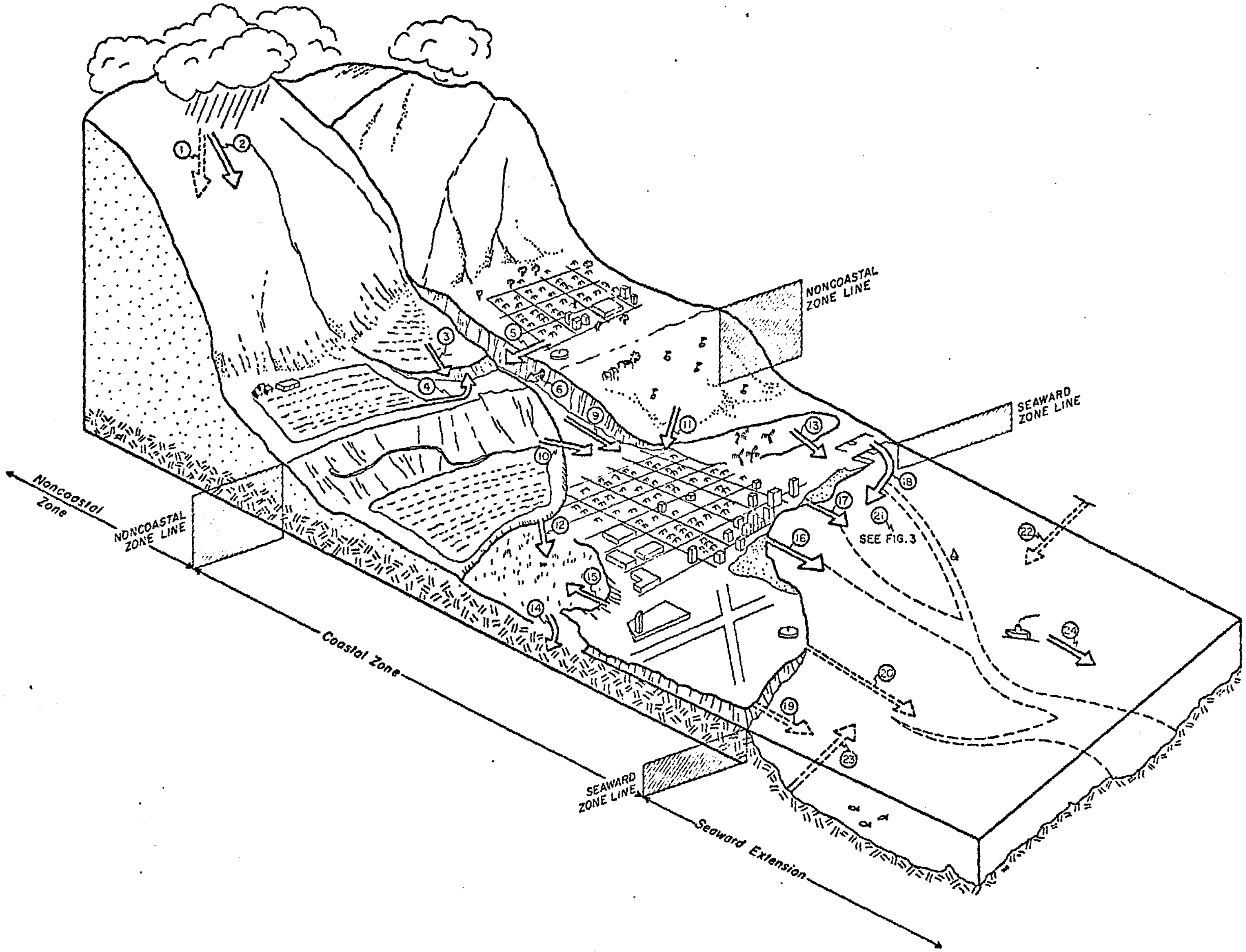


FIGURE 2. PRINCIPAL WATER QUALITY VECTORS IN COASTAL AND NONCOASTAL LAND SYSTEM

There are other, and perhaps better, ways to state this criterion, but its intent may be explained by reference to Figures 3 and 4. Note that Figure 3 passes along across the border of the noncoastal zone water which is of a quality determined by:

1. Surface runoff of rainfall on undeveloped land

2. Groundwater quality which is determined by geologic factors and by soluble materials applied during crop cultivation

3. Surface runoff from agricultural land, and from an inland urban area and its sewerage

Presuming that the surface wash from the city was unacceptable to ocean waters, or that the sewage was inadequately treated to be acceptable, or that farming practice was productive of excess silt and chemicals, whose responsibility might it be to correct such a situation? The criterion suggests that it is the responsibility of the DOH and related state agencies, acting either on their own initiative or on complaint from the Coastal Authority, to impose the regulations and the monitoring necessary to insure that water crossing into the coastal zone via vectors 7, 8, and 9, (Fig. 3) is of such quality that no further treatment is necessary on the part of the Coastal Authority to make it acceptable.

A further rationalizing of this criterion might result from a study of Figure 4, which is envisioned as within the coastal zone. Here management and use of the park land is a function of the Coastal Authority by reason that the activities of people, the presence and activities of which justified the creation of a Coastal Authority in the first place, are the determinant in the quality of water reaching the sea. The same may be said for the golf course. Agricultural crop land is a concern of the Coastal Authority because it lies in the coastal plain and its effects on water quality, although requiring the cooperation of other agencies, are subject to management under the zoning powers of the Coastal Authority, plus the location of its discharge in waters of importance to the local population. Similarly, surface runoff from the city park, the beaches, the airstrip, and the city streets are all under the proper control of the Coastal Authority -- obviously with the assistance and authority of the DOH, etc. The deterioration in surface water quality that entered the zone as vector 9 (Fig. 3), prior to its exit via vector 17 (Fig. 4), is a matter for concern of the Coastal Authority. Other vectors that are coastal zone matters and shown in Figure 4 are: treated sewage, vector 20; marina discharge, vector 18; groundwater seepage, vectors 19 and 21; surface runoff, vector 13; beach runoff, vector 16; and swamp discharge, vector 14. This is to say that the water quality discharges shown in Figure 4 are either the responsibility of the Coastal Authority, acting in concert with other state agencies, or there is no need to create the Coastal Authority.

At this point, it should be made plain that the Coastal Authority is not envisioned as usurping the role of the DOH and other state agencies which, by law, are responsible for water quality but, rather, as being the agency that spotlights the problems within the Coastal Zone so that societal and environmental objectives can be attained by cooperating authorities, and, more important, as leading the land use and land management effort of the state in the direction that enables the flow of water of acceptable quality across the bridges (or via the vectors shown in Figure 4 leading to the sea (Fig. 5).

Figure 4 stresses, by its mere barrenness, the fact that water quality control is a land use function. The vectors depicted here are peculiar to the sea itself, which must be added to those coming across the vectors of Figure 4, in evaluating the quality of the Seaward Extension of the Coastal Zone. Most important are: vector 24, which depicts the commercial and recreational use of the ocean waters; vector 25, which may be influenced by vector 14 (swamp) in Figure 4; and vector 22, which depicts the mixing of quality factors within the ocean itself.

KEY TO FIGURE 2, WITH PRINCIPAL QUALITY TRANSFERS

VECTOR NO.	NATURE OF WATER	TYPICAL MAJOR QUALITY PARAMETERS
1	Fraction of rainfall which infiltrates land surface	Dissolved gases from atmosphere; wind-blown dust particles (volcanic); and, possibly, gases from industrial activity, automobile and bus exhaust, etc.
2	Fraction of rainfall which runs off land surface	Same as vector 1, plus organic debris; soluble products of decaying organic matter; soil and rock detritus containing heavy metals and other minerals; bacteria.
3	Surface runoff from agricultural land (plantation), irrigation overflow	Same as vector 2, plus soil particles with possible adsorbed pesticide and fertilizer compounds; organic debris, possibly high in phosphates.
4	Surface runoff from agricultural land (truck crops), irrigation overflow	Same as vector 3.
5	Surface runoff from inland urban area, rainfall (vector 1), street cleaning; combating fires; lawn sprinkling	Materials such as vector 1: organic debris from vegetation peculiar to city; automobile gas and oil leaks, dust from worn auto tires, sidewalk and street litter, and animal excreta; coliform bacteria; general bacteria; virus.
6	Treated sewage from inland urban area	Increased concentration of chlorides, sulfates, bicarbonates, nitrogen compounds, coliform organisms, virus, etc.; BOD, COD, and other components of treated sewage, depending upon degree of treatment required by regulatory agency.
7 & 8*	Underground seepage	
9	Accumulation of vectors 2, 3, 4, 5, & 6 less fraction of all surface vectors infiltrating into the ground, and fraction of vector 1 which distributes itself anywhere on area drained by vector 9	Components of all vectors in system in unpredictable concentration and combinations.

*NOT SHOWN IN FIGURE 2; see Figure 3.

KEY TO FIGURE 2. Continued

VECTOR NO.	NATURE OF WATER	TYPICAL MAJOR QUALITY PARAMETERS
10	Runoff from natural land area and cover utilized as a public park	Organic debris characteristic of natural vegetation; human and animal wastes.
11	Surface runoff from golf course	Organic debris from greens; miscellaneous litter.
12	Surface runoff from agricultural land; irrigation overflow (see vector 4)	Same as vector 4, depending upon crop and irrigation practice, if any.
13	Surface runoff from city park	Materials characteristic of vector 11, excess irrigation water, including fertilizers; possible herbicidal and insecticidal material; litter and animal excreta from high-intensity use of land.
14	Discharge from tidal swamp; wetland crop cultivation	Water characteristic of vegetated marsh; components of vector 12 (irrigated or unirrigated agricultural crop land; surface runoff, vector 15 from industrial development and airstrip).
15	Surface runoff from industrialized land area; surface runoff from airstrip	Materials characteristic of vector 2; oils washed from paved surfaces; miscellaneous debris and chemicals lost by carelessness or design.
16	Surface wash from beach	Litter, food scraps, lotions, etc., used by people utilizing beach for recreational purposes.
17	Vector 9 plus surface runoff from metropolitan area, storm drains; and seepage from infiltration of rainfall into drainage system from overlying city surface	Characteristics described for vector 9 greatly increased in concentration and variety. Oils, grease, and debris washed from street surface; bacteria and viruses.
18	Debris generated by marina boats	Oils, paint, food scraps, litter, illegal use of toilets on boats, sea organisms (aquatic) incubated by confined waters of marina.
19	Underwater spring and seepage of groundwater	Characteristics of vector 1, plus infiltration from any or all inland areas, including the adjacent airstrip.

KEY TO FIGURE 2. Continued

VECTOR NO.	NATURE OF WATER	TYPICAL MAJOR QUALITY PARAMETERS
20	Underwater discharge of treated municipal sewage	Characteristics of treated sewage containing some industrial waste; nature and concentration depending upon degree of treatment imposed, monitoring schedule, etc. Fertilizers, bacteria and virus, and toxic materials most critical elements.
21*	Groundwater as vector 19 with different constituents.	Seepage similar to vector 19 but from different areas.
22	Water quality determined elsewhere, e.g., open ocean or other sectors of island Coastal Zone	Unpredictable except on basis of knowledge of circulation of currents and the nature of discharge from other adjacent sectors of the Coastal Zone land.
23	Water quality determined elsewhere, e.g., vector 14 (swamp discharge)	Similar to vector 22.
24	Pollutants resulting from commercial and recreational use of seaward sector of Coastal Zone	Oils, fish cleanings, food debris, human excreta, etc.
25†	Rainfall, as vectors 1 plus 2, in Figure 2.	Same quality parameters, as vector 1, this table.

*NOT SHOWN IN FIGURE 2; see Figure 4.
†NOT SHOWN IN FIGURE 2; see Figure 5.

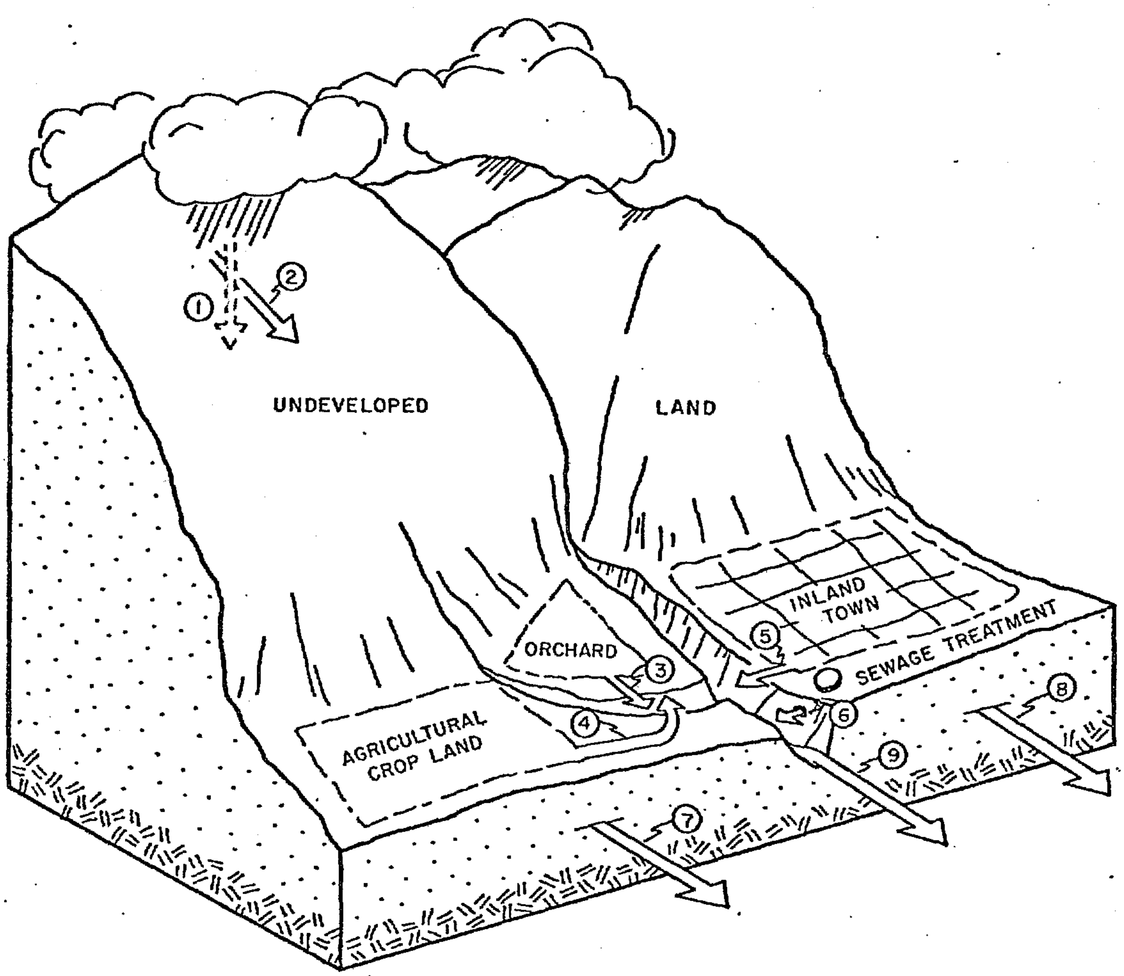


FIGURE 3. PRINCIPAL WATER QUALITY VECTORS IN A TYPICAL (HYPOTHETICAL) NONCOASTAL SECTOR OF A LAND SYSTEM

KEY TO FIGURE 3
SHOWING PRINCIPAL WATER QUALITY VECTORS IN NONCOASTAL SECTOR OF A LAND SYSTEM

VECTOR NO.	NATURE OF WATER	TYPICAL MAJOR QUALITY PARAMETERS
1-2	Precipitation	(See Key to Fig. 2, vectors 1 and 2; repeat in this table).
3-6	(See Key to Fig. 2; repeat in this table).	
9	(See Key to Fig. 2; repeat in this table).	
7	Seepage of groundwater beneath land surface.	Dissolved gases and minerals carried down by vector 1 passing through soil mantle and underground strata of undeveloped land, orchard, and agricultural crop land. (If vector 7 contains components unacceptable to ocean, correction is made under guidance of authorities other than the Coastal Authority via controls in agricultural practice, or, in any event, quality changes in vector 7 are not a responsibility of the Coastal Zone Authority).
8	Seepage of groundwater beneath land surface.	Dissolved gases and minerals carried down by vector 1 passing through soil mantle and underground strata of undeveloped land and inland town. (See note, vector 7, above).

KEY TO FIGURE 4
SHOWING PRINCIPAL WATER QUALITY VECTORS IN COASTAL SECTOR OF LAND SYSTEM

VECTOR NO.	NATURE OF WATER	TYPICAL WATER QUALITY PARAMETERS
9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 20	(See Key to Figure 2; repeat in this table)	
1 & 2	Precipitation presumed to fall on area represented by Fig. 2 to influence underground seepage of undeveloped land, etc., of Fig. 3, and by passage through park land, agricultural land, city, etc., shown in Fig. 6	
21	Underground seepage of water	Quality affected by nature of water entering zone via vector 8, Fig. 3, especially, plus infiltration on golf course, city park, and city areas of Figure 4.

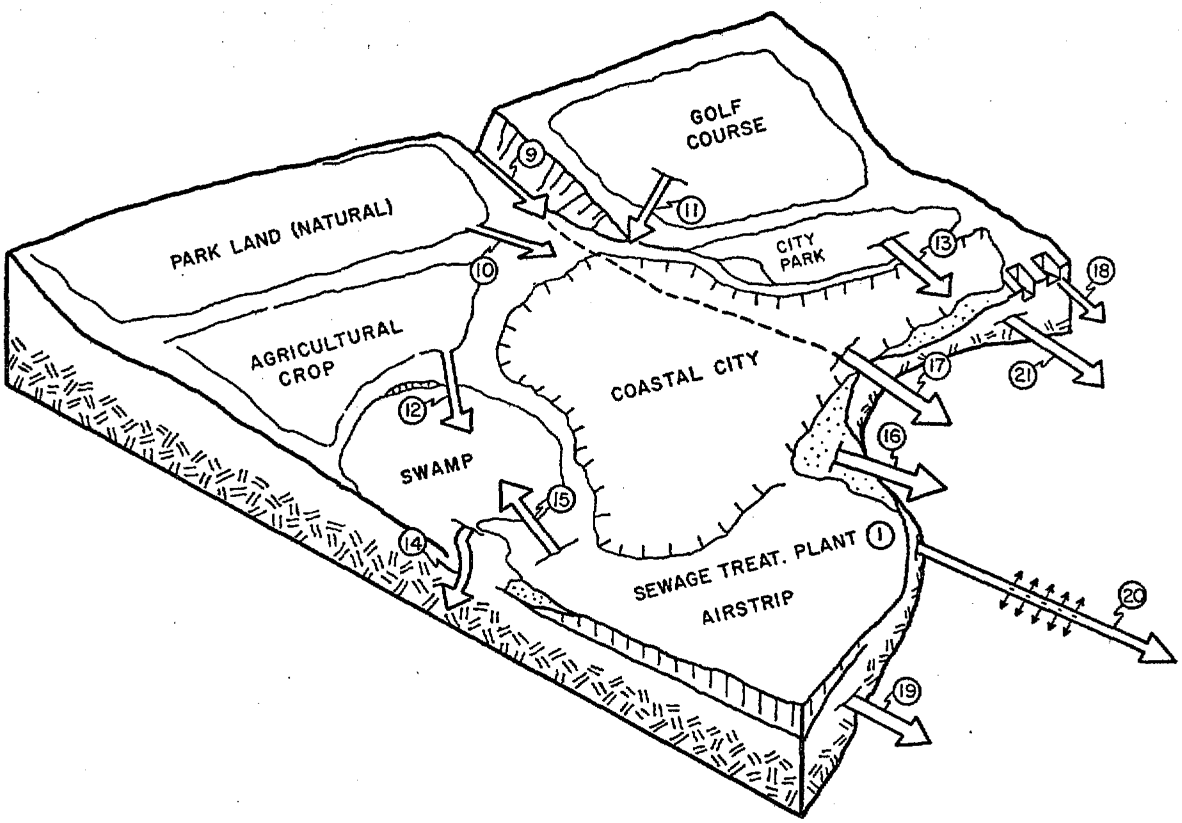


FIGURE 4. PRINCIPAL WATER QUALITY VECTORS IN A TYPICAL (HYPOTHETICAL) COASTAL LAND SECTOR OF A LAND SYSTEM

KEY TO FIGURE 5

SHOWING PRINCIPAL WATER QUALITY VECTORS IN SEAWARD EXTENSION OF LAND SECTOR OF COASTAL ZONE

VECTOR NO.	NATURE OF WATER	TYPICAL WATER QUALITY PARAMETERS
22, 23 24	(See Key to Fig. 2; repeat in this table)	
25	Precipitation, vectors 1 & 2 combined.	Fresh water; atmospheric gases; gases discharged to atmosphere by urban and industrial activity; volcanic dust and gases; windborne dust particles and bacteria; windborne soil particles containing heavy metals or absorbed agricultural chemicals.

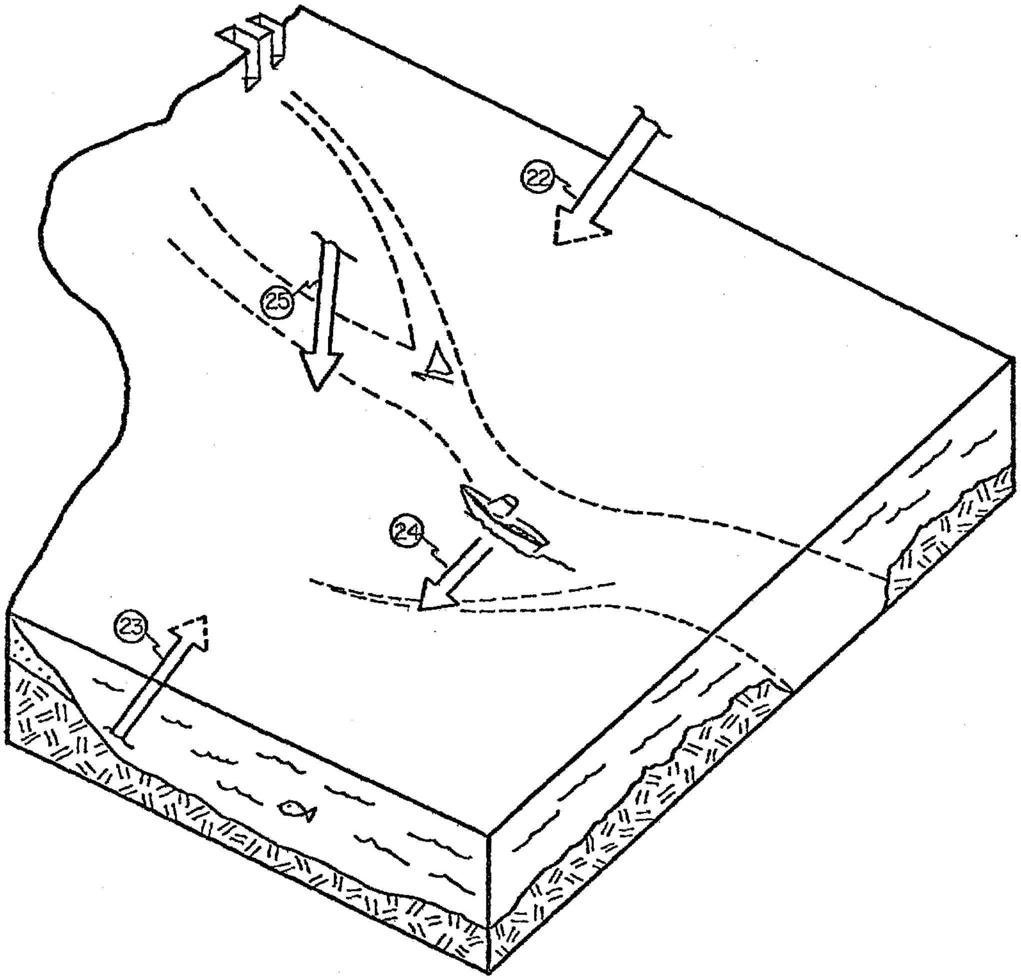


FIGURE 5. SEAWARD EXTENSION OF COASTAL ZONE SECTOR OF A LAND SYSTEM

CHAPTER IV

GENERATION OF WATER QUALITY PARAMETERS THROUGH LAND AND WATER UTILIZATION

Utilization of water and land resources in Hawaii's coastal zones for domestic, commercial, agricultural, and industrial purposes produces a great variety of wastes. Depending on the nature of each situation, the wastes produced contain water quality parameters such as soil particles, nutrients, thermal waste that differ from those in either quantity or quality, or both, present in the affected environment. In other situations, diversion of steam flow for water supply and concrete channelization of streams for drainage purposes not only changes the hydrologic regime but also the water quality parameters in the downstream estuaries and coastal water as well. Besides sources on land, wastes are generated from human activities within the seaward section. In what follows, the nature of typical waste generation resulting from activities in Hawaii's coastal zone is highlighted as a basis for examining coastal zone management for water quality objectives.

Hawaii Land Use Districts

Land uses in Hawaii are classified into four basic districts: agricultural, urban, conservation, and rural (State of Hawaii Session Laws of Hawaii 1961 Act 187).

AGRICULTURAL LAND. Agricultural lands are those with a high capacity for intensive cultivation. In Hawaii, agricultural lands are primarily used for cultivation of sugarcane, pineapple, and diversified crops, and for cattle grazing and forest.

URBAN LAND. Because of locational advantages, i.e., infrastructural benefits from economies of scale and short commuting distances, urban areas tend to take the form of a commercial and industrial core with a residential fringe. The land characteristics preferable for prime agricultural use are also desirable for urban development. It is not surprising that suburban developments such as Mililani Town, Pearl City Highlands, and Pearlridge threatens, or has already supplanted, agricultural uses.

RURAL LAND. The "rural" designation was established to permit small parttime type of farming and to include occupant's residence. As such, "rural" is defined as areas "primarily of small farms mixed with very low density residential lots."

CONSERVATION LAND. The State Land Use law established the Conservation District to: protect watersheds and water supply; preserve scenic and historic areas; provide parkland, wilderness and beach reserves; conserve endemic plants, fish, and wildlife; prevent floods and soil erosion; and protect forestry and related activities.

INSTITUTIONAL ARRANGEMENT. The State Land Use Commission, established by legislation in 1961, is charged to classify all land, public and private, and regulate its use throughout the State. Besides the Land Use Commission, administration of the Land Use law is the concern of the State Departments of Planning and Economic Development, Land and Natural Resources, and Taxation; the counties of Kauai, Maui, and Hawaii; and the City and County of Honolulu Planning Commission. Land uses within urban districts are administered solely by the counties. For agricultural and rural districts, the Commission establishes regulations and the counties are responsible for their administration. The counties may choose to adopt more stringent controls than those imposed by the State. The conservation districts are solely under the jurisdiction of the State Department of Land and Natural Resources. District boundaries may be changed by the Commission through a petition and public hearing process.

Coastal Zone: Land Section

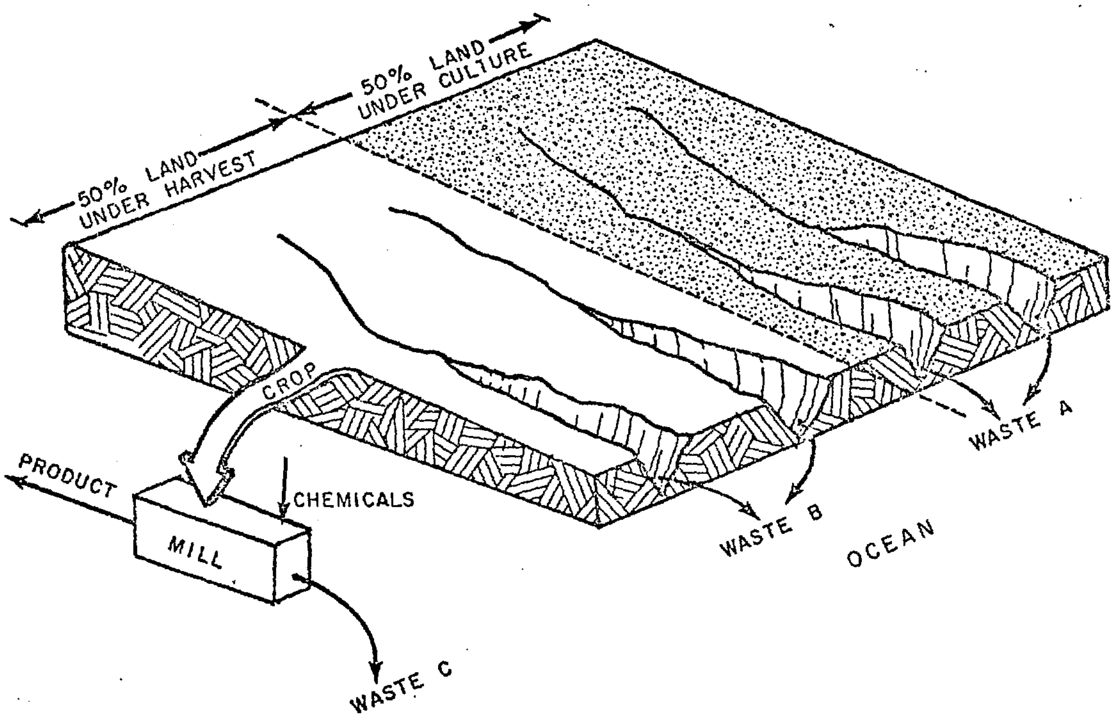
SUGARCANE. Agricultural land under sugarcane cultivation using furrow irrigation can generate irrigation tailwater (excess runoff from the furrows) which carries soil particles, residual fertilizer, and agricultural chemicals. During early growth and during and after harvest, the soils exposed are often transported by both rain or wind producing nonpoint sources of pollution during both cultivation and harvest as depicted in Figure 6. Process of the harvested cane at the mill produces cane wash water which is laden with silt and ash, trash (bagasse), and mill wash water, and rest room wastes. The mill wastes are point sources of discharge and when discharged into coastal water, the mill waste creates a turbid plume clearly visible for miles.

LIVESTOCK. In Hawaii, livestock consists principally of cattle, hogs, and chickens generating feed lot wastes as point sources. Feed lot wastes are high in nutrients (nitrogen, phosphorus and potassium), soil particles, and animal coliform bacteria (State of Hawaii 1971, Zone of Mixing Application: Inaoale Str., Waimanalo and Wailua, Oahu, 25 Aug. 1971). Overgrazing of land by cattle may indirectly increase the potential of soil erosion in grassland and forest and subsequent coastal water pollution. Pinpointing soil erosion to excessive grazing as the only cause is difficult, as botanists and foresters are perennially in dispute with game rangers and ranchers (Pereira 1973).

URBAN. This category includes domestic, commercial, and industrial land uses and their point and nonpoint sources of pollutants, or water quality parameters.

Storm runoff water carries wastes from lawns and streets and from cleared or uncleared vacant land. Water quality parameters thus transported may include fertilizers, pesticides, eroded soil particles, organic debris, street litter and trash, oil and gasoline spillage, animal excreta, and precipitated atmospheric pollutants. Storm runoff water is generally regarded as a nonpoint source for land management purposes even though some of the water is discharged into the ocean at specific points.

Wastewater from domestic, commercial and public areas is commonly known as sewage. Raw sewage contains pathogenic bacteria and viruses of human



SOURCE: Lau et al. 1972.

FIGURE 6. SUGARCANE INDUSTRY AS A WASTE GENERATING SYSTEM

origin, biostimulatory nutrients, salts, grease and other floatables, putrescible organic material, and grit. Raw sewage is one of the few most objectionable wastewaters in Hawaii, notwithstanding its nutrient content as fertilizers and water content or reuse. Even after secondary treatment, the treated sewage effluent still retains considerable amounts of nitrogen and phosphorus, viruses, and most of the salts. Most sewage discharges into the environment are through sewers and thus are regarded as point sources. The only sewage nonpoint sources are the scattered household cesspools allowing effluent to seep into the subsurface. While most collected raw sewage and sewage effluent have historically been discharged indirectly into coastal waters, some are discharged by way of streams or terminally into a reservoir. Of particular concern are those water bodies that seasonally run low or even dry, e.g., the upper tributaries of Waikele Stream on Oahu and Wahiawa reservoir, thus creating serious pollution problems.

Industrial. Industrial wastewaters vary greatly both qualitatively and quantitatively from one industry to the other. Fortunately, the so-called "dirty" heavy industries such as steel mills and chemical plants producing toxic substances are not of serious concern in Hawaii. A few petroleum refineries and wood treatment plants are about the only notable chemical plants in Hawaii. Electric power generating plants in Hawaii utilize great quantities of ocean or brackish waters or even some fresh water for cooling purposes. The same great quantities of water now heated are discharged into Hawaii's coastal waters such as at Kahe and Waiawa on Oahu. The high temperature of the thermal wastewater and certain chemical additives used for inhibiting metal corrosion represent potential polluting sources.

Processing of agricultural products and fisheries in Hawaii include sugarcane (Lau et al. 1973), pineapple (McMorrow et al. 1969), tuna (Chun 1968), and miscellaneous lesser crops. All of these process plants produce considerable biodegradable organic material, suspended material, and their own peculiar parameters such as grease from tuna wastes.

Construction. The grading, filling, and excavating phases of construction denude groundcover and expose soils which are wind-borne and transported in storm runoff, thus presenting a real problem to the quality of Hawaii's coastal and surface waters. The situation is aggravated by intense rainfall producing runoff water that as a rule rapidly drains into coastal water without any detention, natural or otherwise. An example of a problem area is the Hawaii Kai marina (U.S. Corps of Engineers 1975). Not only is the reddish, turbid coastal water aesthetically objectionable, but the sediment is also destructive to benthic biota and siltation presents navigational problems.

FLOOD CONTROL AND STREAM CHANNELIZATION. On Oahu, numerous small streams in metropolitan Honolulu and suburban areas are already, or will be, channelized for urban drainage of storm runoff water. For small watersheds with short stream length draining into the ocean, channelization as a flood control measure is a sound approach (Fok and Lau 1973). Tradeoff should be recognized, however, in that once drainage channels are lined with concrete and complete with hydraulic structures, channel runoff is accelerated and the natural habitat of aquatic life, such as diadromous fish, and aquatic plant life is lost.

DIVERSION OF TERRESTRIAL WATERS FROM COASTAL ZONE. An outstanding situation is the diversion of streamflow for irrigating sugarcane and other uses within or outside the watershed. This usually takes place upstream in the high rainfall area where streamflow is perennial under natural conditions. Depleting the streamflow, which would otherwise reach downstream and the coastal water, obviously would and did alter the stream drainage pattern, water quality, and biota in the downstream sections, as well as the salinity of and biota in the coastal water. Qualitative or quantitative impacts have not been assessed except in overall terms. Examples are found in west Maui, such as Iao; Molokai, such as Waikolu; and northeast Oahu such as Waiahole.

Another situation of diversion with less obvious effects on water quality is groundwater development intercepting groundwater which would otherwise reach the coastal water as spring discharges, diffused seepage, or via wetlands. The Kalauao spring area in east Pearl Harbor is an example of reduced discharge (Lau and Mink 1966); however, the impact of such diversions on coastal water quality has not been investigated.

AESTHETIC ENJOYMENT. Sandy beaches, open air and open spaces, lack of crowding, rocky cliffs, and colorful reefs with abundant reef life, are but some of the superlative amenities enjoyed in Hawaii and which must be safeguarded to retain desirable water quality parameters.

Coastal Zone: Seaward Section

Man's activities in the Seaward Section extending from the shoreline to the 3-mile limit may generate and unload wastes in the coastal water or alter or destroy marine resources in the process of resource utilization. Thus, a net benefit is necessarily the mode for evaluation. In Hawaii, the effects resulting from these activities range from major assets that require careful and thorough planning fully supported by the best of scientific knowledge to minor or negligible benefits that can be rendered reasonably innocuous by broad regulations and lax enforcement.

Given Hawaii's ocean orientation, the Hawaii shoreline is perhaps the most important locus for various recreational and commercial activities. Being the interface between the land section and the seaward section, the shoreline is most vulnerable to pollution by both land and sea activities. In what follows, several activities commonly present in the Hawaii coastal zone seaward section as listed in Table 1 are contrasted in light of their nature for generating wastes or altering marine resources both at the shoreline and in the coastal waters.

SIGHTSEEING, SURFING, BODY CONTACT WATER SPORTS, BOATING. These activities are of essentially nonpollution generating type except for littering. There is no evidence supported by statistical data that the Waikiki Beach water suffers from coliform contamination above the water quality standards (Lau et al. 1973). Motor boating in shallow waters will resuspend sediment and thus increase water turbidity and possibly nutrients in the water column.

BEACH PARK USES, SHORELINE FISHING, SHIPPING. Beach park uses generally produce litter which are generally more noticeable at the shoreline than in the coastal water. Shoreline fishing, as such, is nonpollution generating; over-fishing has decreased the catch on Oahu. Shipboard wastes can be a

TABLE 1

HAWAII COASTAL ZONE ACTIVITIES GENERATING WASTES AND ALTERING MARINE RESOURCES

ACTIVITIES	WASTE GENERATION			ALTERATION OF MARINE RESOURCES		
	Major	Moderate	Minor/None	Major	Moderate	Minor/None
SHORELINE						
Sightseeing			X			X
Beach park uses			X			X
Shoreline fishing			X		X	
Wave/current/sediment regulating structures			X	X		
Harbors (small boat)		X		X		
Harbors (military/ commercial)	X			X		
Marinas (urban residential)	X			X		
COASTAL WATERS						
Surfing & body contact water sports			X			X
Boating			X			X
Shipping		X			X	
Waste disposal	X			X		

problem depending on the stringency of the discharge control regulations and their enforcement.

WAVE/CURRENT/SEDIMENT REGULATING STRUCTURES, SMALL BOAT HARBOR. The construction of these coastal structures is destructive to the benthic biota at the project sites and change the local habitat of the marine organisms during and after construction. While regulating structures like groins do not produce wastes, shoreline activities in small boat harbors together with boating activities can be a moderate source of water pollution in the absence of stringent control regulations.

MILITARY/COMMERCIAL HARBORS, MARINAS, WASTE DISPOSAL. Construction of harbors and marinas undoubtedly alter the natural environment and destroy certain natural marine resources. The Pearl Harbor area undoubtedly has all the potential pollution generating activities because of its naval ship traffic, docking, and maintenance and repair facilities. In addition, Pearl Harbor receives both urban and agricultural surface runoff from Waikele Stream which drains the largest watershed on Oahu, several discharge sources of sewage treatment plant effluent, thermal wastewater, and sugarcane mill wastes. According to a recently completed modeling of Pearl Harbor (Water Resources Engineers 1974, 1975), water quality projections for Pearl Harbor indicate that only minor improvements in dissolved oxygen and nutrients and violation of water quality standards will likely continue, even with the elimination of all point source discharges.

Marinas, such as that at Hawaii Kai, receive only nonpoint sources discharge from essentially urban residential land use; however, water quality parameters, as nutrients (nitrogen and phosphorus) in the water column and pesticides in the sediment, are among the highest found anywhere in Hawaii and there exists a distinct gradation of concentrations of these parameters decreasing from the inland waters towards the ocean (Lau et al. 1973), thus reflecting the use of these materials in the adjoining coastal land and their contribution to the coastal water environment. Indeed, all harbors and the Hawaii Kai marina are classified as Class B waters, the lowest classification for Hawaii coastal waters.

Waste disposal through ocean sewer outfalls, such as Sand Island, discharging raw sewage at an average daily rate of 62 mgd (234,670 m^3/day) contributes major pollution to coastal water as already pointed out. Sludge or wastewater residue, however, is not separately ocean discharged in Hawaii.

CHAPTER V

STRESS INDICATIVE WATER QUALITY PARAMETERS FOR HAWAII COASTAL WATER ENVIRONMENT

The relationship between coastal zone land and water uses, and the coastal water quality and environment in Hawaii can be identified by obvious symptoms in severely mismanaged situations. For example, shoaling or delta forming in an abnormally short time span resulted from deposition of eroded soil from intense and rapid urban development of coastal land in certain parts of Hawaii Kai. Excessively and abnormally turbid coastal water, either in time or place or both is another obvious symptom of possible unsatisfactory activities of land and water uses. Fish and coral kills are even more dramatic and positive evidences. On the other hand, gradual water quality changes persisting over a prolonged period of several years can result in more subtle biological effects, such as changes in diversity and species abundance.

Either harmful or beneficial effects on the coastal water environment may result from man's activities on land and water in the coastal zone. Generally, however, the effects are harmful rather than beneficial because the activities producing them are generally narrowly exploitive in nature rather than planned efforts to intelligently utilize resources.

Wise coastal zone management will require early identification of warning signs of environmental stress which result from mismanaged situations, as well as an accurate evaluation of the nature and intensity of human activity which may be pursued beneficially.

To such an end, the "Quality of Coastal Waters" project examined various situations to discover facts and principles that are directly applicable to Hawaiian coastal waters. For example, it has been revealed that both sediment quality and the aquatic biota should be examined together with the water column. Certain quality parameters of the sediment were found to be more effective indicators than their counterparts in the water column in terms of more than just transient effects.

There are numerous quantifiable physical, chemical, and microbiological quality parameters in a coastal water column but only a few are particularly meaningful for indicating stresses. Point sources clearly should be subjected to effluent quality monitoring which will presumably take into account the characterizing of the quality parameters of the point sources, e.g., BOD for sewage effluent and temperature for thermal wastewater. However, these parameters may or may not be highly sensitive to indicate medium-term or long-term stresses as a result of the immediate attenuation offered by the dilution and dispersion of the coastal water, thus losing their value as an effective parameter for monitoring, e.g., BOD which becomes a virtually meaningless parameter for monitoring of open coastal water. Toxic chemicals should be included in an initial once-over baseline survey especially in coastal waters adjoining those land uses having known usages of these chemicals. This inclusion is recommended despite the sublethal level of these chemicals as is generally the case.

In all situations for monitoring of stresses in coastal waters subject to either point or nonpoint sources of pollution, several water quality parameters are judged to be essential or desirable as stress indicators for monitoring purposes as listed in Tables 2 and 3. Monthly sampling and analysis for these parameters should be sufficient for routine surveillance of coastal waters. Special areas, such as popular swimming beaches, should receive weekly checks on coliforms despite their disputable scientific validity as true contamination indicators. Intensive investigations may be conducted with more frequent sampling and determinations for both essential and desirable parameters and others as needed and as appropriate although not listed in these tables. Biological monitoring of coral, algae, mollusks, and fish by underwater observations and measurements may be less frequent and perhaps every three to five years even for intensive investigation of stressed or potentially stressed areas.

TABLE 2

STRESS INDICATIVE QUALITY PARAMETERS
OF COASTAL WATERS

	COASTAL WATER			
	Open		Partially Enclosed	
Parameters	Essential	Desirable	Essential	Desirable
Turbidity	X		X	
Salinity		X	X	
pH		X	X	
Temperature		X	X	
Total Nitrogen	X		X	
Total Phosphorus	X		X	
Dissolved Oxygen		X		X
Organic Carbon		X		X
Pesticides, Herbicides, Insecticides		X		X
Heavy Metals		X		X
Total Coliform		X		X
Fecal Coliform		X		X
Fecal Streptococci		X		X

TABLE 3

STRESS INDICATIVE QUALITY PARAMETERS
OF COASTAL SEDIMENT

	SEDIMENT			
	Open Coastal Water		Partially Enclosed Coastal Water	
Parameters	Essential	Desirable	Essential	Desirable
Pesticides	X		X	
Heavy Metals	X		X	
STRESS INDICATIVE BIOTA IN COASTAL WATER				
Micromollusc	X		X	
Coral	X		X	
Algae		X		X
Invertebrate		X		X
Fish		X		X

CHAPTER VI

MANAGEABILITY OF SOME HAWAIIAN COASTAL ZONE SITUATIONS

Averting undesirable situations is preferable to having to correct them. During the past few years, experience gained in Hawaii has revealed that the former may indeed be possible for a limited number of situations. On the other hand, there are present management measures or the lack of any measures, for other situations concerning Hawaii's coastal zone that may impart serious consequences because of the dearth of pertinent scientific data and information to evaluate the management measures. In either case, i.e., either the manageable situations or the poorly defined situations, warrant continuous and thoughtful analysis and studies that will demonstrate the adequacy or inadequacy of knowledge and the urgency of research needs.

Manageable Situations

DOMESTIC SEWAGE. Discharge of domestic wastewater into the coastal water environment even after secondary treatment poses a major potential problem. The problem would arise if the discharges were made in near shore shallow water of restricted circulation and within the reef. Indicators of the problem are: (1) increase in turbidity, (2) increase in nutrients and primary productivity with the possibility of eutrophication, (3) buildup of a benthic sludge bank and destruction of corals (if present).

A near classic example of this situation is the discharge of secondary sewage effluent into the southern section of Kaneohe Bay. There the above indicators became especially evident. The final decision made for corrective measures after two intensive studies (City and County of Honolulu 1972; Cox et al. 1973), was the relocation of sewer outfalls and, hence, diversion of the sewage effluent discharges outside the bay and transmission to Mokapu Point, a location of open coast with strong and predominantly offshore ocean currents. The Mokapu Point ocean outfall extends about a mile from the shore in 105-ft (32-m) deep water and is designed to provide high initial dilution of effluents plus dispersion by ocean currents.

Discharge of large quantities of raw sewage or even primary-treated sewage can be a problem even for open coastal areas, if the adjoining coastal waters are intended for recreational uses such as, surfing, swimming, and snorkeling. A classic example is the existing Sand Island sewer outfall which discharges raw sewage at the average rate of 62 mgd (234,670 m^3/day) collected from the entire Honolulu coastal plain from Niu Valley to Halawa Valley. Although the average net transport by coastal currents is off-shore, the proximity to Waikiki and Ala Moana Beaches and shoreward shifting ocean currents and wind require immediate corrective measures to eliminate the slightest chance of beach pollution. The adopted measures include treatment of the sewage and extension of the outfall 9,120 ft (2778 m) from shore and into deeper 240-ft (73.2-m) water which favors submersion of the discharged sewage below the ocean surface and offers initial dilution plus dispersion by ocean currents.

These two examples represent but a glimpse into the wide range of situations where engineering management of wastewater calls for systems that can be specifically designed for the situation (McGauhey 1968).

Water recycling of sewage effluent by irrigation represents a real and acceptable alternative for many situations for Hawaii. In 1975, the rationale for recycling is clear: provide an alternative for ocean disposal, and conserve natural water resources. A 3-yr pilot field investigation recently completed by the University of Hawaii Water Resources Research Center cooperating with sugarcane and public works agencies on Oahu has demonstrated the acceptability of using secondary sewage effluent for irrigation of sugarcane fields and grassland (golf courses) without endangering the subsurface potable groundwater supply from contamination by viruses and salts and without necessarily decreasing the sugar yield. (Lau 1975; Lau et al. 1974; Dugan, Young, and Lau 1974). Thus, land disposal of sewage effluent in Hawaii has become a new management alternative.

GENERATION AND DEPOSITION OF SEDIMENT. Generation and deposition of sediments can occur by water transport during the clearing stage of land development, or during construction and grading prior to landscaping for any development, e.g., housing, highways, and other transportation systems. A recent example of severe silting in coastal water was the result of an intensive urban residential housing development in a valley adjoining the Hawaii Kai marina. Eroded soil has formed thick and extensive shoaling in a formerly navigable marina channel within two to three years. This situation could have been manageable by practicing vegetal or structural soil conservation methods, using desilting traps, and enforcing and implementing more stringent grading ordinances. Presently, dredging is being considered as a temporary corrective measure.

TOXIC CHEMICALS USED IN URBAN RESIDENTIAL LAND. Coastal waters of restricted circulation, such as a marina or a bay abutting urban residential areas, represent a potential toxic chemicals problem in the water and particularly in the sediment. According to QCW project findings, high levels of dieldrin and α and γ chlordanes (used in termite control pretreatment during construction), DDT, DDE, and DDD, were present and predominated in the coastal sediments even in an area of dry climate where dry weather flow of water does not always occur as a transporting agent. The concentration of the insecticides in the marina sediment was much higher than that found in the adjacent coastal sediments. The fate of the insecticides is not exactly known at this state of knowledge; however, there is preliminary evidence that they are biologically available to aquatic fauna, such as certain fishes and especially the benthic or bottom-dwelling organisms, such as crabs, worms and shrimps (Lau et al. 1973). Dieldrin, and α and γ chlordanes have been banned recently by the EPA as DDT was a few years ago.

Heavy metals, such as lead, are present in exceptionally high concentrations (several tens of ppm) in Hawaii's coastal sediments. However, it is known that the Hawaiian soils and rocks, as well as automotive fuel containing lead, are principal sources of lead present in coastal sediments. Similarly, other heavy metals, including copper, zinc, chromium, and nickel are also soil-originated.

The exact origin of mercury and cadmium found in the coastal sediment is uncertain; however, urban storm runoff discharging into the Ala Wai Canal, contains biologically available mercury, a fact reflected in the increased mercury content in shrimp and worms present there after storms (Luoma 1974). Management techniques directly applicable to this situation have not been developed.

SANITATION PRACTICE IN URBAN LAND. Litter, grit, animal excreta, plant cuttings, and trash collection residues are removable items in the program designed to eliminate nonpoint sources of water pollution. This can be rigorously practiced and enforced as is done in Singapore (ca. 1973). Catchment basins which receive these street-swept refuse materials must, however, be cleaned out frequently in order to be effective.

Automobile gas and oil spill, exhaust, and other less visible materials are far more difficult to control. Inventory and quantifications of these materials are unavailable for Hawaii conditions.

AGRICULTURAL LAND: MANAGEMENT OF TAILWATER FROM SUGARCANE IRRIGATION. This represents a manageable situation as has been demonstrated on the McBryde sugarcane plantation on Kauai by flattening the furrow slopes and using settling-evaporation ponds located at the lowest end of the furrow irrigation system and also at likely discharge points into adjoining coastal water. About 70 ponds are presently deployed over a coastal zone spanning 13 miles (20.9 km) and have been demonstrated to be effective (Lau et al. 1973). Their simple construction poses no special initial cost. Sediment accumulated in the ponds is periodically dredged out and reclaimed in the fields.

AGRICULTURAL WASTE MANAGEMENT: SUGAR MILL WASTES. The Kilauea Plantation sugar mill wastes cited earlier represented the ultimate severe point source of agricultural waste in Hawaii. The complete elimination of mill wastes after the plantation's closure in 1971 aided by heavy seas is responsible for the rapid and nearly complete recovery of the coastal water quality and the associated beach environment within one year (Lau et al. 1973).

Another major control measure at McBryde is the use of a hydroseparator followed by retention in a mill reservoir to settle out the sediment from the sugarcane wash water and to recycle the liquid to the irrigation system and the soil back to the field. On the Big Island's Hamakua Coast, the present harvesting practice will be substituted with a dry harvester, thus, eliminating much of the soils and wash water from the mill wastes. Bagasse is being used as fuel for power generators, thus, eliminating another source of waste.

Clearly this is a manageable situation with an acceptable economic expenditure for industry.

SHORELINE STRUCTURES. Piers, jetties, breakwaters, and harbors can be potential problems if coastal water quality is not included as a primary design parameter by ocean or coastal engineers. Environmentally detrimental effects caused by waste discharge into poorly circulating waters created by structures have been cited for Piraeus, Greece and Kaohsiung, Taiwan. In such cases where the competing uses are keen, coastal water quality objectives are compromised; however, the coastal water quality should not be sacrificed to the degree that result in health hazards and total environmental degradation.

SHIPBOARD DISCHARGES AND OIL SPILLS. Oil spills, either in harbors or in open coastal waters, represent problem-prone situations as have been demonstrated time and again. The Smithsonian Institute has now established an inventory and instant reporting system of these type of disasters (Smithsonian Institution 1975). It is unlikely that these types of accidental discharge are totally preventable, but corrective measures for containing their spread and recovery or removal of the spill are available or being developed. Hawaii would benefit, not so much by developing its own measures, but by keeping track of the technological development for testing and possible adoptation in Hawaii.

SPECIAL USE DESIGNATION: HANAUMA BAY. Hanauma Bay is both a state park and a marine conservation district. It is a popular recreational area because of its natural attributes and proximity to Honolulu. It provides a natural habitat for seaweed, fishes, coral, crustaceans, and other organisms. Body contact sports include snorkeling, skin diving, swimming, and underwater photography. Hanauma Bay was designated a marine conservation district in 1967 to protect the diverse marine life from excessive exploitation. Restrictions prohibiting the taking of any aquatic flora and fauna, or substrate materials were imposed allowing marine life to be only viewed and photographed. With this protection, fishes, corals, and other marine life have flourished while the bay continues to serve as a prime recreation area. This protected use situation provides an example of good management of coastal resources.

INSISTENCE OF NATIONAL UNIFORMITY. Prior to the enactment of the Coastal Zone Management Act, Hawaii suffered, and is still suffering, from the lack of institutional flexibility at the federal government level. Ignorance of, or disregard for, Hawaii's unique and distinctive natural environment and insular position within the largest ocean in the world, make it quite different from the other 49 states and therefore, should not be expected to conform absolutely and uniformly in every respect to PL 92-500. This was pointed out with the Sand Island sewer outfall where all scientific facts indicate adequacy or advanced primary treatment, while the federal government insists on national uniformity of secondary treatment. The issue requires unnecessary expenditure, and not environmental protection.

Poorly Defined Situations

SUBSURFACE TRANSMISSION OF WATER QUALITY PARAMETERS. Scientific knowledge and data on the water quality effects of seepage from cesspools and effluent from injection wells, are presently inadequate to predict dilution and dispersion that will take place from the point of discharge to its final destiny in the adjoining coastal water. Situations unique to Hawaii are the Ghyben-Herzberg lens and the permeable basaltic rock. Intensive research is now in progress to help define and predict these water quality effects.

AIRBORNE QUALITY PARAMETERS. Another example of Hawaii's uniqueness are the live volcanoes which emit fumes of little known quality parameters. Mercury and sulfur have been identified in the airborne emission (Siegel and Siegel 1975; WRRC 1975). Also suggested as being air-borne are other heavy metals (H. Y. Young in WRRC 1975). Motor vehicle pollutants (exhaust gases, suspended particulates, and carbon monoxide) are highly concentrated in certain parts of the urban areas of Honolulu. Whether natural or man-made, these quality parameters should be identified and quantitatively defined in terms of water quality effects.

SEWAGE-BORNE ENTERIC VIRUSES. It has now been established that even after disinfection, Honolulu sewage effluents contain pathogenic viruses of human origin (Lau et al. 1975), and that these viruses are being discharged with the sewage effluent into the receiving waters. The fate of these viruses in the coastal water needs to be ascertained and if proved necessary, improved virus inactivation before discharge should be considered to safeguard Hawaii's coastal waters for recreational use. Research in this direction is now in progress at the Water Resources Research Center.

TOXIC CHEMICALS PRESENT IN BIOTA. It has been established that nearshore fishes in certain Hawaii coastal waters contain mercury and pesticides (Lau et al. 1973). While mercury concentrations in fishes are seldom high enough to be of concern, their presence in estuaries adjoining urban areas clearly indicates the need for further studies (Luoma 1974).

BIOSTIMULATION. Nutrient additions to Hawaii coastal waters of restricted circulation, such as south Kaneohe Bay and Hawaii Kai marina, have resulted in various undesirable changes in the water quality and biota in these waters. However, a more exacting definition of eutrophication through biostimulation is needed for Hawaii in order to assist planning and management of other Hawaii coastal zone lands and water.

ECOLOGICAL INVENTORY. A situation like Hanauma Bay has demonstrated wise marine resource utilization. A similar situation exists on the west Hawaii coast where urban land development is beginning and can develop to a massive scale. Here, the unexploited marine resources should be a determinant for determining appropriate land development. An on-going ecological inventory should continue to provide the baseline data and guideline necessary for wise resource utilization.

GLOSSARY

Benthic dweller (benthic biota)	Organisms of, pertaining to, or living on the bottom sediments
Biological substrate	The base or material on which organisms live
Biota	All animal and plant life of a region or place
BOD	Abbreviation of biochemical oxygen demand denoting the amount of dissolved oxygen in water required in the process of decomposing organic matter by bacteria
Conservative quality parameters	Unchanging and nondissipating quality parameters
Detritus	Particulate organic matter products of the decomposition of dead organisms
Diadromous fish	Fish migrating between fresh and salt waters
Ecosystem	A functional system which includes the organisms of a natural community together with their environment
Effluent injection well	Wells used to inject wastewater into the subsurface
Eutrophication	A state of overenrichment of a water body with nutrients, thus producing a dense growth of plant and animal life
Fringing coral reef	Coral reef attached directly to or bordering the island shores
Ghyben-Herzberg lens	A body of fresh water floating on top of salt water permeating the subsurface rock
Hydrology	The science dealing with the occurrence, distribution, circulation, and properties of the waters of the earth, and their reaction to the environment
Intertidal areas, zones	The part of the biogeographic (littoral) zone above the low-tide mark
Littoral processes, zones	Actions pertaining to the biogeographic zone between the high- and low-water marks
Nonpoint source of waste	Diffuse discharge of waste into receiving water
Pelagic fish	Fish living in the open portion of ocean waters above the abyssal zone and beyond the outer limits of the littoral zone
Point source of waste	Discrete point discharge of waste into receiving water

Primary productivity	The photosynthetic process rate by which radiant energy is stored in the form of organic substances
Submerged sewage field	Trapping and spreading of a rising sewage plume below the ocean surface by natural stratification of salinity and temperature
Waste water	Unnecessarily large amounts of water used, thus, wastage of water
Wastewater	Effluent or liquid waste by-products of sewage and industrial processing
Water quality parameters	Characteristics or factors quantifying specific qualities of water

BIBLIOGRAPHY

Chun, M.J. 1968. "Characterization of a tuna cannery waste." Master's thesis, University of Hawaii.

______; Young, R.H.F.; and Anderson, G.K. 1972. *Wastewater effluents and surface runoff quality*. Tech. Rep. No. 63, Water Resources Research Center, University of Hawaii.

City and County of Honolulu. 1972. *Water quality program for Oahu with special emphasis on waste disposal: Final report.*

Cox, D.C.; Fan, P.F.; Chave, K.E.; Clutter, R.I.; Burbank, N.C.; Lau, L.S.; and Davidson, J.R. 1973. *Estuarine pollution in the state of Hawaii--Vol. II: Kaneohe Bay study*. Tech. Rep. No. 31, Water Resources Research Center, University of Hawaii.

Dugan, G.L., and Young, R.H.F. 1973. Effects of coastal waste disposal in Hawaii. *Jour. Environ. Eng. Div., Proc. Amer. Soc. Civil Engr.* 99(EE5):691-701.

______; Young, R.H.F.; and Lau, L.S. 1973. Water quality and effluent standards of Hawaii. *Jour. Hydraul. Div., Proc. Amer. Soc. Civil Engr.* 100(HY9): 1245-56.

Fok, Y.S., and Lau, L.S. 1973. Flood computations for the Hawaiian Islands. *Proc. Intl. Symp. on River Mechanics* 1:159-69, International Association for Hydraulic Research Common Fluvial Hydraulics, Bangkok, Thailand.

Lau, L.S. 1967. Seawater encroachment in Hawaiian Ghyben-Herzberg systems. *Proc. Natl. Symp. on Groundwater Hydrology*, pp. 259-71.

______, and Mink, J.F. 1966. A step in optimizing the development of the basal water lens of southern Oahu, Hawaii. In *Proc. Intl. Assoc. of Scientific Hydrology*, Pub. No. 72, pp. 500-8.

______; Young, R.H.F.; Kanehiro, Y.; Green, R.E.; Hylin, J.W.; Young, H.Y.; Klemmer, H.W.; Kay, E.A.; Reed, S.A.; Stroup, E.D.; and Povey, D.C. 1972. *The quality of coastal waters: First annual progress report*. Tech. Rep. No. 60, Water Resources Research Center, University of Hawaii.

______; Kay, E.A.; Reed, S.A.; Russo, A.R.; Klemmer, H.W.; Townsley, S.J.; Yamauchi, H.; Green, R.E.; Chun, M.J.; Dugan, G.L.; and Young, R.H.F. 1973. *The quality of coastal waters: Second annual progress report*. Tech. Rep. No. 77, Water Resources Research Center, University of Hawaii.

______; Ekern, P.C.; Loh, P.C.S.; Young, R.H.F.; Burbank, N.C.; and Dugan, G.L. 1974. *Water recycling of sewage effluent by irrigation: A field study on Oahu--Second progress report for July 1972 to July 1973*. Tech. Rep. No. 79, Water Resources Research Center, University of Hawaii.

______; Dugan, G.L.; Ekern, P.C.; Young, R.H.F.; and Burbank, N.C. 1975. *Water recycling of sewage effluent by irrigation: A field study on Oahu--Final progress report for August 1971 to June 1975*. Tech. Rep. No. 94, Water

Resources Research Center, University of Hawaii, in press.

Luoma, S.N. 1974. Mercury cycling in a small Hawaiian estuary. Tech. Memo. Rep. No. 42, Water Resources Research Center, University of Hawaii.

Matsushita, G.K., and Young, R.H.F. 1973. *Baseline quality data for Kalihi Stream.* Tech. Rep. No. 71, Water Resources Research Center, University of Hawaii.

McGauhey, P.H. 1968. *Engineering management of water quality.* New York: McGraw-Hill.

McMorrow, M.J.K.; Young, R.H.F.; Burbank, N.C.; Lau, L.S.; and Klemmer, H.W. 1969. *Anaerobic digestion of pineapple mill wastes.* Tech. Rep. No. 27, Water Resources Research Center, University of Hawaii.

Pereira, H.C. 1973. *Land use and water resources in temperate and tropical climate.* London: Cambridge University Press.

Peterson, F.L., and Lau, L.S. 1974. Subsurface waste disposal by injection in Hawaii: A conceptual formulation and physical modeling plan. Tech. Memo. Rep. No. 41, Water Resources Research Center, University of Hawaii.

Siegel, S.M., and Siegel, B.Z. 1975. Geothermal hazards, mercury emission. *Environ. Sci. & Technol.* 9(5):473-75.

Smithsonian Institution. 1975. Center for short-lived phenomena.

State of Hawaii, Department of Health. 1971. Zone of mixing application, Inaoale Stream, Waimanalo and Wailua, Oahu.

______. 1972, 1973. Environmental impact statement for Kahe, Waiawa, and Honolulu Harbor power plants.

______. 1974. *Public health regulations.* Chaps. 37, 37A, 38.

______. 1975. Draft consolidated environmental program plan for FY 1976.

State of Hawaii, Department of Planning and Economic Development. 1969. "Geographic statistics of Hawaii." Mimeographed.

State of Hawaii, Hawaii State Legislature. 1961. *Session laws of Hawaii.* Act 187, First Hawaii State Legislature, Regular Session.

______. 1975. *Session laws of Hawaii.* Act 21, Eighth Hawaii State Legislature, Regular Session.

Takasaki, K.J. 1974. Hydrologic conditions related to subsurface and surface disposal of wastes in Hawaii. Water Resources Investigations 1-74 Open-File Rep., U.S. Dept. Interior, U.S. Geological Survey.

U.S., Corps of Engineers. 1975 Draft environmental impact statement, Hawaii Kai marina dredging.

Water Resources Engineers Inc. 1974. Validation and sensitivity analyses of stream and estuary models applied to Pearl Harbor, Hawaii. Submitted to EPA.

______. 1975. Application of the dynamic estuary model to Pearl Harbor, Hawaii in conjunction with the establishment of waste load allocations. Submitted to EPA.

Water Resources Research Center, University of Hawaii. 1975. *Annual report.* In press.

Wu, I-P. 1969. Flood hydrology of small watersheds: Evaluation of time parameters and determination of peak discharge. *Trans. Amer. Soc. Agr. Engr.* 12(5):655-63.