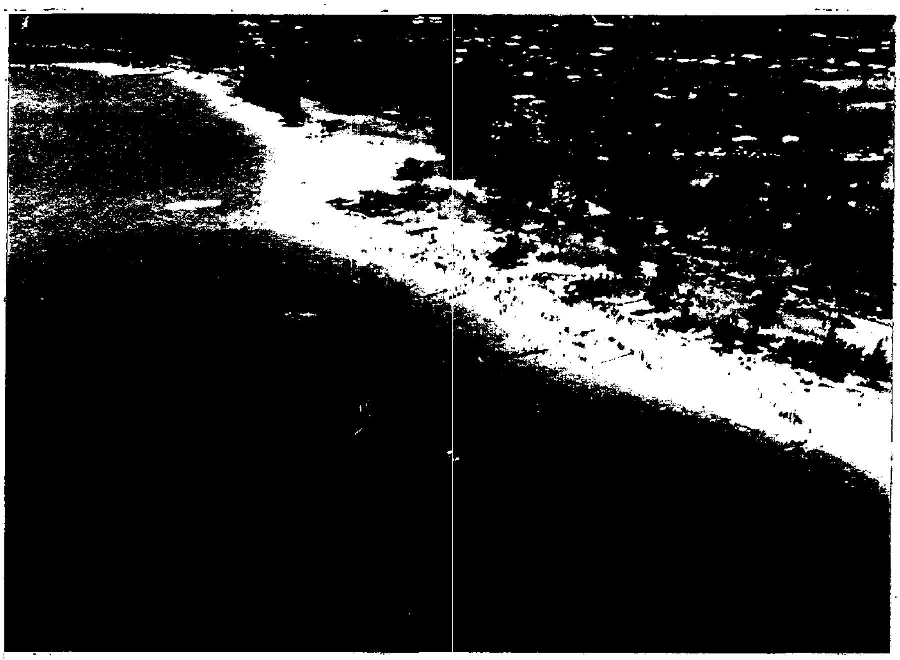
HAWAII SHORELINE EROSION MANAGEMENT STUDY

VOLUME I

OVERVIEW AND CASE STUDY SITES



FINAL REPORT

JUNE 1989

HAWAII SHORELINE EROSION MANAGEMENT STUDY

OVERVIEW AND CASE STUDY SITES

(Makaha, Oahu; Kailua-Lanikai, Oahu; Kukuiula-Poipu, Kauai)

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VOLUME I

1.0 BACKGROUND AND OVERVIEW

1.1 STUDY PURPOSE AND SCOPE

The Hawaii Coastal Zone Management (CZM) Program provides policy guidance for the use, protection and development of land and ocean resources within Hawaii's coastal zone. The cornerstone of the Program is the Hawaii CZM Act, Chapter 205-A, Hawaii Revised Statutes, which sets forth objectives and policies in each of seven areas. Included is an objective to reduce hazards to life and property from erosion and policies to protect coastal resources uniquely suited for recreational activities, to communicate adequate information on coastal hazards, and to resolve overlapping or conflicting permit requirements.

Hawaii's beaches are one of the State's most important resources, yet many are threatened by erosion. Erosion causes the loss of valuable shoreline property and damage to coastal development. Structural (physical) as well as non-structural (administrative) remedies are necessary to control, prevent, and/or manage the erosion and erosion-related impacts to our island beaches and shorelines. Structural remedies to erosion often block shoreline access and diminish the quality of and opportunities for shoreline recreation. Management efforts have been constrained because the effects of erosion are difficult to predict and jurisdiction is fragmented among several agencies. There are several county, state, and federal regulations which govern activities in shoreline areas. As discussed in this report, these regulations cause overlapping and sometimes conflicting erosion management priorities, and beach protection suffers because of the lack of clear governmental direction and policy.

The purpose of this study is to provide a comprehensive overview of erosion and erosion management in Hawaii, as an initial step towards the goal of developing a uniform (and perhaps more streamlined) method or regulatory process for the implementation of structural and non-structural measures. Specific study tasks included the following:

- o Description of the nature of shoreline erosion and erosion-related problems in Hawaii;
- o Discussion of structural and non-structural measures which have been used and/or which are available to prevent or manage erosion and erosion-related problems;
- o Evaluation of the effectiveness of existing measures, as well as the problems

associated with implementation and management of such measures;

- o Development of recommendations to improve the existing implementation and management of structural and non-structural measures, including recommendations to improve decision-making and streamline the administrative processes;
- o Examination of case study sites to serve as specific examples; and
- o Development of general recommendations to improve the overall erosion management in Hawaii.

This report provides the results of the study, organized in five major chapters. This Chapter 1 provides background information on the coastal processes and erosion problem in Hawaii. Chapter 2 describes the structural (physical) measures for preventing erosion and erosion damage, discusses the relevant factors to consider in the selection of appropriate structural measures, and discusses typical implementation problems and recommendations. Chapter 3 describes the existing regulatory regime and the non-structural (administrative) measures used in Hawaii and other states for erosion management, discusses the issues and problems arising in the context of erosion management and offers recommendations. Chapter 4 describes the analysis of case study sites on Oahu (Makaha and Kailua-Lanikai) and Kauai (Kukuiula-Poipu), including recommendations for future erosion management controls (structural and/or non-structural) for each specific site. Chapter 5 contains overall recommendations for improving erosion management in Hawaii.

Although this report begins with a description of physical processes and typical structural responses (revetments, seawalls, groins, breakwaters, etc.), the underlying premise is that through improved planning and coordination a more rational system for regulating development and protecting properties against the hazards of coastal erosion can be developed. At present the erosion management system in Hawaii can be described as an ad hoc, de facto system in which the duties of various government agencies with respect to erosion management have not yet been clearly defined. It goes without saying that the ultimate success of any erosion management program depends upon cooperation not just between government agencies, but also between the public sector and property owners. As such, the recommendations provided are intended to stimulate further dialogue regarding the most appropriate approaches that Hawaii can take in addressing the problems of coastal erosion.

Numerous recommendations and suggestions to improve the planning, design, and implementation of shore protection, erosion control, and erosion management are presented throughout this study report. Some of the suggestions are based on fundamental coastal engineering and planning principals. Specific recommendations regarding structural and non-structural erosion control and management measures are discussed in Chapters 2 and 3. General recommendations to improve the management and regulatory regime with a view towards developing a more coordinated approach towards addressing shoreline erosion and its problems are provided in Chapter 5. These recommendations are intended to provide an initial basis for discussion and evaluation by those governmental bodies charged with erosion management responsibilities. It is hoped that subsequent more detailed effort will follow to formulate definitive implementation strategies.

1.2 COASTAL PROCESSES AND EROSION IN HAWAII

The understanding of coastal processes involves the understanding of the structure and composition of the materials involved, the forces acting to change these materials, the interrelationships between processes, and the changes through time of interactions between materials and processes. Brief descriptions of the island geology, oceanographic factors, and the interaction between the two are provided herein. A comprehensive study which has formed the cornerstone for the understanding of island coastal processes is "Hawaiian Beach Systems" by Moberly and Chamberlain[1]. This reference is recommended for any person desiring a basic technical understanding of the island coastal system.

COASTAL GEOLOGY

Each of the Hawaiian islands were formed by one or more volcanoes. The general succession of volcanism has been from the northwest down the island chain to the southeast, with Kauai being the oldest of the eight principal islands and the island of Hawaii being the youngest. The bedrock formations influence coastline evolution (such as the characteristic pali cliffs) and the composition of the lava results in relatively rapid weathering in the Hawaiian climate.

Major geologic coastal features are bays which are generally either drowned river valleys or embayments between adjacent volcanoes. Most bays generally have sandy beaches. Examples of river valleys drowned by the postglacial rise of sea level and having bayhead beaches include Hanalei, Hanamaulu, and Hanapepe on Kauai, Waimea and Kahana on Oahu, Halawa on Molokai, Honokahua on Maui, and Waipio on Hawaii. Maalaea Bay on Maui is an example of a bay between adjacent volcanoes, in this case Haleakala and West Maui. Other examples include Hilo Bay, between Mauna Loa and Mauna Kea, and Kawaihae Bay, between the lobes of Kohala, Mauna Kea, and Mauna Loa. Other bays have been formed by erosion of limestone coasts, tuff or cinder cones, or differential erosion of young lavas.

Wave attack on a shoreline unprotected by beach deposits can lead to erosion of the bedrock in the surf zone. As the base is steepened and undermined, higher masses of rock may dislodge and fall. Waves remove the rubble and continue attack on the shore. This process leads to formation of most sea cliffs. Examples of sea-cliff coasts include the Napali Coast of Kauai, Kaena Point on Oahu, the sea cliffs of East Maui, and the Hamakua Coast of Hawaii.

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[1] R. Moberly and T. Chamberlain, "Hawaiian Beach Systems", prepared for State of Hawaii Dept. of Transportation, Harbors Division, published by Hawaii Institute of Geophysics, University of Hawaii, Report No. HIG-64-2, May 1964.

CORAL REEFS

Coral reefs play a major role in the Hawaiian beach system by providing a major source of beach material and by protecting the shoreline from wave attack by dissipating considerable breaking wave energy. Reefs consist of a skeleton or framework of corals and coralline algae, the voids of which are partly filled not only with corals and algae, but with foraminifera, mollusks, echinoids, bryozoans, hydrocorals, and calcareous non-coralline algae. The reef can exist in the high energy nearshore zone not only because of its mass, but also because damage from severe storms can be repaired by new growth.

The most common type of reef in Hawaii are fringing reefs, and are most developed around the older islands. The fringing reefs on the windward coasts of Kauai and Oahu are generally wide and shallow. The shallowest and flattest reefs are generally found on the leeward and protected coasts, having narrow beaches if present at all. These reefs were most utilized by the ancient Hawaiians for their fish ponds, as exemplified by the shallow reef on the south shore of Molokai. Reefs fringing the west and north shores generally are more irregular and deeper than the reefs on windward or south shores, and have the best beaches. These beaches have large seasonal changes and their sand is well sorted. The only barrier reef in Hawaii is at Kaneohe Bay on Oahu. It is about five miles in length, one mile in width, with a deep lagoon behind it.

AREAS OF EXCEPTIONAL MARINE DEPOSITION

Some coasts of the islands have a long-term history of local aggradation of the shoreline due to sediment accretion. Interaction between wave action and sediment provided by the rivers in Hanalei resulted in a series of crescentic beach ridges inland of the present one, evidence of the advance of land. The Mana Plain of western Kauai appears to have formed as cuspate beaches that trapped alluvium washed from the hinterlands. The shoreline at Maui's Maalaea Bay is a barrier-beach coast separating Kealia Pond from the bay. The pond is slowly filling with alluvium washed in from the land side and sand driven in from the shore side.

LITTORAL BUDGET

The coasts are continually exposed to waves, which are responsible for moving sediment (littoral drift) and changing the composition, structure and volume of beaches. Most beaches are continually in a state of flux, with fluctuations being pronounced during different seasonal conditions. Yearly and multi-yearly fluctuations can also occur related to long period meteorological cycles. The concept of a littoral sand budget can be applied to quantify the rates of sand input, transport, and loss. If the rates of input and loss are balanced over a given period of time, then the coast is considered to be in equilibrium. If the erosional processes are not in equilibrium with the accretional processes, then net erosion over a period of time will occur. When there is a stretch of coast along which the rates of sand input, transport, and loss are in equilibrium and there is little or no exchange of nearshore sediment with adjacent shores, then the littoral unit is termed a "littoral cell". In Hawaii, these littoral cells are typically separated by rocky promontories or by other littoral barriers to longshore transport such as deep channels.

Sediment input to a littoral cell is contributed by rivers, coastal erosion of bedrock, and biological activity of coral reefs. Sediment losses are due to transport to deepwater, transformation of beach sand into beachrock, abrasion of sediment grains, and transport inland due to storm waves or wind.

An example of a littoral cell is a fringing reef shoreline bounded by deepwater sand channels. The windward Oahu coastline between Laie and Kaaawa consists of a series of littoral cells delineated by the deepwater channels (termed "awa"). Sediment input is primarily contributed by the streams and the fringing coral reefs, while sediment losses are primarily due to transport of the sediment into the surge channels. Sand is moved seaward through the awa into the deeper offshore areas where wave energy cannot transport the sediment back towards shore. The deficit between the supply and losses has resulted in net long-term erosion along much of this windward Oahu coastline.[2]

Offshore sand deposits which are repositories of sediment lost from beach areas may be used as sources for replenishment of eroding shores. Ideally, the sand should be replaced within the same beach littoral cell to maintain an equilibrium sand budget if there has been net loss from the shore. This recycling of sediment within a littoral cell will prevent potential deficit problems which could occur if sand is removed from one littoral cell and placed into another. This concept is important for nearshore sand deposits where the source is more easily defined within the littoral cell and there is some probability that sand from the deposit may occasionally be transported back to the beach by natural processes. In some cases, sediment is lost to very deep offshore areas with no possibility of being transported to the shore by natural processes. In addition, the littoral cell source(s) of the sediment may not be easily distinguished. These sand deposits may be considered as general replenishment

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[2] Sam O. Hirota, Inc., "Beach Erosion Study, Various Parks - Windward Oahu", prepared for City and County of Honolulu Dept. of Parks and Recreation, December 1988.

sources for eroding shores at locations removed from the general vicinity of the sand deposit without concerns of potentially aggravating shoreline erosion. Because the transport of sediments depends on many variables, including wave characteristics and physical shoreline characteristics, it is difficult to establish general criteria to determine when a particular sand deposit is not available to the littoral cell sand budget. Site specific evaluations should be accomplished on a case-by-case basis because of the complex relationship between offshore submerged sand deposits and the beach littoral system.

LITTORAL TRANSPORT

Waves and wave-generated currents are the primary forces that move sediment along the coast. The interaction of the waves with the land mass results in a variety of different modes of sediment transport in the littoral zone. Waves "transform" as they approach land, similar to how light transforms when it interacts with solid bodies. When waves approach shore, refraction causes the wave front to bend and attempt to align parallel with the ocean bottom contours and the shore. Refraction can cause wave heights to increase (due to convergence) or decrease (due to divergence).

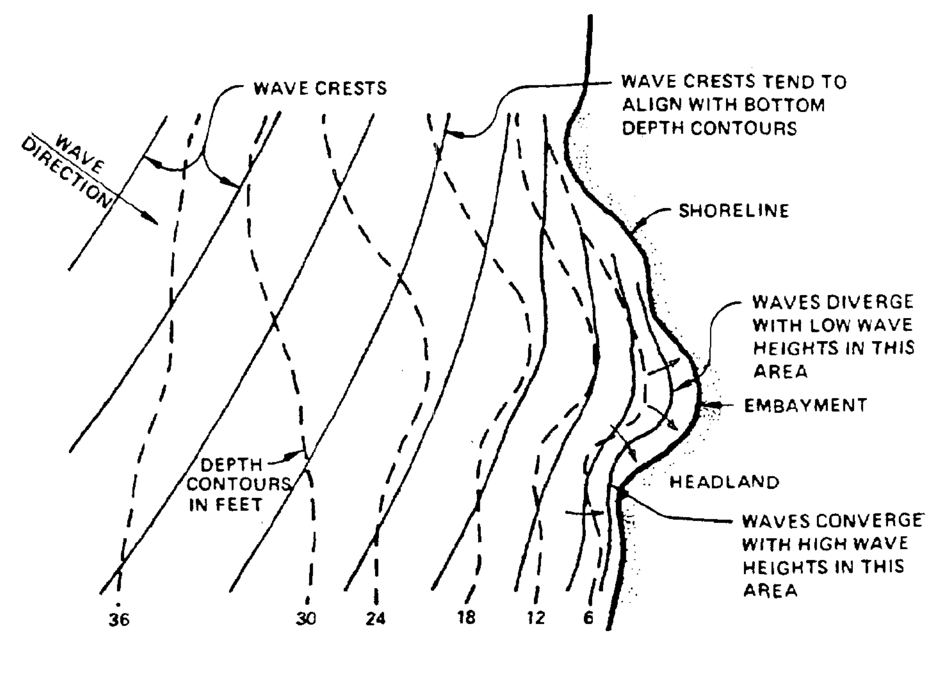

FIGURE 1-1 SCHEMATIC DESCRIPTION OF WAVE REFRACTION
(Adopted from U.S. Army Corps of Engineers, "Help Yourself, A Shore Protection Guide for Hawaii", 1979)

Diffraction can also cause waves to change direction, as when waves propagate past a physical barrier such as a breakwater. Lateral transfer of energy along the wave front will enable waves to travel into the sheltered region behind the obstruction, although with much reduced wave height.

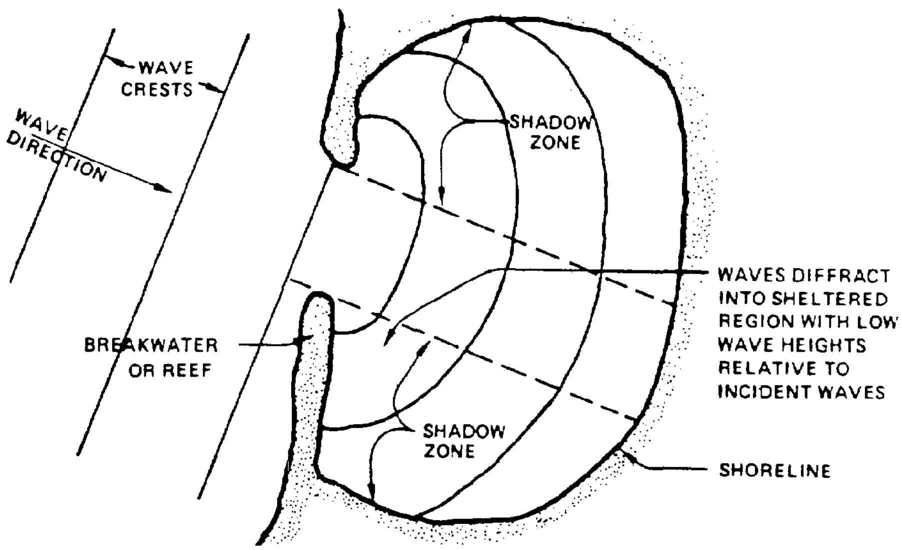

FIGURE 1-2 SCHEMATIC DESCRIPTION OF WAVE DIFFRACTION
(From U.S. Army Corps of Engineers, "Help Yourself, A Shore Protection Guide for Hawaii", 1979)

When the waves approach shallow water, the wave length will become compressed, resulting in increasing wave height (shoaling) until the wave breaks. The breaking process dissipates considerable wave energy due to the turbulence. This turbulence can suspend sediment in the water column, enabling the transport of sand by currents in the littoral zone.

Sediment transport in the littoral zone occurs as longshore transport or onshore-offshore transport. In most case, both types of transport will occur because of the varying wave characteristics. Longshore transport occurs because waves arrive at an angle to the beach, moving sediment in the direction of wave breaking. Longshore transport occurs both in the surf zone as well as on the beach face (swash zone). Transport in the surf zone is due to suspension of sediment by breaking wave turbulence and subsequent transport by the wave-generated longshore currents. Transport in the swash zone is due to the uprush and downrush of waves on the beach face. Longshore transport potential increases with increase in wave height and angle between the wave crest and beach.

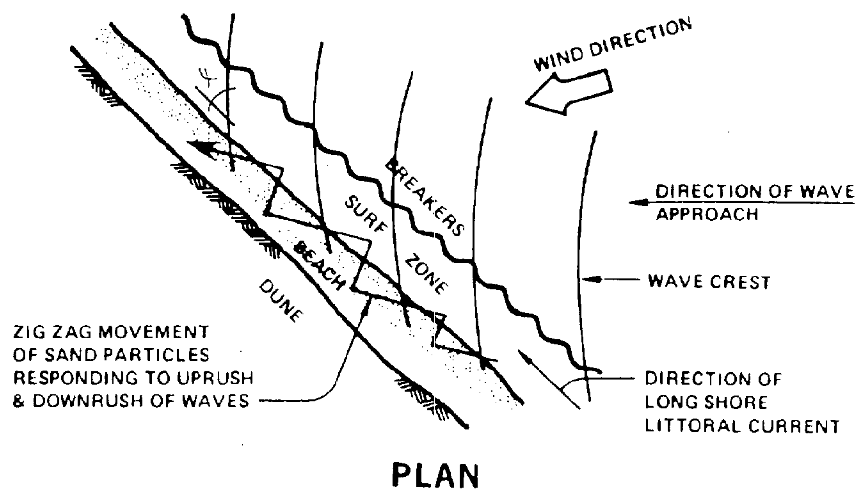

FIGURE 1-3 SCHEMATIC DESCRIPTION OF LONGSHORE TRANSPORT
(Adopted from U.S. Army Corps of Engineers, "Help Yourself, A Shore Protection Guide for Hawaii", 1979)

Onshore-offshore transport is the movement of sediment perpendicular to the shore because of the interaction of the waves with the beach or because of physical networks of reefs and channels. Low, long period waves can rebuild beaches by transporting sediment shoreward. The swells break and run up the beach until their energy is expended, depositing material up to the runup height on the beach. High, steep waves can erode the beach and deposit the beach material offshore. Storm waves associated with higher than normal water levels can also cause erosion of sediment from the beach and offshore deposition. For shallow fringing reef areas where the wave conditions over the reef are generally depth-limited and less variable, the onshore-offshore transport occurs with the shoreward transport of sand over the reef, and the offshore transport of sand in the deep channels through the reef.

Because meteorological conditions and wave conditions generally vary seasonally, the beach changes typically vary seasonally. For littoral cells bounded by headlands or promontories, changes in wave approach direction can cause substantial fluctuations in the beach width at the ends of the beach as the sediment moves from one end to the other end. Fluctuations in beach width are not as noticeable in the middle portion

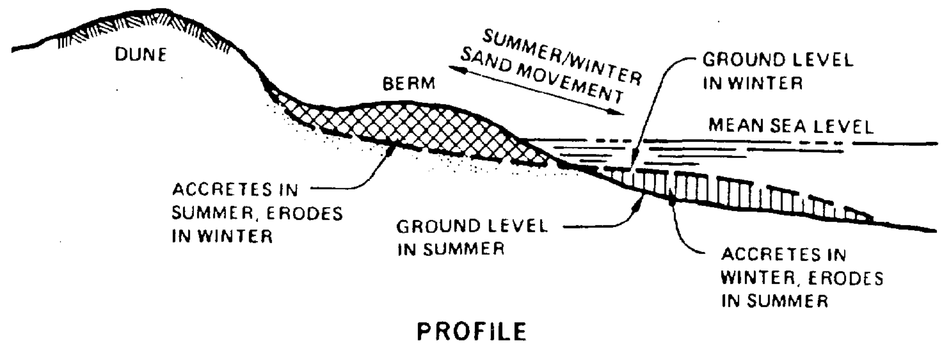

FIGURE 1-4 TYPICAL SEASONAL ONSHORE-OFFSHORE TRANSPORT
(From U.S. Army Corps of Engineers, "Help Yourself, A Shore Protection Guide for Hawaii", 1979)

of the shoreline reach where the nodal point occurs. Long-term meteorological cycles, such as shifts in the mean wind direction, can cause long-term trends in erosion and accretion.

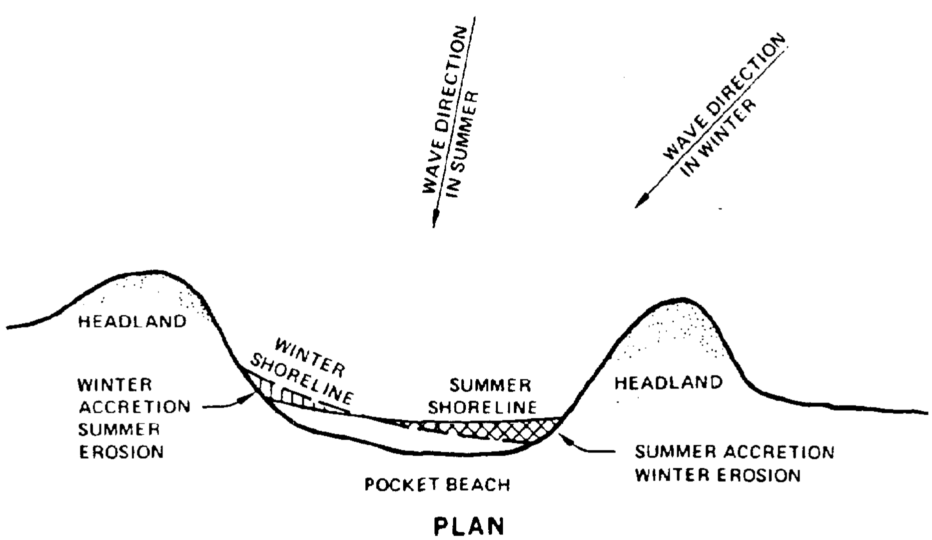

FIGURE 1-5 TYPICAL SEASONAL FLUCTUATIONS WITHIN A LITTORAL CELL
(From U.S. Army Corps of Engineers, "Help Yourself, A Shore Protection Guide for Hawaii", 1979)

Sediment transport occurs not only in beach areas but also along rocky shoreline areas. Any coastal zone exposed to breaking wave energy, whether offshore in the surf zone or onshore in the wave runup zone, is susceptible to sediment transport processes and erosion. Erosion of sediment seaward of rocky shorelines can result in greater wave energy attacking the shore and increased erosion damage to backshore areas due to wave runup and scouring of fastlands situated landward of the rocky tidal shores. Thus, even if coastal areas are fronted by rocky shores that are stable, wave runup and overtopping of the rocky shores can lead to progressive erosion damage to unprotected backshore areas. Decrease in backshore elevations due to these erosional processes or due to human intervention (such as grading and leveling of dunes for development) can allow increased wave inundation and subsequent increased erosion damage potential.

WAVES

Ocean waves are generated by wind stress acting on the sea surface. The global wave climate is therefore related to global wind patterns. On a regional basis, the winds can be highly variable, both temporally and spatially, resulting in a constantly dynamic sea state. On a site specific basis, the nearshore wave characteristics can be very different from the open ocean deepwater wave climate due to sheltering effects of land masses and wave transformation effects in shallow water.

The deepwater wave climate in Hawaii is seasonal, and is related to the weather patterns throughout the entire Pacific Basin. *Northeast tradewind waves* are generated by the prevailing tradewinds and may be present throughout the year. However, they are largest and most dominant during the summer months when the tradewinds are strong and persistent. These waves typically have periods of 5 to 8 seconds and heights 4 to 8 feet. During the winter season, the tradewinds diminish in frequency and winds can be light and variable or from the southeasterly through southwesterly direction. These "Kona" winds can be strong when generated by local fronts and extra-tropical storms, resulting in *Kona storm waves*, with periods of 6 to 10 seconds and heights to 15 feet. During the winter months, severe storms in the North Pacific near the Aleutians or by mid-latitude low pressure systems generate large waves which arrive in Hawaii as 10 to 15 second swell. These *North Pacific swell* can have large heights to 20 feet and are the famous north shore waves which have popularized such surfing spots as Waimea Bay, Pipeline, and Sunset Beach. During the summer months in Hawaii, severe winter storms in the Southern hemisphere can generate large waves that travel 5,000 miles across the ocean before reaching Hawaii. These waves decay into low, long period *south swell*, having heights less than 5 feet with periods to 18 seconds. Because of the long wave periods, south swell can easily have breaking heights that are twice the deepwater height. Hawaii is rarely affected by *hurricanes*, although several have come close to the islands. Hurricane Iwa in November 1982 was the most recent and by far the most destructive hurricane to affect Hawaii. Hurricanes typically pass south and west of the island chain, leaving the southwesterly shores most vulnerable to the destructive waves.

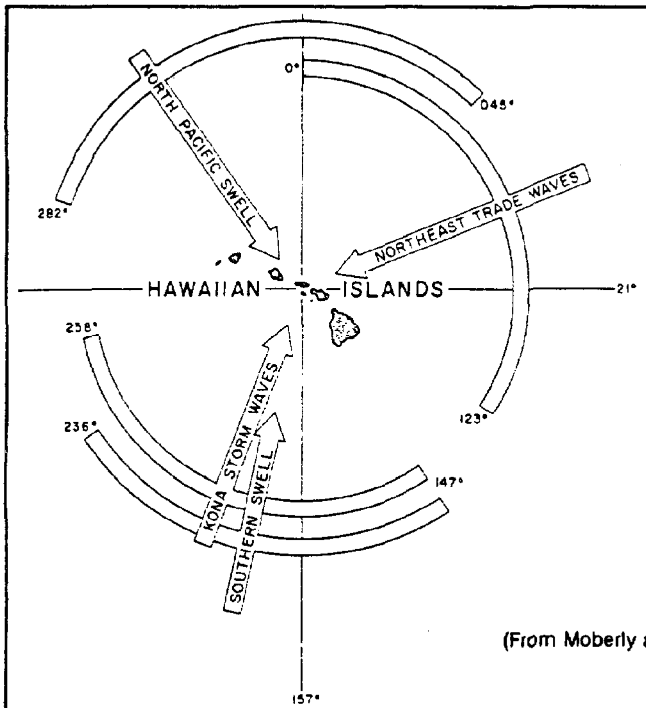

FIGURE 1-6 TYPICAL WAVE TYPES FOR HAWAIIAN WATERS
(From Moberly and Chamberlain, "Hawaiian Beach Systems", 1964)

The wave characteristics offshore specific coastal areas are dependent on the island geometry. For example, the south shore of Oahu is shielded by the island mass from the North Pacific swell and most of the northeast tradewind waves. Thus, the wave climate is typically mild except in the summer during periods of south swell. The offshore wave characteristics can also be comprised of two or more different wave types occurring simultaneously because of their different meteorological generating sources. For example, swell wave groups which arrive from distant regions will frequently occur together with locally-generated wind waves.

WATER LEVEL FLUCTUATIONS

The elevation of the water surface in relation to the beach or shoreline can greatly affect the erosion potential. Higher than normal water levels during storms allows

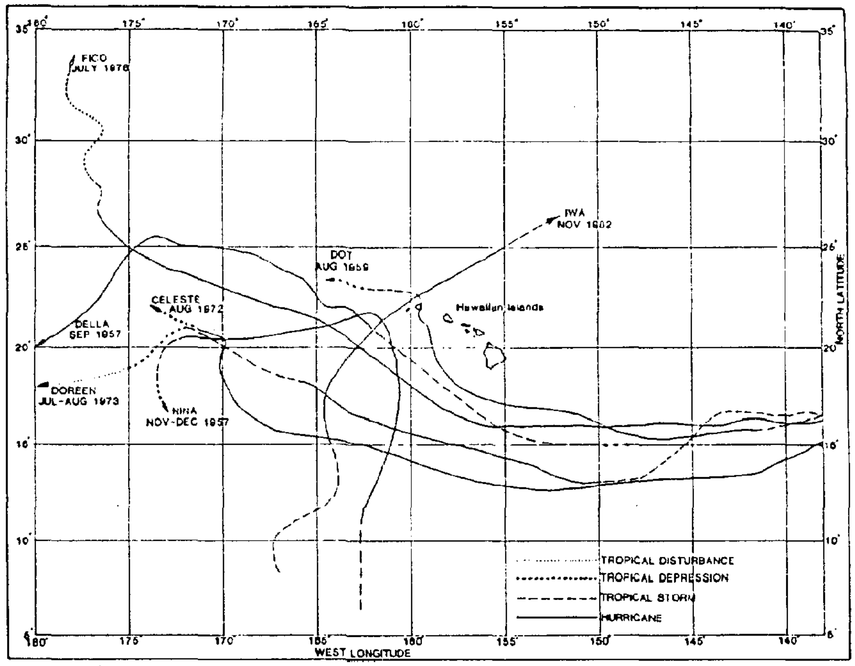

FIGURE 1-7 TRACKS OF HURRICANES AFFECTING HAWAII FROM 1957 THROUGH 1982
(Compiled from National Weather Service data)

waves to break at higher elevations on the beach, causing wave overtopping and erosion of the backshore area. The typical semi-diurnal tidal range in Hawaii is about 2 feet. Superelevation of the water surface (termed "setup") can occur during storms due to strong onshore winds and large offshore breaking waves. A decrease in atmospheric pressure, such as found in the center of hurricanes, can also cause an increase in water level. During the passage of Hurricane Iwa, studies have indicated that the increase in water level (above that of the expected tide level) was about 5 feet in some places along the south shore of Oahu.[3] The high water levels not only caused severe erosion but also considerable wave damage to existing structures, especially in the Poipu area on Kauai.

CURRENTS

Currents that have dominant roles in the littoral processes are longshore currents and offshore currents. Longshore currents are generated by waves breaking at an angle to the beach. These currents are usually not in themselves strong enough to move

[3] Charles L. Bretschneider and Edward K. Noda and Associates, "Hurricane Vulnerability Study for Honolulu, Hawaii, and Vicinity, Vol. 2, Determination of Coastal Inundation Limits for Southern Oahu from Barbers Point to Koko Head", prepared for U.S. Army Corps of Engineers, 1985.

bedload sediment. However, they are responsible for moving large quantities of suspended sediment that are stirred up from the bottom by the turbulence of the breaking waves. Offshore currents, known as rip currents, can occur along a long straight beach at somewhat regular intervals, in channels through reefs, or near coastal structures which divert the longshore currents offshore. These currents occur when water that is piled up against the shoreline seeks to flow seaward. Depending on the generating mechanism, rip currents can reach high velocities sufficient to scour and transport bottom sediments.

TSUNAMIS

Tsunamis are generated by seismic occurrences and propagate across the ocean as long period waves, having periods from about 20 to 30 minutes. The tsunami wave at the shoreline can resemble a rapidly rising tide, with low flood velocity and little potential for erosion or scouring of the shoreline. On the other hand, if the tsunami forms a bore-like wave, then the runup on dry land is in the form of a surge. In this case, the current velocities can be large and can cause erosion and scouring of shoreline areas. However, tsunamis are infrequent events and not a significant factor in coastal erosion processes.

1.3 PROBABLE LONG-TERM EROSION TRENDS

In the long-term, erosion will probably continue for several reasons:

- o Decrease in production and supply of sand in the littoral zone;
- o Human intervention in the coastal zone;
- o Natural hazards such as storms and hurricanes;
- o Rising sea level.

SAND PRODUCTION AND SUPPLY

The sands which comprise beaches in Hawaii are generally calcareous grains of biochemical origin, made up of the fragments of skeletal parts of marine invertebrate animals and algae. From samples and analysis of 90 beach systems in Hawaii, foraminifera was found to be the predominant component of white sand beaches in the islands.[4] Other major components were mollusks, red algae, and echinoids. Corals were found to be fifth in order of prominence in calcareous sands. Reduced biological activity on reefs is reducing this major sand source. The coral skeletal material provides the framework of the reefs inhabited by the foraminifera, mollusks, and echinoids. Parrotfish and other grazing reef fish are thought to be significant producers of coral sands. These fish cause bioerosion of the coral and coralline algae by scraping and nibbling. Coral fragments pass through their digestive tracts and are redeposited on the reef as small sand grains. One estimate of the rate of calcareous fragments produced annually by fishes on a Bermuda reef was 2300 kg/hectare.[5] Over-fishing of reefs in Hawaii contribute to the decrease in sand production within the littoral system.

The other major source of sand beaches is detrital material originating from the land after weathering and erosion. Detrital sand grains are volcanic in origin, either fragments of bedrock or fragments of specific minerals from rock. The black sand beaches on the Big Island are comprised of volcanic glass grains from lava flows entering the ocean. Because of the episodic nature of these geologic events, these black sand beaches may be susceptible to erosion without a continuous replenishing sand supply. Olivine is a common component of sand beaches near river mouths and

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[4] R. Moberly and T. Chamberlain, "Hawaiian Beach Systems".

[5] J.E. Bardach, "Transport of Calcareous Fragments by Reef Fishes", Science, v. 133, 1961.

rocky coasts, giving the beaches a green hue. Sand sample analysis[6] has shown that olivine constitutes the dominant component of beaches at Hanauma and Waimea on Oahu, Lumahai on Kauai, and Olowalu on Maui. Quartz, the most common component of sand on most continental coasts, are absent in Hawaii. Reduced production of calcareous sands may result in beaches having an increasingly greater percentage of detrital grains and darker overall color, making them less desirable for recreation.

HUMAN INTERVENTION

The history of human intervention in the coastal zone may have altered the natural processes to such an extent that some of the beaches cannot recover. Shorelines that have already been "hardened" by shore protection structures may cause aggravated downdrift erosion problems by preventing erosion of the shore that the structure is protecting. Navigation channels cut through reefs can function as sediment traps by removing sediment from the active littoral zone. It is unreasonable to assume that existing coastal structures or facilities can be completely removed. Thus, the cumulative impacts on the littoral processes will probably contribute to long-term erosion.

The taking of sand from beaches and nearshore areas for other uses permanently removes sediment from the littoral zone and is another contributor to long-term erosion. While commercial removal of sand from the shoreline area is illegal in Hawaii (except for the purposes of beach replenishment), the noncommercial taking for personal use (not in excess of one gallon per person per day) is allowable. With the limited sand resource presently available in our littoral zone, not even the taking for personal use should be allowed.

Drainage channels and stream mouths that traverse beaches regularly become plugged with sand due to natural littoral processes. These drainage ways must periodically be cleared of sediment to maintain their flow capacity. In some cases, this sediment is permanently removed from the area to be used for other purposes, or because the sand is "dirty" from stream sediment and detritus that mixes with the sand, making it unsuitable for placement back on the beach. This can lead to substantial permanent loss of sediment from the beach littoral zone and long-term accelerated erosion.

[6] Moberly and Chamberlain, "Hawaiian Beach Systems".

STORMS AND HURRICANES

Storm and hurricane waves can cause considerable episodic loss of sediment from the active littoral zone. Hurricane Iwa in November 1982 caused severe erosion and wave damage to south and west-facing shores of the islands. Offshore Kahe on Oahu, it was observed that nearshore reef areas that were previously covered with sand were denuded by the hurricane wave activity. It was estimated that the depth of sand along the reef fronting Hawaiian Electric Company's (HECO's) generating plant was reduced by approximately 3-5 feet, and at least 11,000 cubic yards of sand was eroded from Kahe Beach.[7] Subsequent decrease in the sediment entrained by the cooling water system of HECO's plant indicates that the loss of sediment from the nearshore zone may have been permanent. Unless sand lost to deepwater areas is mined and replaced on the beach or in the active littoral zone, then net long-term loss of sediment will contribute to continued long-term erosion.

RISING SEA LEVEL

Long-term rise in sea level due to land subsidence and global sea level rise will lead to shoreline recedence and increasing potential for erosion damage. Several studies have suggested that the rate of eustatic[8] sea level rise may accelerate due to future warming of the atmosphere associated with the "greenhouse effect", melting of glaciers, and expansion of near-surface ocean water due to global ocean warming. The Marine Board of the National Research Council convened a committee on "Engineering Implication of Changes in Relative Mean Sea Level" to examine the knowledge concerning mean sea level changes, establish the rate of relative sea level change based on past data, develop projections of future sea level rise, examine the responses of sandy shorelines and wetlands to sea level rise, examine the consequences on engineering works and built facilities, and to develop recommendations. The results of the 2-year study effort are summarized in the publication Responding to Changes in Sea Level, Engineering Implications[9]. The following are some of the conclusions and recommendations contained in the published report:

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[7] Hawaiian Electric Company, Environmental Dept., "Annual Report, Kahe Generating Station NPDES Monitoring Program", April 1983.

[8] Eustatic means a global change of oceanic water level. The difference between the eustatic change and any local change in land elevation results in the relative mean sea level change at a particular location.

[9] Report by the Committee on Engineering Implications of Changes in Relative Mean Sea Level, Marine Board, Commission on Engineering and Technical Systems, National Research Council, published by the National Academy Press, Wash. D.C., 1987.

- *Relative mean sea level, on statistical average, is rising at the majority of tide gauge stations situated on continental coasts around the world. Relative mean sea level is generally falling near geological plate boundaries and in formerly glaciated areas such as Alaska, Canada, Scandinavia, and Scotland. Relative mean sea level is not rising in limited areas of the continental U.S., including portions of the Pacific Coast. The differences are due to differing rates of vertical motion of land surfaces due to subsidence or uplift.*

- *Large, short-term (2-7 year) fluctuations worldwide are related to meteorological phenomena, notably shifts in the mean jet-stream path and the El Nino-Southern Oscillation (ENSO) mechanisms, which lead to atmospheric pressure anomalies and temperature changes that may cause rise or fall of mean sea level by 15-30 centimeters over a few years.*

- *The risk of accelerated mean sea level rise is sufficiently established to warrant consideration in the planning and design of coastal facilities. Accelerated sea level rise would contribute toward a tendency for exacerbated beach erosion. The prognosis for sea level rise should not be cause for alarm or complacency. Three plausible variations in eustatic sea level rise was adopted by the committee. The three scenarios provide a useful range of possible future sea level changes for design calculations. Present decisions should not be based on a particular sea level rise scenario. Rather, those charged with planning or design responsibilities should be aware of and sensitized to the probabilities of and quantitative uncertainties related to future sea level rise.*

- *The two response options to sea level rise are stabilization and retreat. Retreat is most appropriate in areas with a low degree of development. There does not now appear to be reason for emergency action regarding engineering structures to mitigate the effects of anticipated increases in future eustatic sea level rise. Sea level change during the design service life should be considered along with other factors, but it does not present such essentially new problems as to require new techniques of analysis. The effects of sea level rise can be accommodated during maintenance periods or upon redesign and replacement of most existing structures and facilities. Construction of almost any conceivable protection against sea level rise can be carried out in a very short time relative to the rate of sea level rise.*

Because the rate of future sea level rise is uncertain, the committee examined three possible scenarios of eustatic sea level rise to the year 2100: rises of 0.5 m, 1.0 m, and 1.5 m (1.6 ft, 3.3 ft, and 4.9 ft, respectively). The general shape of the curves is concave upward with greater rates of rise in the distant future than those in the next decade or so. The equation adopted for the eustatic rise in sea level is:

$$E(t) = 0.0012t + bt^2$$

where: $E(t)$ = eustatic component in sea level rise above present level (meters)
t = time from present (years)
b = coefficient (m/yr^2)
= 0.000028 for E(114) = 0.5m
= 0.000066 for E(114) = 1.0m
= 0.000105 for E(114) = 1.5m

The total relative sea level change above present levels at time t from present is:

$$T(t) = L(t) + E(t)$$

where: $T(t)$ = total relative sea level change
$L(t)$ = local change due to subsidence or uplift
$E(t)$ = eustatic change

Given the equation for eustatic change, the total relative sea level change can be written as:

$$T(t) = (0.0012 + M/1000)t + bt^2 \text{ (meters)}$$

where: M = 0.4 mm/yr (subsidence) determined for Honolulu from tide gage measurements assuming a eustatic rate of 1.2 mm/yr.

By the year 2010, the total relative rise in sea level above present levels for Honolulu is estimated to be 0.3 feet for the worst case scenario. By the year 2050, the total relative rise is estimated to be between 0.71 to 1.75 feet, for the best and worst case scenarios. Thus, for the next 50 years or so, the relative rise in sea level will not have major implications for most coastal areas in Hawaii.[10] However, by the year 2100, the total relative rise is estimated to be between 1.8 to 5.1 feet. Depending on the coastline characteristics, sea level rise on the order of a couple feet or more could have major implications with respect to higher wave activity and erosion damage as well as flooding or inundation tendencies.

[10] In the short-term, however, local subsidence due to seismic events can lead to accelerated erosion at specific coastal sites, such as at Kalapana on the South Puna coast of Hawaii. Such seismic events are fortunately infrequent.

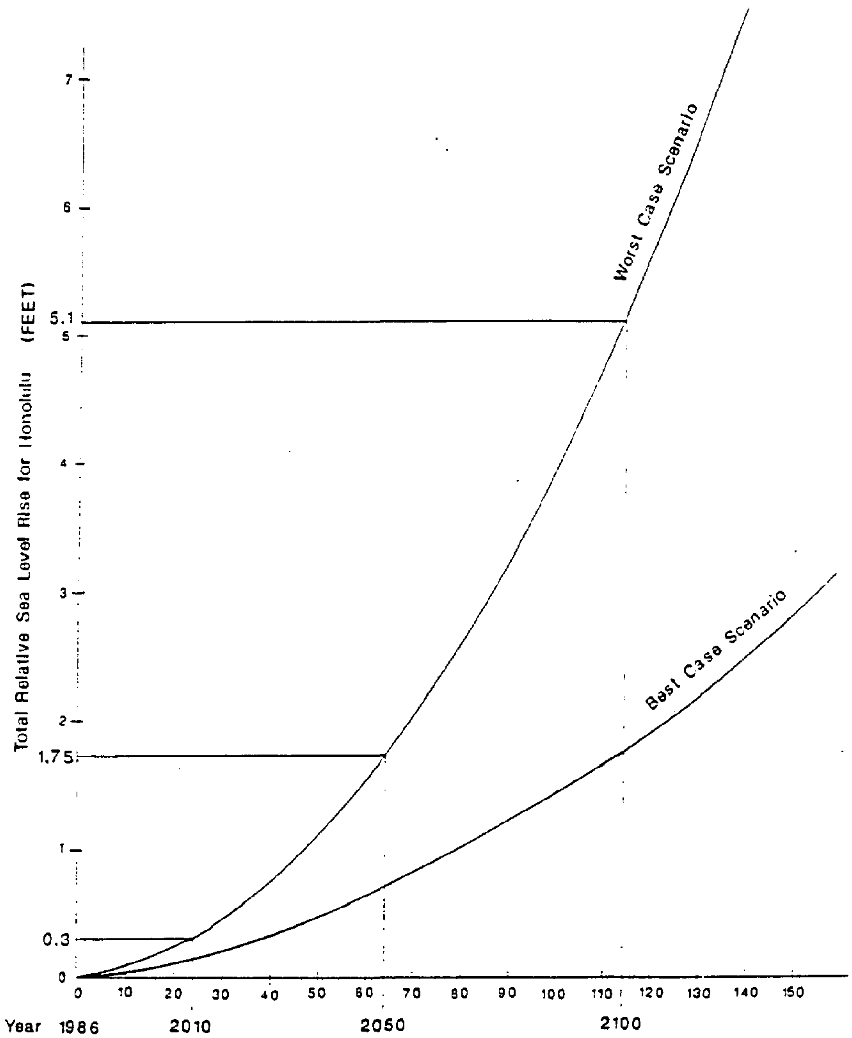

FIGURE 1-8 ESTIMATED TOTAL RELATIVE SEA LEVEL RISE FOR HONOLULU
(From Edward K. Noda and Assoc., "Honolulu Waterfront Master Plan, Ocean Engineering Considerations", 1989)

To reiterate the previous recommendations, planners should be aware of the probabilities related to future sea level rise, and should consider the effects during the design service life of structures, along with other factors. However, there does not now appear to be reason for emergency action. The effects of sea level rise can be accommodated during maintenance periods or upon redesign and replacement of existing structures and facilities. The determination of the preferable response option, whether it is stabilization or retreat, will depend on the consideration of priorities and the existing development. For example, for highly developed areas such as on the south shore of Oahu, shoreline stabilization could probably be justifiable versus retreat of development mauka from the shore because of the cost of the existing infrastructure and the functions, such as the very high cost for relocating Honolulu International Airport, and the water dependency of Honolulu Harbor. The Honolulu shoreline has also been substantially altered by dredging, filling, and shoreline stabilization activities such that virtually none of the "natural" shoreline exists. For less developed areas where the "natural" shoreline has been relatively unaltered, retreat may be the preferable long-term management concept. Long-term planning should obviously take into account the full range of socio-economic, environmental and technical factors in responding to probable long-term sea level rise.

1.4 METHODS FOR ESTIMATING LONG-TERM SHORELINE CHANGES

A common method for estimating the future long-term shoreline changes is to evaluate the historical shoreline changes and to factor in the consideration of the erosion mechanisms. A simple extrapolation into the future based on historical changes is probably reasonable for relatively short time frames on the order of say 20-30 years. However, global processes may change dramatically over much longer time frames that are difficult to predict, such as global rise in sea level which is thought to exponentially increase. Other factors such as possible decrease in sand production and supply, long-term effects of coastal structures and development, and infrequent occurrence of extreme events, all contribute to the uncertainty of future estimates based on historical trends. Thus, erosion management and planning should include periodic re-studies or updates of the future estimated shoreline changes every 10-15 years to minimize the possible errors due to simple extrapolation of historical information.

A conventional method for the evaluation of historic shoreline movements involves the use of available aerial photographs. In the evaluation of beach shorelines using aerial photographs, it is sometimes difficult to accurately define the shoreline. In the past, the waterline was sometimes used to define the shoreline, but this reference line has inherent problems associated with the tidal elevation and the wave run-up characteristics at the time of the photograph, as well as the contrast quality of the photograph. Selection of the vegetation line can reveal the erosion of fastlands, but cannot provide information on the beach width changes when accretion as well as erosion of beaches occur. Another problem with vegetation lines is that they can sometimes be artificial or man-made (vegetative plantings or shore protection) and not reflective of the natural landward limit of dynamic shorelines.

When using aerial photographs, two representative shorelines should preferably be defined: the vegetation line and the beach toe line[11] (or waterline[12]). The vegetation line is an indicator of the seaward limit of fastlands (i.e. landward limit of active beach zone). The beach toe line (or waterline) is an indicator of the seaward limit of the beach zone. The beach toe line is more appropriate than the waterline for beaches fronted by shallow reef flats, since there is generally good contrast on the photograph between the beach and reef flat, and the beach slope generally does not change significantly because of the depth-limited wave conditions over the reef. The waterline

[11] The beach toe is the point at which the beach slope intersects the shallow reef flat.

[12] The waterline is the point at which the water surface intersects the beach slope, and can vary depending on the tidal stage.

is more appropriate for beaches that are not fronted by shallow reef flats since it is often difficult, if not impossible, to define the beach toe line on these photographs. (Lack of contrast between the beach toe and sandy nearshore bottom, limited clarity through a deeper water column, and turbidity due to suspended sediment in the nearshore breaker zone, all contribute to this problem.) In general, these representative lines would behave in similar manners when viewed over long time frames. For short term conditions, this may not be true because of seasonal changes in beach width and beach slope.

Vertical or near-vertical aerial photos are necessary to minimize distortion of horizontal scales. Such photographs can be obtained from companies which specialize in photogrammetry or aerial surveys. The aerial photographs are typically enlarged to a map scale of about 1" = 100 ft to 1" = 200 ft, depending on the degree of resolution desired. Computer analysis and mapping is the preferable method for comparison and processing of the information since the aerial photos cannot usually be enlarged to an exact scale.[13] Digitizing of the information from the photos into a computer aided drafting (CAD) system provides the flexibility to overlay the photos exactly by electronically minimizing the distortions and scale differences using specific targets (such as the corner of buildings, etc.) which appear on some or all of the photographs. The vegetation lines, beach toe lines (or waterlines) and the selected targets are electronically digitized relative to an arbitrary x,y coordinate system. By matching the selected target locations, the horizontal length scales can then be calculated and the digitized lines undistorted and rectified to a basic x,y coordinate system. Computer software is used to perform this undistortion and rectification. The historic beachlines from separate photos can then be computer plotted in overlays to develop an understanding of the horizontal shoreline and beach changes due to historic trends in beach erosion or accretion processes.

The loss or gain of shoreline is quantified by calculating the area between the vegetation lines (or beach toe lines) of subsequent year photos. This area divided by the length of shoreline will yield the average horizontal change per unit length of shoreline for that shoreline reach over the time period between photos. Cumulative plots of these values will graphically show the average accretion or erosion trends for the particular shoreline reach. When horizontal shoreline changes are highly variable along a shoreline reach, then comparison of horizontal distances along selected transects will yield information on the accretion or erosion patterns at those particular locations.

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[13] "Controlled" photos can be enlarged to exact scales by using visual targets that have been surveyed and established prior to taking the aerial photo. This involves considerable effort and cost. Most historical aerial photos are not controlled photos.

The area between the vegetation line and beach toe line (or waterline) is the active beach zone. When the beach width is highly variable along the shoreline reach, i.e. vegetation line and beach toe line relative to each other displays variability over time, some type of average value is desired to represent the relative changes in quantity of sediment contained within the beach. To provide this measurement, the area between the vegetation line and beach toe line (or waterline) for each photo is calculated by numerical integration. This area divided by the length of the beach provides a value representing the average beach width per unit length of beach within the littoral cell or along the entire reach. By using the earliest aerial photograph as the base year, the net difference between the base year value and subsequent year values when cumulated and plotted will graphically indicate the erosion or accretion trends within the beach zone. The slope of the line yields the average yearly rate of accretion or erosion. If the beach vertical profile is known, then the volume change of sediment gain or loss from the beach can be determined from the history of horizontal beach width change.

Historical data on both the vegetation line and beach toe line (or waterline as the case may be), provides complementary information on the long-term shoreline changes. Changes in beach zone width indicates the gain or loss of usable beach area. Horizontal movement of the vegetation line over long time frames indicates historical loss of gain of shoreline. Sometimes the beach width can remain relatively constant even though the shoreline undergoes long-term erosion or accretion. The general public may not perceive the long-term shoreline changes since the beach width is visually easier to interpret as representing erosion or accretion. Other beaches may show large fluctuations in beach width while the vegetation line remains relatively constant. A historical database of shoreline change as well as beach width change will provide planners and engineers with a sound basis for erosion management planning and design.

If there is a long enough historical record, sometimes long-term cycles on the order of 10-30 years can be seen, as revealed by previous studies[14]. Certain shoreline reaches that are sensitive to wind and wave direction may display long term cycles that correlate with long-term historical shifts in wind direction.

Digitizing and analysis of beachlines as described above is a labor-intensive effort in comparison to processing of information along few selected transects. The "transect"

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[14] Edward K. Noda and Associates: "Beach Processes Study, Kailua Beach, Oahu, Hawaii", prepared for the U.S. Army Corps of Engineers, 1977; and "Windward Oahu Beach Erosion Study", prepared for Sam Hirota Inc. and the City and County of Honolulu Dept. of Parks and Recreation, 1988.

method, by which changes at specific points along a shoreline are measured on historical aerial photos, does not provide as complete coverage of information from the photos as digitizing of continuous beachlines. However, it is a cost-effective method for evaluation of island-wide or statewide coastal reaches, and could be used in an initial phase effort to identify problem areas and to prioritize coastal or specific beach areas for subsequent more detailed studies. Once priority erosion planning areas are identified, then more detailed analysis of these specific areas should be accomplished to aid in developing specific "coastal protection" or "erosion management" plans. More detailed analysis should include continuous beachline analysis of aerial photos at a minimum, and could include land surveying as well.

Similar to the transect versus beachline approaches in analyzing aerial photos, land surveying effort could range from accomplishing discrete profile measurements (surveying along a transect) to topographic surveys which provide land truth data over an entire area in sufficient detail such that elevation contour lines can be drawn for the coastal reach. For planning purposes, surveyed profiles along the aerial photo transects would be appropriate and least costly. For detailed engineering and design of specific erosion control or protection measures, topographic (and possibly even hydrographic surveys) will be necessary.

A program of data acquisition should be established to build upon the existing (and somewhat spotty) historical data base of aerial photos and should include land survey data as well. For coverage of large areas, aerial photography is generally the most cost-efficient approach. For detailed data along specific coastal reaches, land surveying is preferred. A possible data acquisition program could consist of state-wide aerial photographic coverage, supplemented with surveyed profiles at priority erosion planning areas. Additional surveying of continuous beachlines at these priority erosion planning areas could provide an added level of detail to the database, as well as to document the jurisdictional shoreline boundary changes for regulatory purposes.

1.5 GENERAL HUMAN RESPONSES TO SHORELINE CHANGES - SHORELINE PROTECTION/STABILIZATION VERSUS EROSION MANAGEMENT/REGULATION

Erosion of beaches and shorelines is a natural process and is usually not considered a problem until the erosion threatens or has caused damage to man-made structures and improvements or interferes with coastal activities. In unpopulated areas, erosion may go unnoticed for years before it is recognized, usually by the landowner whose valuable property is being lost to the sea (thus becoming subject to State jurisdiction[15] under the Conservation District rules).

A natural human response to shoreline recession has been to prevent the loss of fastlands and/or to prevent erosion damage to existing improvements by armoring the shore against wave attack. As the principles of sediment transport were better understood, indirect shore protection methods such as groins and offshore breakwaters were added to the shore protection arsenal. Artificial restoration of beaches with periodic beach nourishment has been hailed in recent times as the environmentally sound alternative for prevention of erosion damage in lieu of structures. This response of maintaining existing fastlands and beaches assumes that humankind can overcome the forces of nature and should expend the necessary resources to attempt to do so. With a rising global population and limited land areas, this concept has validity.

However, in the more realistic planning time frames, say on the order of 25-50 years, there is a growing concern that the expenditure of resources to keep our shores and beaches from receding is not justifiable in terms of other priorities and the sometimes detrimental impacts due to human interventions. Attempts to protect or stabilize the shoreline has frequently resulted in aggravation of the erosion problem on adjacent shorelines and downdrift reaches. There is a growing awareness of the need to manage and regulate human activities in the coastal area to minimize the erosion damage potential. In some states, the government has banned all construction of shore protection structures which are designed to "harden" the shore, in order to prevent loss of beaches and dunes. Shoreline setbacks are another common management or regulatory tool used by coastal states for minimizing erosion damage potential. However, for shorelines which are chronically receding, shoreline setbacks are only a temporary measure for postponing the erosion damage potential into the next 20-30 years or so once a permanent structure is situated at the shoreline.

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[15] There is a "public trust" doctrine that is invoked with submerged lands (i.e. access along the shoreline, navigational rights, fishery rights, recreational rights).

In Hawaii, because of the relatively limited land area available for development and the intensity of existing development in certain coastal areas, there will continue to be a need to consider the shoreline protection/stabilization options as well as the management/regulation options. Unlike mainland east coast states that have many miles of sandy beaches, Hawaii's volcanic island coasts consist of relatively short stretches of beach interspersed with rocky shorelines, artificially filled shorelines, coastal cliffs, limestone beachrock shorelines, etc. Shoreline erosion problems are caused not only by loss of sediment from beaches, but also erosion damage to backshore areas due to wave runup and overtopping of the existing shoreline. Thus, this study intends to identify the structural (physical) as well as nonstructural (management/regulation) options for preventing or minimizing erosion damage and to show how some of these options can be used effectively in Hawaii.

2.0 SHORELINE PROTECTION/STABILIZATION

In the context of this study, "structural" measures for mitigating erosion and erosion-related damage are defined to include physical measures which are used to protect and stabilize the shoreline. These measures include traditional structures such as seawalls, revetments, offshore breakwaters and groins, as well as physical measures which are not considered structures in the pure engineering tradition such as beach fills or beach nourishment (sand replenishment). Because of the possible combinations of beach nourishment and structures, any physical measure to protect or stabilize the shoreline will be considered "structural" in the broader context of erosion management as discussed in this report.

2.1 RANGE OF MEASURES

Following are descriptions of some of the general types of shore protection/stabilization measures:

BULKHEADS AND SEAWALLS

Bulkheads are retaining walls whose function is usually to protect the retained soil from slumping or sliding into the water. Bulkhead structures have vertical faces and are generally utilized in low-to-moderate wave conditions. Seawalls are usually classified as structures whose primary purpose is to protect the backshore from heavy wave attack and consequently are relatively large and massive structures. Seawalls usually have vertical or near-vertical faces, which could include a recurving shape near the seawall top to re-direct the wave splash seaward. Bulkheads are usually constructed of concrete or steel sheet pile. Seawalls are typically concrete or grouted rock walls.

Due to the near-vertical and vertical design of bulkhead and seawall faces, this feature tends to accelerate the erosion of beach material fronting the structure due to wave reflection and the downrush flow following the wave crest which scours material at the base of structure. Thus, while adequate toe protection can be designed to prevent undermining of the structure, accelerated beach erosion leading to a complete loss of the fronting beach is a typical consequence. For sandy shorelines where it is desirable to minimize the potential for accelerated beach erosion, the use of bulkheads and seawalls is not desirable.

Bulkheads and seawalls only protect the backshore area immediately behind the structures and consequently, beach erosion may continue on adjacent sides of the structure and in front of it. Care must be exercised in the design to insure that subsequent beach erosion of adjacent unprotected beach sections will not flank the structure, leading to failure due to undermining from the backside.

REVETMENTS

Revetments are sloping structures typically constructed using rock of sufficient size to remain stable under design wave attack. The structural support for the revetment is obtained from the shoreline slope itself, and thus the underlying slope must be in a stable configuration. Revetments may also display a tendency to accelerate the erosion of the fronting beach due to wave reflection and down wash scour, but not as seriously as with a vertical-faced structure. Permeable rock revetments are effective in dissipating wave energy and are more conducive to beach accretion than vertical impermeable seawalls.

Revetments usually consist of an armor layer, underlying filter layer(s) and toe protection. The armor layer must be designed to resist dislocation by wave attack and the slope of the revetment must resist slumping. Typical armor materials include quarry-stone and concrete blocks of various configurations. If properly designed and constructed, these rubble-type structures are durable and not prone to catastrophic damage due to its flexibility.

In a similar manner to bulkheads and seawalls, revetments only protect the backshore zone immediately behind them and provide no protection to adjacent unprotected beaches. Thus, the prevention of flanking and possible undermining of the revetment at each of its ends is an important design consideration.

BURIED SHORELINE STRUCTURES

For beaches which undergo seasonal erosion/accretion cycles and with relatively stable vegetation lines, storm events or unusually extreme seasonal erosion can result in loss of fastlands and damage to facilities located landward of the usually stable vegetation line. Shoreline protection structures such as revetments or gabions can be constructed at the vegetation line to prevent erosion damage in the event that unusually extreme erosion occurs. These structures would be constructed by excavating landward of the beach, placing the structure, and then burying the structure such that it would not become exposed until such time as an extreme erosion cycle occurs. When the erosion cycle reverses and the beach accretes, the structure would again become buried by the beach.

It is important to design the structures to withstand the wave attack which would be expected if the beach completely erodes and exposes the structure to direct wave attack. Sloping rubble revetments or other similar structures which are permeable and can dissipate wave energy are preferable to vertical impermeable seawalls, since the latter would hinder sand buildup in front of the structure during the accretion cycle.

Because these structures would be exposed infrequently, materials which would normally not be used in permanent shore protection structures because of lower durability could be considered. Such structures include gabions, which are large fabricated wire baskets filled with smaller rock than would normally be used in rubble revetments. The basket holds the stones together to form a large stable unit, and the baskets are stacked to achieve the desired height. While the baskets can be obtained with plastic-coated wire to inhibit rust in a marine environment, the coatings can wear and abrade permitting the wire to quickly rust and break. Gabions are considered a low-cost "temporary" shore protection alternative because of their low durability and high maintenance requirements[16].

OFFSHORE BREAKWATERS

Offshore breakwaters are constructed parallel to the shoreline as a single structure or multiple structures in series. While the previously described structures provide direct protection for the shore, offshore breakwaters are used to provide indirect protection by dissipating the incoming wave energy, thereby forming a relatively protected area in the lee of the structure. Since littoral sediment transport processes require breaking wave energy to transport the littoral materials in the surf zone, a reduction of the incident wave energy will directly reduce the littoral sediment transport. If the longshore-moving littoral transport is the dominant process, then littoral material will accumulate in the shadow zone of the breakwater, usually resulting in a seaward accretion of the shoreline. This accreting shoreline behind the breakwater will also result in a similar erosion of material on the downdrift side since sand has been removed from the littoral stream.

Sometimes, the accreting shoreline will continue to move seaward until it reaches the offshore breakwater, forming a configuration called a tombolo. Once the seaward migration of the shoreline in the lee of the breakwater has stabilized, the updrift longshore transport rate must equal the downdrift transport rate and the localized erosion of the immediate downdrift shoreline would cease. Under this steady state scenario, the localized downdrift erosion will not be rebuilt and thus, it may be necessary to provide sand fill to restore the beach to its pre-breakwater situation. In this light, to avoid the downdrift erosion following construction of an offshore breakwater, sand fill could be placed in the shadow zone to rapidly stabilize the beach

[16] Brochures by U.S. Army Corps of Engineers: "Low Cost Shore Protection", 1981, and "Help Yourself, A Shore Protection Guide for Hawaii", 1979.

such that steady-state conditions are reached very quickly.

The effectiveness of offshore breakwaters in protecting beaches from erosion as well as the sand trapping efficiency is a function of many variables including the breakwater length, distance from shore, efficiency of the breakwater design in reducing incident wave energy, the ambient wave conditions and the littoral transport characteristics. The cost of a breakwater is proportional to its length and increases as the square of its depth. Thus, offshore breakwaters are only viable options when the offshore water depth is relatively shallow. Breakwaters are typically constructed of rock or concrete armor units.

OFFSHORE MAN-MADE REEFS

In the same way that natural reefs dissipate considerable wave energy, man-made reefs can trip long-period swell waves and cause much of the energy to be dissipated in the breaking process. These offshore man-made reefs can be designed as submerged breakwaters, wide shoal areas suitable for surfing, or complex reef modules that provide habitat for marine life. These offshore structures could provide recreational opportunities as well as serve to mitigate erosion. Man-made reefs do not completely block or stop all wave energy because of their low profiles. However, sufficient wave energy can be dissipated to allow suspended material to be deposited behind the reef structures or to substantially reduce beach erosion.

Construction materials can include stone or concrete units of various configurations placed in a rubble mound, as well as a number of patented modular systems such as the Surgebreaker and Longard tube.

GROINS

Groins are structures which are constructed perpendicular to the shoreline and can be used in a series or as a single groin. Groins are effective in stabilizing shorelines when the dominant sediment transport process is the longshore movement of littoral material. In the short term following construction of a groin, sand will accumulate on the updrift side of a groin, while erosion will occur on the downdrift side since the sand trapped on the updrift side no longer replenishes the downdrift side. The beach shoreline will rotate and develop an equilibrium plan shape which will be parallel with the local wave crest at the shoreline. When this equilibrium shape is reached and the accreting beach toe reaches the tip of the groin, littoral material will then bypass the groin in a steady state flow. If the longshore transport is not predominantly in one direction, then groins can be used to divide a littoral cell to prevent excessive seasonal erosion and accretion changes at the boundaries of the littoral cell.

There are many considerations to the design of a groin. For the given nearshore wave conditions, the length and height of a groin will dictate the degree of sand by-passing over the top and around the seaward end, which in turn dictates the updrift shoreline shape. A groin that is too long may not allow sediment to travel around its end, thus causing continual downdrift erosion and an unsatisfactory updrift shoreline configuration. Moreover, if the groin extends beyond the breaker zone, the sediment moving around the groin end may be deposited offshore where the normal wave-induced littoral forces may not be able to transport it shoreward. A groin that is too short may not trap sufficient sand to provide the required updrift beach width.

In order to mitigate the characteristic erosion of the downdrift shore, multiple groins can be constructed along a long stretch of shoreline, forming a groin field. Moreover, sand fill can be initially placed between groins to rapidly stabilize the beachline, and thereby greatly reduce the downdrift erosion effects in the short term. In the design of a groin field, the optimum spacing between groins is a difficult evaluation and is a function of many variables including the groin characteristics, offshore topography, incident wave directions, littoral transport characteristics and the desired shape of the shoreline between groins. If groins are too far apart, the downdrift erosion between groins will be extensive. If groins are spaced too close together, they will be very inefficient and possibly ineffective.

Groins can be constructed of a variety of materials including rock and concrete units in rubble mounds, timber, steel or concrete sheet-pile, and patented systems such as the Longard tube. A Longard tube is circularly woven polyethylene fabric tube that is filled by a patented process with a mixture of water and sand under pressure. Longard tubes are considered low cost "temporary" measures as they can be easily cut or damaged and are a potentially high maintenance measure.

BEACH FILL OR BEACH NOURISHMENT

Erosion damage can be mitigated by providing beach fill or beach nourishment, whereby sand is placed onto the eroding beach by mechanical means. While structures seek to provide permanent solutions to shoreline erosion, beach nourishment can be classified as a temporary solution, where periodic nourishment will generally be required. In recent years, beach nourishment has gained support since it provides a "soft" impact on the shoreline versus the "hard" effects due to structures. Moreover, there are no erosion effects to the adjacent shorelines due to beach nourishment, while shore protection structures may result in some type of erosion effect on the beach which needs to be considered in the design process.

On the other hand, the concept of continual maintenance cost for beach fill may not be acceptable and over many years the cumulative cost may greatly exceed the initial cost for other alternative measures. Moreover, in Hawaii there is a definite lack of supply of onshore sand which would be appropriate material for beach fill, and thus, the present cost of beach nourishment is very high.

The selection of the appropriate beach nourishment material must be carefully considered since the equilibrium beach profile is sensitive to the sand grain size distribution. In general, for compatibility, the selected beach fill material should have similar characteristics to the existing beach material where the nourishment will be applied. In the determination of the volume of beach fill material to be applied, it should be noted that fine sediment fractions will be rapidly suspended and carried offshore by wave action, thereby reducing the in-place volume of fill material. It is not unusual to have an expected loss of 20% of beach fill due to the loss of the fine fractions.

In the evaluation of the volume of beach fill required to widen an existing beach, the concept of an equilibrium beach profile is appropriate. The equilibrium beach profile is the stable beach profile that has been shaped by the local wave forces interacting with the local beach sediments and the unique topography and hydrographic features of the shoreline and nearshore zone. The typical methodology to obtain the equilibrium beach profile is to directly measure the profile at the candidate beach. Clearly, there is no constant equilibrium beach profile, since wave conditions are continually changing, but the basic concept is useful.

It is usually assumed that any beach fill material placed on the beach, when subject to constant local wave attack, will adjust itself such that a similar equilibrium beach profile will be obtained except that the entire profile will have been shifted seaward due to the fill. In other words, an identical shaped beach profile will be developed, parallel to the pre-fill profile, displaced a distance seaward. This distance seaward is the expected increase in width of the dry beach. The volume of beach fill required to obtain a unit increase in width of beach is determined by the volume between the parallel equilibrium beach profiles. The importance of the above discussion is that the initial placement of beach fill width will not be the final equilibrium dry beach width after adjustment by wave forces. In many cases, the final width may be substantially less than the initial beach fill width.

The plan shape of beach fill deposition will also adjust itself to the natural environment. For example, along a straight coastline, if beach nourishment is proposed for a short section of the shoreline such as at a beach park, the beach fill will cause a seaward projection along the shoreline which the natural forces will attempt to smooth out. In a similar concept to the equilibrium beach profile in the offshore direction, an equilibrium shoreline plan shape in the alongshore direction can be envisioned. Any discontinuity or anomaly from this equilibrium shoreline will concentrate wave forces and the beach fill will be redistributed or diffused alongshore until the shoreline again reaches the equilibrium shape, but displaced a small distance seaward. Thus, the design of a beach nourishment project must consider the existing shoreline plan shape onto which the fill is placed, in order to determine the resulting effects of the fill in meeting the project goals.

STRUCTURES AND BEACH FILLS

As noted previously, combinations of structures with beach fill may be appropriate as indicated for the offshore breakwater and groin field concepts. When structures are used to stabilize major beach fills, then the requirement for periodic nourishment may be reduced or eliminated.

Another combination structure and beach fill solution is the perched beach concept. Perched beaches are usually constructed by placing sand fill behind a structural barrier or sill which surrounds the three perimeter sides of the beach. The beach fill is placed within the protective perimeter sill and filled to a desired elevation which could be above or below the normal water level. This creates a beach recreational area, but usually there will not be a beach face fronting the perched beach perimeter structure. While it is possible to construct a perched beach with a sill and beach fill elevation below the normal water level, there is a serious liability associated with this design. The drop-off at the sill edge into deeper water creates a serious hazard to unwary and inexperienced swimmers.

DUNES AND VEGETATION

Dunes are formed by the wind blowing sand across the beach until it meets an obstruction, where the sand accumulates into a mound or ridge. Sand dunes provide some protection to low-lying backshore areas by reducing the potential for storm wave overtopping of the foreshore and flooding. Sand dunes can also reduce the potential for erosion damage to backshore areas by acting as additional storage reservoir for sediment if the beach is eroding.

Vegetation can be used to increase the height and volume of sand dunes where the wind is predominantly onshore, as well as retard the loss of sand blown offshore by winds. Vegetation can also help to reduce erosion by binding the soil with their root systems and by serving as ground cover to reduce scouring of bare sediment. Plant varieties that are adapted to the coastal environment should be used. Vegetation must be considered as a "temporary" shore protection measure, since the vegetation alone will not survive storm wave attack or prevent persistent direct wave erosion. Vegetation may slow the rate of erosion but will not eliminate or prevent erosion. The life span of the planted vegetation may be as short as the period between major storm wave attacks. However, even after the established vegetation is undermined and topples at the shore, the fallen trunks and branches and the residual root mats continue to dissipate wave energy.

2.2 DETERMINING THE APPROPRIATE STRUCTURAL MEASURE

This discussion pertains to the choice of appropriate structural measures and does not include consideration of non-structural options or alternatives such as governmental controls and regulations. (Chapter 3 focuses on discussion of management and regulatory controls.) Planners should consider the full range of socio-economic, environmental, and technical factors in the development of coastal protection or erosion management plans for specific case sites. Governmental bodies also need to establish priorities and policies to deal with conflicting needs and values, such as between private property owners and the general public. Only then can rational evaluation of viable alternatives (structural and non-structural) be developed. It is not the intent of this study to dictate the appropriate alternatives - this choice can only be made after comprehensive site evaluations are accomplished and upon establishment of priority considerations by those charged with the coastal management responsibilities.

The selection of the most appropriate shoreline protection or stabilization measure for a given site is a function of many variables, some of them technical, while others relate to qualitative criteria such as land use functions, benefit versus cost, etc. For example, for public beach parks, the use of the park and beach area for recreational purposes is very important. Thus, the concept of simply protecting the park area from erosion may not be fully compatible with its use requirements. In particular, it is desired that a sandy beach face be available so that recreational use of the beach face is available and allows easy access to the ocean for other ocean related recreational activities. In this regard, some of the shore protection measures such as seawalls and revetments may not be functionally suitable for the beach parks. On the other hand, when existing structures are in danger of wave damage or collapse due to the undermining of their foundations by erosion, it may be necessary to utilize a shore protection measure such as a seawall or revetment to provide relatively permanent shore protection. Thus a choice of the preferable structural alternative(s) will depend on site-specific evaluation of the full range of factors applicable to the site. These factors to be considered include:

- o Geological/physical shoreline features
- o Land use and degree of development
- o Benefit versus cost

Following is a summary of some of the major considerations pertinent to these factors and the potential suitability of structural measures that may be appropriate depending on certain conditions. Table 2-1 provides a quick reference guide to the discussion. The complexities of the coastal erosion processes and sometimes extenuating circumstances of a particular site and situation may contraindicate the general guidelines described below. It is important that the general guidelines herein not be used as a substitute for professional engineering and design of any site-specific shore protection/stabilization measure.

FACTOR: GEOLOGICAL/PHYSICAL SHORELINE FEATURES

CASE 1: Extensive sandy offshore and beach area:

- o Beach nourishment is preferable provided suitable sand source is available and economical to obtain.
- o Offshore structures (breakwaters, man-made reefs) are potentially viable for moderate nearshore water depths. If the nearshore bottom slope is steep, deep water depths and high wave conditions would make the structure cost-prohibitive. Typically designed to allow sand by-passing if littoral transport is predominantly alongshore to minimize downdrift erosion impacts.
- o Groins are potentially viable when littoral transport is predominantly alongshore. Not suitable when littoral transport is predominantly in onshore-offshore direction. Typically designed to allow sand by-passing to minimize downdrift erosion impacts.
- o Buried shoreline structures are suitable for cyclical (seasonal or extreme storm event) erosion to provide a line of defense against erosion damage to structures and property. Not particularly suitable for chronic erosion if the goal is to maintain the sand beach.
- o Revetments are suitable if the priority goal is the protection of structures and property. Generally the most direct protection measure and least costly of the suitable measures. Design of the revetment toe and foundation are critical to achieving structural stability.
- o Bulkheads and Seawalls are not suitable for highly dynamic sandy offshore and beach environment.

CASE 2: Sandy beach area but limited offshore sand supply (i.e. offshore reefs and reef flats):

- o Beach nourishment or beach fill in combination with structures are preferable provided suitable sand source is available and economical to obtain.
- o Offshore structures (breakwaters, man-made reefs) are potentially viable for moderate nearshore water depths. If the nearshore bottom slope is steep, deep water depths and high wave conditions would make structure cost prohibitive. Typically designed for minimal or no sand by-passing unless periodic nourishment is provided. Requires consideration of downdrift erosion if littoral

transport is predominantly alongshore.

- o Groins are potentially viable when littoral transport is predominantly alongshore. Not suitable when littoral transport is predominantly in onshore-offshore direction. Should be considered in a groin field if beach areas are narrow to minimize downdrift erosion impacts. Typically designed for minimal or no sand by-passing unless periodic nourishment is provided.
- o Buried shoreline structures are suitable for cyclical (seasonal or extreme storm event) erosion to provide a line of defense against erosion damage to structures and property. Not particularly suitable for chronic erosion if the goal is to maintain the sand beach.
- o Revetments are preferable if the priority goal is the protection of structures and property, and the secondary goal is maintenance of the beach. Revetments are a more direct measure of protection and generally less costly than offshore structures, groins and beach nourishment.
- o Bulkheads and Seawalls are suitable if erosion is chronic and the priority goal is the protection of structures and property. Generally the least costly measure.

CASE 3: Rocky shoreline area:

- o Bulkheads and Seawalls are preferable if the priority goal is the protection of structures and property from erosion and wave damage. Generally the most direct measure of protection and least costly.
- o Revetments are suitable for high wave energy environments. Generally more costly than seawalls for moderately low wave environment and take up considerable more space due to the sloping seaward face of the structure.
- o If the goal is creation of beach area, beach fill is potentially viable if contained by structures such as groins, breakwaters, or as in a perched beach.
- o Measures other than seawalls and revetments are generally not economically viable because of the high costs and relatively greater uncertainties regarding shore protection efficacy.

<u>FACTOR: LAND USE AND DEGREE OF DEVELOPMENT</u>

CASE 1: Preservation, open space and parks:

- o Beach nourishment of eroding sandy beach areas or beach fill in combination with containment structures are preferable to enhance public access and enjoyment of the shoreline, provided that suitable sand source is available and economical to obtain.
- o Offshore structures (breakwaters, man-made reefs) are potentially viable as a means of protecting/stabilizing beach areas while providing additional offshore recreation opportunities such as surfing, diving, fishing.
- o Groins are potentially viable as a means of stabilizing beach areas when littoral

transport is predominantly alongshore.

- Buried shoreline structures are effective for cyclical (seasonal or extreme storm event) erosion to provide a line of defense against erosion damage to public structures and improvements. Not particularly suitable for chronic erosion if the goal is to maintain the sand beach.
- Revetments are preferable if the priority goal is the protection of public structures and improvements, and the secondary goal is maintenance of the beach. Revetments are a more direct measure of protection and generally less costly than offshore structures, groins and beach nourishment.
- Bulkheads and Seawalls are suitable if erosion is chronic and the priority goal is the protection of public structures and improvements. Not advisable for highly dynamic sandy offshore and beach environments. Generally the least costly measure.

CASE 2: Residential:

- For properties fronted by sandy beach area, revetments are preferable for protection of structures and property. Revetments are more conducive towards maintaining the sandy beach than impermeable seawalls. For highly dynamic sandy offshore and beach areas, revetments are less prone to failure than seawalls if properly designed.
- For properties fronted by rocky shoreline, seawalls are preferable for protection of structures and property from wave runup and erosion damage. Seawalls are least costly (financially affordable) and take up less space along the shoreline than sloping revetment structures, thus maximizing use of the backshore areas as well as preserving the open space public shorefront seaward of the structure.
- For properties fronted by sandy beach area but with limited offshore sand supply, such as areas fronted by reef flats, seawalls may be suitable if erosion is chronic.
- For properties subject to cyclical (seasonal or extreme storm event) erosion, buried shoreline structures are effective to provide a line of defense against erosion damage.
- Measures other than seawalls and revetments are generally not economically viable because of the high costs and relatively greater uncertainties regarding shore protection efficacy.

CASE 3: Resort:

- Beaches and beach access to the water are highly desirable for resorts situated along the shoreline. Relatively high costs associated with measures to maintain or provide recreational beach areas may be justifiable in terms of the added value to the resort.
- Measures that restrict access to the shoreline and water are not suitable nor

generally desirable unless the protection of structures or improvements from imminent erosion damage precludes other alternatives.

CASE 4: Commercial or business use:

- o Shoreline areas which are presently developed for commercial or business uses generally have considerable infrastructure investment relative to the parcel land area. This situation is similar to residential properties where measures other than seawalls and revetments are generally not viable because of the high costs and relatively greater uncertainties regarding shore protection efficacy of other measures.
- o Depending on the exact nature of the use, however, more costly measures may be justifiable in terms of added value to the commercial activities. For example, relatively high costs associated with measures to maintain or provide beach area may be justifiable for a visitor-attraction facility.

CASE 5: Essential public facilities:

- o For essential public facilities fronted by sandy beach area, revetments are preferable for protection of facilities. Revetments are more conducive towards maintaining the sandy beachfront than impermeable seawalls. For highly dynamic sandy offshore and beach areas, revetments are less prone to failure than seawalls if properly designed.
- o For essential public facilities fronted by rocky shoreline, seawalls are preferable for protection of facilities. Seawalls are generally less costly and take up less space along the shoreline than sloping revetment structures, thus maximizing use of the backshore areas as well as preserving the open space public shorefront seaward of the structure.
- o Measures other than seawalls and revetments are generally not viable for protection of essential public facilities because of the high costs and relatively greater uncertainties regarding shore protection efficacy.

<u>FACTOR: BENEFIT VERSUS COST</u>

CASE 1: Protection versus relocation:

- o The cost to construct and maintain a particular shore protection or stabilization measure must be weighed against the cost of the existing improvements or land intended to be protected by the proposed measure. Obviously, if the cost of the protection measure is far greater than the cost to relocate the structure being threatened by erosion damage, then the prudent decision might be to relocate the structure, provided that relocation is a viable alternative.
- o For chronic erosion, the alternative of relocation is less viable since the long-term consequence will be the permanent and possibly complete loss of the

usable parcel area.

CASE 2: Total cost (construction plus maintenance) versus benefits:

- o The total cost of initial construction plus the long-term maintenance over the desired lifetime of the improvements or uses to be protected is a factor to consider in the choice and design of the protection measure. For example, a gabion seawall, while less costly to construct than a rock masonry seawall, may require replacement every 5 years compared to the more permanent rock masonry seawall. Suppose that the cost to construct (and reconstruct) the gabion wall is $5,000 every five years; the cost to construct the rock masonry wall is $15,000 with an expected life of 20 years; the house intended to be protected is valued at $150,000; and the owner intends to live in the house for another 20 years. The prudent choice would be the rock masonry seawall since it affords more permanent protection at a lesser cost over twenty years than the gabion wall, and is economically justifiable in terms of the value of the house. Suppose though that the house is valued at $50,000 and the owner intends to sell the house within the next 5 years. In this case, the more prudent choice would be the gabion wall.
- o "Permanence" of a structure or measure is not necessarily the preferred goal for shore protection or stabilization. Where the level of protection is not extremely critical, for example the stabilization of open park lands, "temporary" measures with low initial construction cost, but potentially high maintenance cost, may be appropriate. Such measures could include beach fill to restore beach damage due to an unusually severe erosion cycle, vegetative plantings to slow the erosion process (will not prevent erosion), or low cost structures which may prevent typical yearly erosion loss but will not prevent storm wave erosion damage.

CASE 3: Intangible costs and benefits:

- o For protection of public works improvements or essential public facilities, intangible benefits such as public safety and convenience may dictate the choice of a costly permanent shore protection structure rather than a less costly measure which would require frequent maintenance and is less "reliable" in terms of level of storm wave protection, even though the latter has been determined to be less costly in the long term.
- o Other intangible benefits or costs could include aesthetics and social well-being in relation to public parks and beaches and how the public perceives certain protection measures. For example, offshore breakwaters may be unacceptable if the scenic vistas from the shore are completely blocked by the structures.
- o Maintenance of public access to and along the shoreline is another consideration which may limit the choice of alternatives. For example, if

unobstructed beach access is a desired benefit, then shoreline structures are less desirable than beach nourishment. There is also a range of intangible benefits and costs depending on the specific design of a particular structure. For example, a revetment can be designed to provide varying degrees of shoreline access, such as steps built into the structure to provide limited access points to and from the water, and wide crest widths for walkways or terraces built into the face of the slope (rather than a uniform slope) to allow lateral access alongshore. These features will add to the construction cost but could yield desired benefits of public access to varying degrees.

There are an infinite number of site-specific circumstances comprised of various combinations of factors. It would be beyond the scope of this study to attempt to define each specific circumstance and the most appropriate structural measure for the specific circumstances. Even if one were able to generally characterize certain factors as described above, there are probably over 100 possible different combinations of these factors for which one could deduce a preferable measure. Figure 2-1 is an example flow chart which shows a typical evaluation process whereby suitable alternative measures are identified according to the desired goals and other factors.

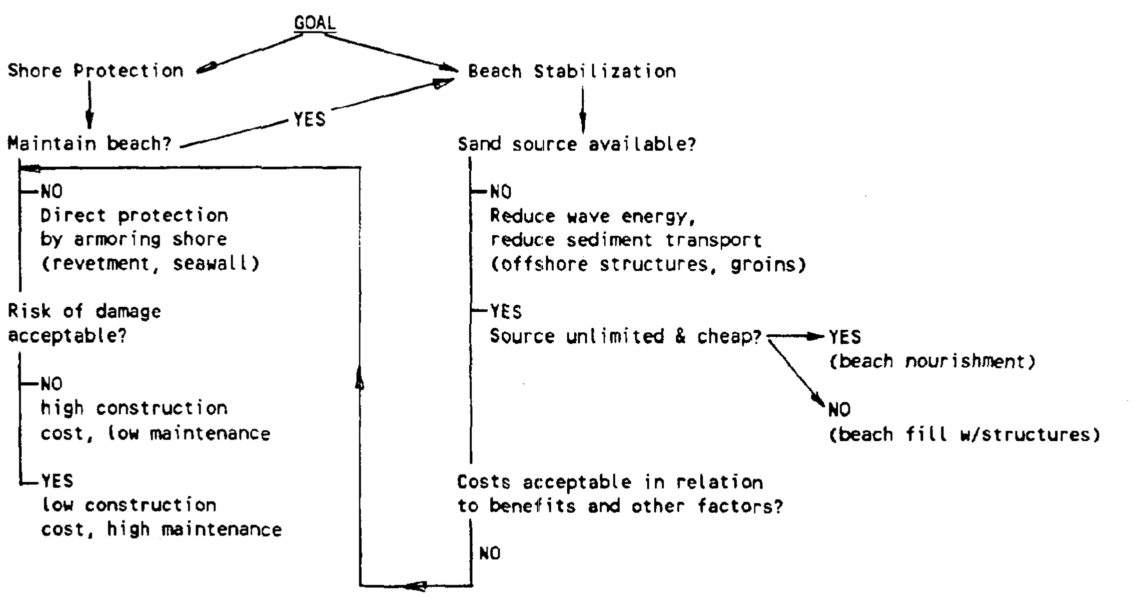

FIGURE 2-1 EXAMPLE FLOW CHART TO EVALUATE SUITABLE STRUCTURAL MEASURES

The specific design of any particular measure (structural and functional characteristics) is also dependent on the factors surrounding the particular circumstance. For example, an offshore breakwater can be designed high and massive for complete containment and protection against an extreme design storm event, or submerged for incomplete storm wave protection but to provide adequate beach stabilization under typical wave conditions. The approximate cost and time to implement each type of measure is in turn dependent on the specific design and the site conditions. For the example of the offshore breakwater, the submerged breakwater could be one-half the cost of the high breakwater.

The choice of the appropriate measure and the specific design of the measure can only be made after consideration of all factors, adequate site investigations and coastal engineering analysis, and the identification of priorities. There may be several alternative measures that would technically be suitable for a particular erosion problem, depending on the specific design of each measure. A particular measure, on the other hand, if improperly designed may not be appropriate even if the general concept is generally accepted as appropriate. The purpose of this discussion is to broaden the perspectives of persons not versed in coastal engineering, and to provide a general overview of the evaluation process in determining the appropriate structural measure for shoreline protection or stabilization.

TABLE 2-1

FACTORS TO CONSIDER IN CHOICE OF APPROPRIATE SHORE PROTECTION/STABILIZATION MEASURE

FACTOR	PREFERABLE <1>	SUITABLE <2>	NOT SUITABLE <3>
Geological/Physical Shoreline Features			
Case 1: Extensive sandy offshore & beach area	Beach nourishment	Offshore structures Groins Buried structures Revetments	Seawalls
Case 2: Sandy beach but limited offshore sand supply	Beach nourishment Beach fill w/ structures	Offshore structures Groins Buried structures Revetments Seawalls	-----
Case 3: Rocky shoreline area	Seawalls	Revetments Beach fill w/ structures	Offshore structures Groins Buried structures Beach nourishment
Land Use and Development			
Case 1: Preservation, open, parks	Beach nourishment Beach fill w/ structures	Offshore structures Groins Buried structures Revetments Seawalls	-----
Case 2: Residential	-----	Revetments Seawalls Buried structures	Offshore structures Groins Beach nourishment Beach fill w/ structures
Case 3: Resort	Beach nourishment Beach fill w/ structures Buried structures	Offshore structures Groins Revetments Seawalls	-----
Case 4: Commercial, business	-----	Revetments Seawalls Buried structures Offshore structures Groins Beach nourishment Beach fill w/ structures	-----
Case 5: Essential public facilities	-----	Revetments Seawalls	Offshore structures Groins Beach nourishment Buried structures
Benefit versus Cost			
Case 1: Protection vs. relocation	Consider cost of protection measure versus value of existing improvements or land		
Case 2: Total cost vs. benefits	Consider initial construction cost plus long-term maintenance costs over desired lifetime		
Case 3: Intangible costs & benefits	Consider public safety, convenience, aesthetics, social well-being		

2.3 MEASURES TYPICALLY USED IN HAWAII

Almost all of the previously described measures have been used in Hawaii in one form or another. New materials or new design and construction methods have been developed over the years, but the basic concepts are not new. The basic concepts behind all of the previously described shore protection/stabilization measures are:

- provide direct protection by armoring the shore;
- provide indirect protection by reducing the damaging wave energy that reaches the shore;
- replenish the beach sediments and/or reduce the transport of sediments out of the littoral cell.

Bulkheads are rarely used on Hawaii coastal shores because of the relatively high wave exposure. Bulkheads are typically used in sheltered embayments or harbors to stabilize shoreside areas adjacent to boat berthing or docking facilities.

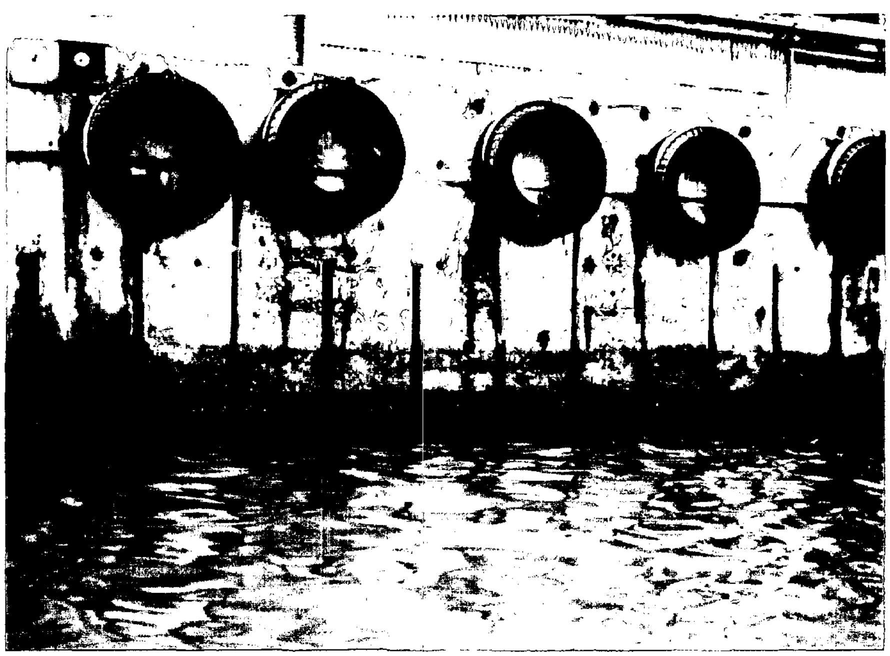

FIGURE 2-2 SHEETPILE BULKHEAD IN HONOLULU HARBOR, OAHU

Seawalls are commonly used in Hawaii. A typical seawall design is a variation of the standard gravity retaining wall, typically concrete masonry or grouted rock walls. The seawalls may be reinforced if necessary, depending on the wave exposure. Because a suitable hard foundation is usually found above the waterline, such as limestone beach rock, reef or basalt material, the seawall can typically be constructed "in the dry" as in standard land construction. Where a suitable non-erodible foundation cannot be found above the waterline, then the design and construction become more difficult since standard cement or mortar will "wash out" if unconfined below the waterline. A common cause of failure of seawalls is inadequate design or construction of the foundation, leading to scouring or leaching of backfill material at the base of the wall.

FIGURE 2-3 ROCK MASONRY SEAWALL AT MAKAHA, OAHU

Revetments are also commonly used in Hawaii. A typical revetment design consists of large quarried or field stones underlain with smaller rock layers and/or filter cloth. Because the structure does not rely on a bonding agent for structural integrity, the design and construction below the waterline is not a serious constraint. However, when the stones cannot be placed on a hard foundation, such as in a dynamic sandy beach environment, the design and placement of the revetment toe and foundation are critical to achieving structural stability. A common cause of failure is scouring of the toe or leaching of backfill material through the revetment slope, leading to slumping and unraveling of the stone layers.

FIGURE 2-4 ROCK REVETMENT AT KUKUIULA, KAUAI

Buried shoreline structures have been used, though not frequently. It generally requires some foresight since the structure is emplaced in anticipation of a severe erosion cycle. In some cases, revetments have been constructed in reaction to a severe erosion cycle, and have subsequently become naturally "buried" during the accretion cycle. A further variation to this concept is the construction of a revetment to repair damaged shoreline due to an extreme storm event, and placing beach fill in front of the revetment to restore the beach to its pre-storm condition. Portions of the shoreline in Poipu on Kauai were repaired in this manner subsequent to the devastation by Hurricane Iwa.

Offshore breakwaters have been used for public works shore protection projects, where the government can afford the relatively high costs associated with construction. The typical breakwater design consists of large quarried or field stones, with a core of

FIGURE 2-5 BURIED REVETMENT AT POIPU, KAUAI

The seaward face of the revetment is covered by the beach fill and the revetment crest, which is at the approximate elevation of the backshore, is hidden from view by the naupaka hedge.

smaller rock. Breakwaters are more commonly used in Hawaii in conjunction with boat harbors and navigation improvements rather than for shore protection/stabilization.

Offshore "man-made reefs" is a relatively new concept. This concept applied to traditional breakwater design has led to tests of submerged breakwaters and "reef" breakwaters. "Reef" breakwaters are constructed of a homogeneous pile of rock that can be reshaped by storm wave action into a stable configuration. This stable configuration depends on the size of rock and the wave characteristics. The advantage of reef breakwaters is that smaller rock can be used than in traditional breakwater design, and the construction is much simpler. This method has not been applied in Hawaii yet. Natural offshore reefs, however, are abundant in Hawaii and provide substantial protection to existing beaches and shores.

Groins have been used in Hawaii more commonly in the past than at present. Groins are a cheaper measure than offshore breakwaters for reducing the transport of sediments, and thus were a favored method for beach stabilization. In more recent times, the concern of aggravated erosion impacts to downdrift shores has led to an

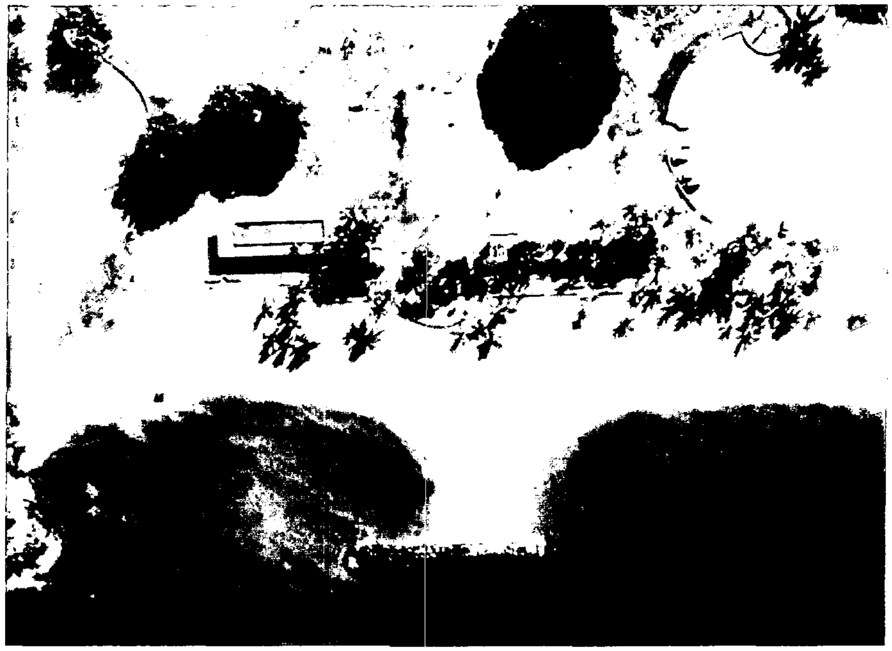

FIGURE 2-6 OFFSHORE BREAKWATER AT HALEIWA BEACH PARK, OAHU

FIGURE 2-7 NATURAL TOMBOLO FORMED BY PROTECTIVE OFFSHORE REEF ROCK AT POIPU BEACH PARK, KAUAI

unfavorable view towards the use of groins. However, groins can be used effectively in certain circumstances when downdrift impacts are not a problem or when designed as a groin field to stabilize the entire stretch of shoreline within a littoral cell.

FIGURE 2-8 GROIN AT WAILOA RIVER MOUTH, HILO BAY, HAWAII

Situated at the extreme east end of the Bayfront beach, longshore transport of sediments eastward resulted in a continual shoaling problem at the mouth of the Wailoa River. The groin effectively traps the littoral drift and helps to stabilize the beach while mitigating the shoaling problem.

Beach fill (with and without structures) has been accomplished in Hawaii, but there is presently no inland source of significant quantities of suitable beach sand. Man-made sand (crushed limestone) has been used on occasion but is not a suitable material for beach fill because of the angular grain characteristics and the tendency for the crushed material to "cement" or harden in place. The option of mining sand from the shoreline and nearshore areas by the State or County for beach replenishment only recently was made a legally viable option in general.[17] Recycling of sand within a littoral cell is an effective method for beach stabilization. For example, sand from an eroding beach may be naturally deposited offshore in such a manner that it is "lost"

[17] Act 375, HB No.2271, approved June 15, 1988, amended HRS Section 205A-44 and HRS Chapter 171, to allow sand mining in the shoreline and offshore areas by the State or County for the purpose of beach replenishment or protection of shoreline areas.

from the active littoral zone, as in a deep offshore channel. Mining of the offshore sand repository and replacement of the sand on the beach is an environmentally sound measure. The concern for maintaining and creating new recreational beach areas will lead to increasing need to locate suitable offshore sand reservoirs for beach fill purposes.[18] Maintenance clearing of drainage channels and stream mouths due to sand blockage is another source of beach fill. The sediment should be washed and separated as necessary and replaced on adjacent beaches to the maximum extent practicable to prevent depletion of sediment from the littoral cell.

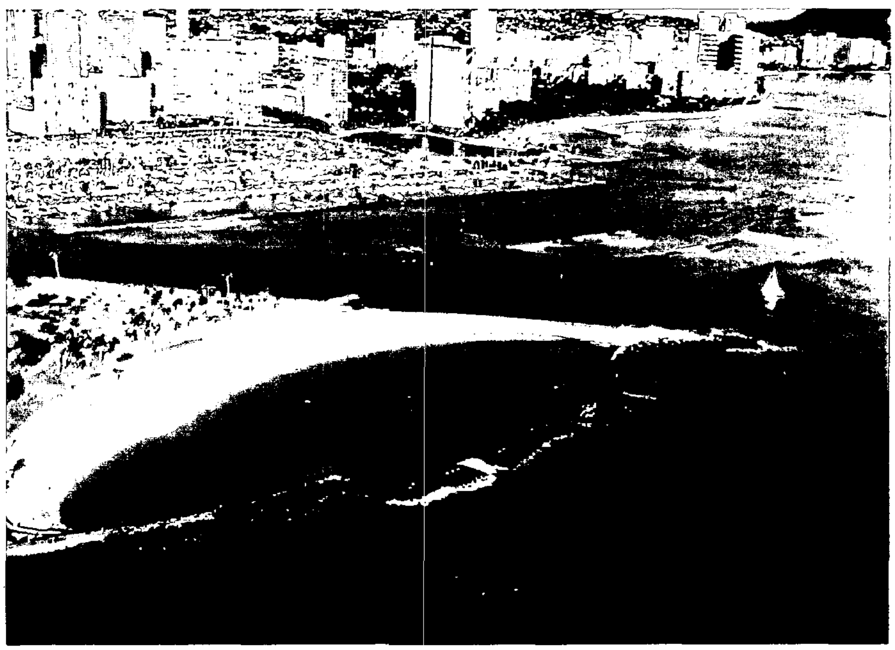

FIGURE 2-9 BEACH FILL WITH CONTAINMENT STRUCTURES AT MAGIC ISLAND PARK, OAHU

[18] Previous investigations to locate and quantify suitable sand resources for beach restoration purposes are numerous. For more information on this subject, consult the following references:

"Sand Mining in Hawaii: Research, Restriction, and Choices for the Future", by Steven J. Dollar, Sea Grant Technical Paper UNIHI-SEAGRANT-TP-79-01, Feb 1979.

Ocean Innovators: "Kailua Bay Offshore Sand Survey", prepared for U.S. Army Corps of Engineers, Jan 1978; "North Kaneohe Bay Offshore Sand Reconnaissance and Sampling", prepared for U.S. Army Corps of Engineers, Oct 1978; "Offshore Sand Sampling North and Windward Shores, Oahu", prepared for Marine Affairs Coordinator, Office of the Governor, Feb 1979; "Sand Deposit Investigation Offshore Nanakuli, Oahu", prepared for U.S. Army Corps of Engineers, Feb 1977; "Offshore Sand Deposit Data Collection, Kualoa Regional Park", prepared for U.S. Army Corps of Engineers, Feb 1977.

2.4 TYPICAL PROBLEMS AND RECOMMENDATIONS FOR IMPROVING THE MANAGEMENT OF SHORELINE PROTECTION PROJECTS

Structural or functional problems with shore protection or stabilization measures are generally the result of:

- o inadequate knowledge of the environmental site conditions;
- o inadequate knowledge of the short and long-term littoral processes;
- o inadequate design of the measure;
- o improper construction and/or maintenance;
- o goals or priorities which may constrain the selection of a particular measure.

In this section, typical problems are discussed with recommendations to mitigate the probability of structural or functional problems. One thing to keep in mind, however, is that there is an intrinsic risk that a measure will not perform optimally because of the highly dynamic nature of the ocean and coastal environment. While it is possible to reduce this risk by taking proper care in the planning, design, and construction of the shore protection/stabilization measure, the intrinsic risk is due to the inability to predict future global and regional weather patterns with any confidence.

ENVIRONMENTAL SITE CONDITIONS

Adequate site investigations need to be accomplished to determine the geological/physical characteristics as well as the typical and extreme wave characteristics. The presence or nonpresence of a hard non-erodible foundation for a structure is a critical design factor. Inadequate toe and foundation design for structures not founded on hard material is a typical cause of structural failure.

For revetments, the required weight of the armor stone is proportional to the cube of the wave height (H^3). Thus, the determination of the design wave height is important. If the design wave height is too low, then the revetment may not be stable under storm wave attack. However, a design wave height that is too high may result in unnecessarily high costs for the structure. Unfortunately, this is one design criteria factor that frequently receives the least site specific investigation. It is generally costly and impractical to obtain a sufficiently long wave data record for a specific nearshore site to determine the design wave characteristics. Thus, the determination of the design wave characteristics usually is based on theoretical analysis assuming a depth-limited wave condition or by nearshore wave transformation analysis of deepwater wave characteristics. If the analysis is accomplished by a coastal engineer, then it is reasonably safe to assume that the design wave height is conservative. Often, individuals not familiar with the site and with extreme wave events will be lulled into assuming that the typically mild wave climate should be the design wave condition. However, a structure designed for stability under maximum annual wave conditions will probably not survive an extreme 50-year storm event.

The unpredictability of nature is a problem in determining the design wave conditions. Extreme deepwater wave height is frequently determined by statistical analysis of a long period of record, by which one can estimate the wave height associated with a particular frequency of recurrence. The recurrence interval, commonly referred to as the return period, corresponds to the average interval of time for which a given event will recur given a sufficiently long period of record. For example, a 50-year design wave has a better than 50% chance of occurring once in a 50-year period, while a 100-year design wave has a better than 50% chance of occurring once in a 100-year period. However, there is also a probability that the design event will recur within a period less than its recurrence interval. For example, the 50-year design event has a 40% chance of recurring in a 25 year period, and a 2% chance of recurring in any given year. What this can mean is that a site which is exposed to typical maximum 5-foot waves and which has not been subjected to 20-foot waves in the past 50 years can tomorrow be devastated by extreme waves.

For structures sited in shallow water or on the shore, the depth-limited wave condition or maximum breaking wave height at the structure is typically used for design since this makes the selection of the design deepwater wave less critical and sometimes obviating the need for determining the deepwater design wave recurrence period.

LITTORAL PROCESSES

When the goal is to stabilize a beach, knowledge of the littoral processes is critical to the functional as well as structural design. For example, a groin field will not stop erosion if the predominant mode of littoral transport is onshore-offshore transport due to seasonal wave characteristics. When the predominant mode of littoral transport is onshore-offshore, revetments and seawalls can sometimes serve to protect against storm wave damage without significantly affecting the onshore transport processes if the structures are situated above the normal reach of waves during the accretion stage. If there is insufficient volume of existing littoral materials, structures intended to stabilize a beach may need supplemental beach fill to prevent short-term erosion damage to downdrift shores. How and where to place the beach fill in anticipation of downdrift effects requires knowledge of the littoral transport characteristics.

The concept of a "littoral cell" is important for beach nourishment. In Hawaii, sandy beaches coexist with nearshore reefs. In some areas, live coral coverage nearshore can be quite high. Indiscriminate use of beach nourishment can possibly result in serious detrimental impacts to nearshore reefs, which may end up becoming smothered by the sand that is eroding from the beach. Recycling of sand within a littoral cell is a way of insuring that the sand resources are conserved within a physical area without depleting or creating additional loading to the system. The maintenance of stream mouths along sandy shorelines is a continual effort, whereby sand which blocks the stream mouth must be removed periodically. If littoral transport is predominantly alongshore, then placement of the sediment on the downdrift shore is the prudent "beach nourishment/recycling" action. Removal of the material from the littoral cell could lead to long-term depletion of sediment from the littoral cell and future erosion problems. On the other hand, placement of the sediment on the updrift shore would negate the stream clearing effort in short order.

The analysis and evaluation of littoral processes requires training and experience. Theoretical knowledge of wave mechanics and coastal processes is essential to a complete understanding of the littoral processes at any site and the ability to design suitable protection and stabilization measures. Often the project budget and time limits the extent of the field measurement program and the level of analysis. Individual homeowners, for example, are sometimes hardpressed to afford the cost of shore protection construction, much less the cost of detailed analysis to characterize and quantify the littoral processes within the entire littoral cell (which could extend over a shoreline reach that is many times greater than their property shorefront).

For shorelines in which there is a public desire and priority need to maintain a sandy beach, then it would be appropriate for government to absorb the cost for accomplishing appropriate studies and analysis to define the littoral processes and to identify the range of measures that are technically feasible for shore stabilization along the particular coastal reach. This type of effort, similar to the case study site evaluations in this present study effort, would form the basis for future area-wide planning decisions and would give private landowners a headstart in developing appropriate engineering solutions to their erosion-related problems that are consistent with the public goals.

STRUCTURAL AND FUNCTIONAL DESIGN

The appropriate design of any measure goes hand in hand with adequate knowledge of the environmental site conditions and the littoral processes. Some of the more important design concerns are:

- o Is the structure designed to remain stable under the design wave conditions over its design life expectancy? (i.e. Rocks that are too small may result in revetment failure during the first major storm.)

- o Is the structure designed to remain stable over its design life expectancy given the nature of the littoral processes? (i.e. Flanking of a seawall may occur of chronic erosion continues on adjacent shores.)

- o Is the structure designed with suitable consideration of the foundation characteristics and scouring potential? (i.e. Lack of toe protection or adequate filter layers can result in undermining or slumping of the structure.)

- o Is the measure designed to minimize downdrift effects which can aggravate erosion problems to adjacent shores? (i.e. Groins will typically cause downdrift effects if not designed in consideration of the littoral processes within the entire littoral cell.)

- o Is the measure designed with appropriate consideration of future maintenance requirements and with adequate commitment to these requirements? (i.e. Beach nourishment requires a long-term commitment to periodic nourishment for long-term functional stability.)

- o Is the measure designed with consideration of other pertinent factors and priorities? (i.e. Protection of an essential public works facility demands a direct method of protection designed for an extreme storm event.)

Because of the specialized engineering required for the planning and design of shore protection and stabilization measures, it is highly desirable for persons proposing such work to consult a practicing coastal engineer. A person desiring to construct a high rise building, for example, will retain the services of a structural engineer to insure that the building design is structurally sound and cost-effective. Similarly, a coastal engineer would be better equipped to plan and design appropriate coastal engineering measures for the desired purpose.

A good technical reference for design purposes is the Shore Protection Manual[19], prepared by the U.S. Army Corps of Engineers. This manual provides good basic design principles, data, and design methods. This manual should be specified as the

[19] Shore Protection Manual, Volumes I and II, Coastal Engineering Research Center, Waterways Experiment Station, U.S. Army Corps of Engineers, 1984, available from the Superintendent of Documents, U.S. Government Printing Office.

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prepared by Edward K. Noda and Associates, Inc. and DHM inc. ; prepared for
Hawaii Coastal Zone Management Program, Office of State Planning, Office of the
Governor. %
$   7  260     Honolulu, Hawaii : 'b The Program, 'c [1989] %
$   8  300     2 v. : 'b ill., maps ; 'c 28 cm. %
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minimum design reference manual for any proposed shore protection or stabilization project which requires review by governmental agencies. This will encourage the use of basic coastal engineering design principles by the majority of other professional engineers who have not had formal education or experience in coastal engineering. While it may still be appropriate to require a coastal engineering evaluation and impact assessment of the proposed work, possible re-design efforts could be averted by proper attention to coastal engineering design requirements at an early stage in the planning and design.

CONSTRUCTION AND MAINTENANCE

No matter how appropriately a measure is designed, improper construction in a manner that is not in accordance with the plans and specifications can result in structural and/or functional failure. A typical problem is the case when the depth of the reef rock ledge is found to be deeper than estimated at the toe of the structure. If the plan does not state that the toe must be placed on hard material, and that the depth of the rock ledge is only estimated, the Contractor may not excavate any deeper than indicated on the plan. Thus, the toe of the structure would be susceptible to scouring and undermining, leading to structural failure. If the depth of the rock ledge is very deep or discontinuous in certain places, and it is not practical for the Contractor to excavate deep enough to find it, then the toe and foundation of the structure may need to be redesigned. Failure of even a short section of protective structure could lead to progressive failure of the entire structure. However, Contractors will often "do the best they can" given the differing site condition, without realizing how critical their field adjustments can be to the future stability of the structure. Once covered over, critical features such as the toe and foundation are not visible to the inspector. Adequate site investigations prior to design and good construction plans will minimize these problems. If there are any uncertainties with respect to the site conditions, then the plans should indicate the possible variability of these conditions and provide the Contractor with alternative design sections for anticipated differing conditions. For example, a modified toe section, for the case when the structure cannot be placed on hard reef foundation material, should be a standard detail on plans for structures in sandy reef flat areas.

A measure that is designed with a certain long-term commitment to maintenance, such as beach nourishment or beach fill with structures, may also functionally "fail" because of lack of necessary maintenance. Public projects which rely on public funding for major maintenance actions often have poor maintenance records. For example, other priorities for limited funds may mean that a scheduled beach nourishment activity will have to be postponed. This could result in more than desired depletion or recession of the beach and susceptibility of backshore improvements to erosion and wave damage. Beach nourishment, while highly desired, should not be used as a shore protection measure by itself because of the required commitment to long-term periodic nourishment. Where shore protection is an important consideration, structures should be used in combination with beach fill to reduce or eliminate the potential for future erosion damage to backshore improvements when periodic beach nourishment is not accomplished for any reason.

Problems related to construction and maintenance are not easily remedied and are inherent in construction of any improvement, whether it is a revetment, high-rise office building, or public school building. Any measure which can be taken to improve the quality of the construction plans and specifications, improve the inspection and monitoring of construction activities, and assure the appropriate maintenance of completed construction, will greatly improve the quality of any constructed improvements in general.

OTHER PRIORITIES AND CONSTRAINTS

The typical problems of inadequate site investigations, inadequate coastal engineering analysis to determine the littoral processes, inadequate design, construction and/or maintenance, all can be attributed to a typical common constraint - cost and expense. For example, it is difficult for a homeowner to justify the high cost of detailed planning and coastal engineering studies for protection of a 100-foot shoreline reach that can be armored for less than it would cost to do the comprehensive engineering studies. In most cases, chances are that if a homeowner built a structure that was similar to what a neighbor built, then it would probably work. Unfortunately, they may realize this is not always the case after the first severe storm.

One way of reducing overall cost is for adjacent landowners to jointly undertake the engineering studies, design and construction. For example, the engineering and design costs are generally of the same order of magnitude whether the coastal reach is 100 feet or 500 feet. Thus, the engineering and design cost shared by five homeowners is roughly 1/5 the cost if done individually. Construction cost can also be cheaper since the seawall can be continuous for the entire reach, with return walls only necessary at the end lots. Also, mobilization and demobilization cost for equipment is spread over 500 linear feet of seawall versus 100 linear feet, making the cost per foot cheaper.

The concept of increasing the planning and design area increases the range of options that can be considered potentially viable. Larger planning areas allow more flexibility in design approach, and the ultimate planning area from a coastal perspective is the natural boundaries of a littoral cell. As discussed previously, it may be appropriate and desirable for government to fund the cost for accomplishing littoral studies and analysis to identify the range of alternatives for an extensive coastal reach or a defined littoral cell. The case study sites evaluated in this present study is an example of the type of planning and engineering effort necessary to form the basis for more rational and organized approach to future area-wide shore protection implementation and management.

Similar in concept to County Development Plan Districts, "coastal protection plans" could establish the desired shore protection or stabilization goals, and the priority public use activities within specified coastal reaches. Because the range of measures could overlap the jurisdictional boundary between the County and State, the coastal protection plans should ideally be separate rather than incorporated into existing planning maps such as the State Land Use District maps or the County Development Plan, Zoning, or SMA maps. The plans should be jointly developed and administered by the State and County under their regulatory mandates. Chapter 5 discusses a possible approach towards developing these plans.

The present regulatory process is a typical problem which constrains the selection of the shore protection measure. The location of the proposed shore protection measure in relation to the jurisdictional shoreline[20] boundary between the County and State determines whether the applicant needs to acquire permits from only one level of government versus two (and possibly even three if the U.S. Army Corps of Engineers is involved). Because it is difficult to obtain a Conservation District Use permit from the State for construction of shore protection[21], many homeowners will purposely construct shore protection that does not extend seaward of the certified shoreline, which in most cases is the vegetation line. In this case, only a shoreline setback variance must be obtained from the County, and no permits are necessary from the State. This limits the shore protection options to seawalls and revetments. Now suppose that progressive erosion has resulted in less than 10 feet remaining between the house and the vegetation line fronted by a beach. While a revetment may be the preferable measure for the particular situation, lack of adequate space to construct the revetment entirely landward of the vegetation line may mean that the homeowner's only viable option is construction of a vertical seawall. An integrated permitting process could resolve some of these problems associated with jurisdictional constraints. Coastal protection plans that are jointly administered would also mitigate these problems.

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[20] "Shoreline" means the upper reaches of the wash of the waves, other than storm and seismic waves, at high tide during the season of the year in which the highest wash of the wave occurs, usually evidenced by the edge of vegetation growth, or the upper limit of debris left by the wash of the waves.

[21] Discussions with DLNR personnel indicate that a Conservation District Use Application (CDUA) for permit to construct shore protection for private property is generally denied.

A typical issue in establishing the priorities, constraints, and goals is the question of individual rights versus the rights of the public at large. To what extent can the government impose constraints on individuals for the good of the general public before it is considered unreasonable or "taking"? The Courts have established that government must fairly compensate developers when they have established vested interest in a parcel and are subsequently denied the right to develop the parcel as planned. Thus, it may be reasonable to expect that if government denies private property owners the right to protect their land and existing improvements from erosion and wave damage because it may not be the appropriate measure for retaining the sand beach, then it may be appropriate for government to compensate owners by purchasing their lands and improvements or to subsidize the high cost of constructing more suitable beach improvement and stabilization measures. While shoreline setbacks are a method of maintaining the public priorities with minimal loss of individual rights, the variance procedures for shore protection recognize the need to preserve individual rights to welfare and safety when their homes are threatened by erosion or wave damage.

3.0 EROSION MANAGEMENT AND REGULATION

3.1 MANAGEMENT OF EROSION: A REGULATORY PERSPECTIVE

Previous sections have described what is known about erosion processes in Hawaii. Erosion has been described as involving many different factors such as geologic features, wave patterns, wind direction, weather conditions, currents, sea level rise, and the presence of numerous natural and man-made physical structures. In addition to erosion occurring gradually over time, there are also instances of episodic erosion caused by severe storm events such as hurricanes or tsunamis. Erosion is not only difficult to control, but it is also difficult to forecast and predict with certainty, either for specific parcels of property or for large reaches.

Other sections in this report have also described "structural approaches" to managing erosion problems. These include the construction of various physical barricades, on land--revetments, seawalls, bulkheads, etc.--as well structures located in water--groins, man-made reefs, and other measures for reducing wave action. In some respects, "non-structural" approaches, that is, regulating development along the shoreline, are preferable to structural remedies because of the following reasons:

- the construction of man-made barriers may be detrimental to the physical environment and to beach ecosystems;
- some of the structural remedies (such as seawalls, revetments, bulkheads, etc.) may limit or impede beach access;
- in some instances, structural remedies may end up shifting the erosion problems to other areas;
- non-structural remedies are, in most cases, more flexible than structural remedies (i.e., setback regulations, development restrictions, etc. can be adjusted if erosion rates change).

Erosion is a type of problem that people and their regulatory systems may be inclined to ignore or treat in a reactive manner. Erosion problems may impact a specific property owner or group of owners in just one area. The lines of public versus private responsibility for controlling and mitigating the effects of erosion may be blurred. There may also be jurisdictional or interagency conflicts between federal, state, and local government responsibilities. Regulations to control development in areas prone to erosion can be justified on the following grounds:

- government's responsibility to protect its citizens from natural hazards;

- erosion damage can generate large public and private costs, through the loss of property, construction of structural remedies, and the loss/reduction of tax revenues;

- erosion often leads to individual actions (such as the construction of seawall or revetments) which may have unintended consequences or externalities;

- with shoreline erosion, public lands or resources (beaches and ocean) under control of government agencies are often involved;

- erosion problems may occur gradually over time and impose a disproportionate share of the costs to future generations;

- the public's "right to know" can be applied to erosion sensitive areas, particularly when residential and commercial uses are proposed;

- erosion management can be seen as part of a larger set of policy initiatives involving open space preservation, beach access, shoreline development and ocean resource management.

3.2 FEDERAL PROGRAMS RELATED TO EROSION CONTROL AND PRACTICE IN HAWAII

The major federal programs related to erosion control and management include: (1) those established under the Coastal Zone Management Act of 1972; (2) the national flood insurance programs administered under the Federal Emergency Management Agency; and, (3) the U.S. Army Corps of Engineers (USCOE).

Perhaps because much of the country's erosion problems occur in those areas where land meets water (ocean or freshwater bodies), it is not surprising to find that erosion is addressed under the federal Coastal Zone Management Program (CZM). The Coastal Zone Management Act (P.L. 92-583) was signed into law on October 27, 1972. The Act authorized the creation of a federal grant-in-aid program to be administered by the Secretary of Commerce, who in turn delegated responsibility of the program to the National Oceanic and Atmospheric Administration (NOAA). The purpose of the Coastal Zone Management Act (CZMA) was to provide assistance and encouragement to coastal states to develop and implement rational programs for managing coastal zones. Broad guidelines for the development and approval of an individual state's CZM program were provided in the Act and included:

- the identification and evaluation of coastal resources requiring management and protection by the state;
- the examination or formulation of new policies which are "specific, comprehensive, predictable and enforceable" to manage coastal resources;
- the determination of specific uses and special geographic areas subject to the management program;
- the consideration of national interests in the planning for and siting of facilities;
- the design of sufficient legal authorities and institutional arrangements to implement the program and ensure conformity to it.

To date, 29 of 35 eligible coastal states, including Hawaii, have federally approved CZM programs. Once an individual state has received approval of their CZM program, they become eligible for a variety of different grants and loans. Federal funds can be used for activities including planning, research, training, land acquisition, and implementation of coastal management initiatives. When the federal program was first established, many of the grants were available on a 90-10 or 80-20 percent federal-state, matching basis. The CZMA presently calls for a gradual shifting over to a 50-50 split between federal and state funds.

Shoreline erosion is explicitly referred to in the CZMA as an area of concern to be addressed by policy. Moreover, in a survey of coastal managers, shoreline erosion was listed as one of the top management issues for coastal states.[22] The federal CZM office encourages greater cooperation among all levels of government in the planning for and management of hazard prone areas through the adoption of resource management laws which are jointly administered by local, state, and federal agencies.

The Federal Emergency Management Agency (FEMA) was established in 1977, as part of an Executive Order issued in furtherance of the National Flood Insurance Act of 1968, the Flood Disaster Protection Act of 1973, and the National Environmental Policy Act of 1969. The purpose of FEMA is to provide leadership in floodplain management and the protection of wetlands. FEMA's activities include the management of construction and development in wetlands and flood prone areas so as to reduce the risk of flood loss and minimize the impact of floods on human health, safety and welfare. FEMA promotes the use of nonstructural flood protection methods to reduce the risk of flood loss.

The U.S. Army Corps of Engineers (USCOE), which was created in 1802, is responsible for the planning, construction, operation, and maintenance of civil works projects for flood control, navigation, and shore protection. As such, many of their activities, such as the construction of seawalls, breakwaters, jetties, and harbor improvements are directly related to erosion control. Federal law allows protection of the shoreline against erosion. Although the USCOE may undertake investigations of erosion problems under specific authorization from Congress and can provide assistance for protection of public shores, they have no authority to construct erosion control projects aimed solely to protect private property.

In addition to construction programs, the USCOE is also involved in the regulation of shoreline activities. Until 1968, the primary thrust of the USCOE's regulatory activities was the protection of navigation, but since then, the program has evolved to one involving the consideration of the full public interest.[23] The USCOE coastal jurisdiction extends from the mean high water mark seaward to the 3-mile limit. The shoreline demarcation for the Corps is different from the State of Hawaii's use of the vegetation

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[22] OCRML Natural Hazards Issues Study Group. 12/88-1/89

[23] Federal Register, 11/13/86, p. 41220. (See Appendix A)

line as its jurisdictional demarcation. (See Figure 3-1).

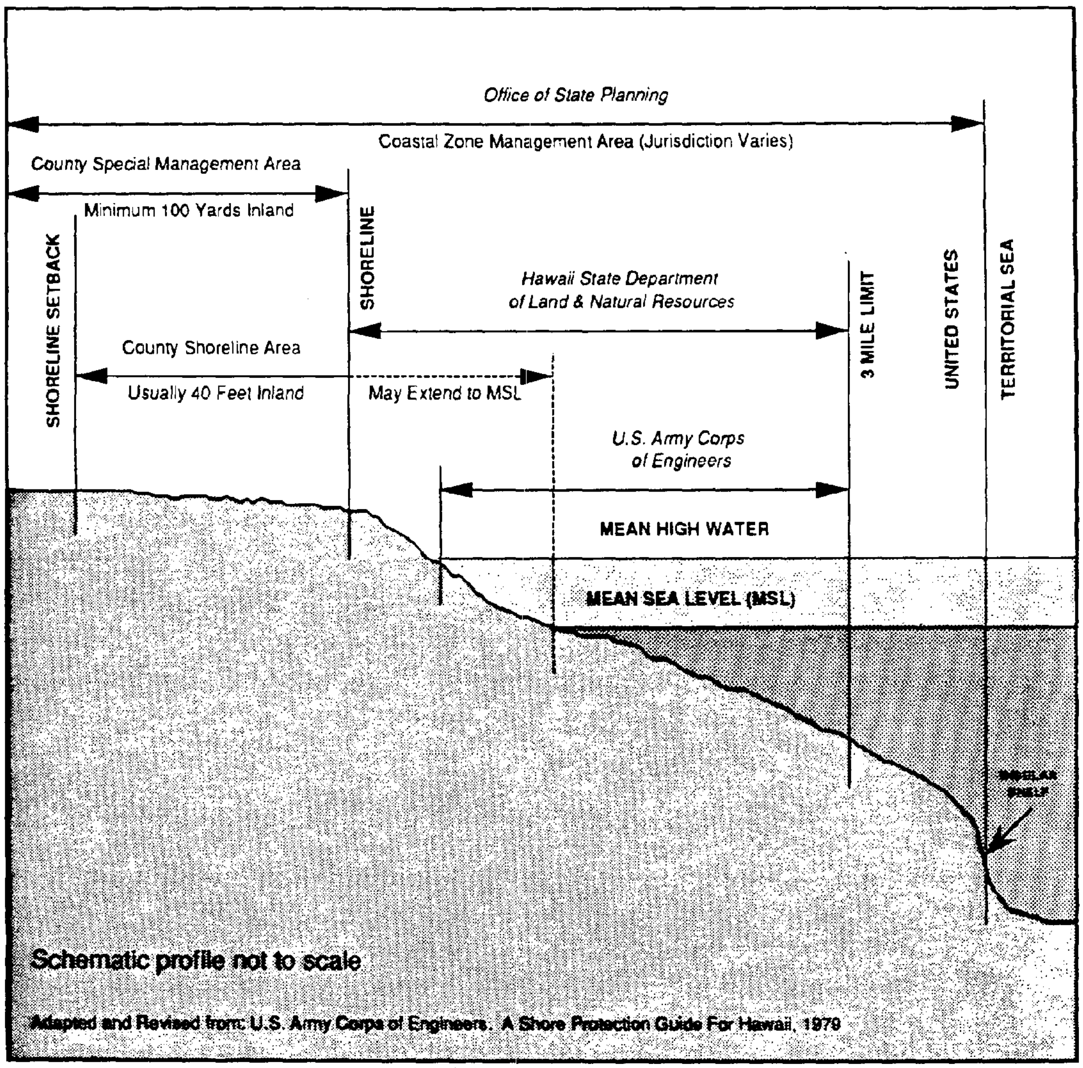

FIGURE 3-1 COASTAL JURISDICTION

The USCOE regulatory program is based on the following laws:

- o the River and Harbor Act of 1899;
- o the Fish and Wildlife Act of 1958;
- o the National Historic Preservation Act of 1969;
- o the Environmental Policy Act of 1969;
- o the Federal Water Pollution Control Act of 1972;
- o The Coastal Zone Management Act of 1972;
- o the Marine Protection, Research and Sanctuaries Act of 1972;
- o the Endangered Species Act of 1973; and
- o the Clean Water Act.

The authority for administering the regulatory program has been delegated to the 36 district engineers and the 11 division engineers. Any individual, firm or government agency who plans to do work "in, under, across, or on the banks of navigable waters" must obtain a permit from the USCOE. These permit requirements apply to erosion control structures (construction of riprap, revetments, groins, breakwaters, and levees)[24] as well as other projects in the affected areas. Certain projects which are limited in scope may be permitted under the Nationwide permit program. Nationwide permits are used to authorize similar types of activities throughout the nation and are designed to permit certain activities to occur with little delay or paperwork. Specific conditions must be met in order for a nationwide permit to be valid.[25] There are approximately 10-30 nationwide permits approved for the State of Hawaii per year.[26] Activities that do not meet the conditions of the nationwide permit must be authorized by an individual or regional permit.

Because the nationwide permit attempts to simplify the permit process for minor work and accommodate local guidelines, this permit is often considered the easiest to obtain. Therefore, the public, knowingly or unknowingly, often assumes that it is not necessary to obtain other required State or County permits even if the proposed action is also within State or County jurisdiction. This misunderstanding continues to occur even though the public, when obtaining a nationwide permit, is informed by the Corps

[24] USCOE, Regulatory Permit Program. 1977.

[25] These conditions are contained in the excerpt from the Federal Register, Vol. 51, No.219, Thursday, November 13, 1986, Rules & Regulations, contained in this document as Appendix A.

[26] This range is provided by the Army Corps of Engineers which indicated the following breakdown of nationwide permits for the State of Hawaii for FY 1987-88: 59 permits total for the State of Hawaii, 36 permits for Oahu alone, and 6 specifically for bank stabilization. There are other shoreline related nationwide permits not included in these figures.

that they must follow through with applicable State or county permit processes. There is, however, no formal system to disseminate shoreline permit information among the Federal, State, and County levels. Therefore, dissemination occurs on an ad hoc basis. The USCOE generally notifies the appropriate State or County agency by sending a copy of the permit whenever a nationwide permit is approved. On the contrary, the USCOE is not always notified when the State or Counties approve permits affecting the shoreline areas if the requested action does not affect Federal jurisdiction. Therefore, the USCOE approval process is often conducted without knowledge of other State or County approval actions in the project area.

3.3 STATE PROGRAMS RELATED TO EROSION CONTROL AND PRACTICE IN HAWAII

In Hawaii, as in other states across the country, government has the constitutional power to regulate land use. This authority, commonly referred to as the "police power," provides government with the power to regulate public and private activity to protect the health, safety, and welfare of the general public. This power to regulate is manifest in many different forms including: zoning subdivision development requirements, building codes, as well regulations imposed by other state and local government agencies.

Erosion control and management in Hawaii is presently covered by the following state regulations:

- o Chapter 205, HRS, State Land Use Law;
- o Chapter 183, HRS, Part IV, Relating to Forest and Water Reserve Zones;
- o Chapter 205A, HRS, Coastal Zone Management; and
- o House Bill 1902 of the 1989 Legislature, Relating to Coastal Zone Management.

CHAPTER 205, HRS, STATE LAND USE LAW

The major state law governing land use in Hawaii is Chapter 205, HRS, which establishes the Land Use Commission and identifies four major land use districts in which all lands in the State shall be placed: urban, rural, agricultural, and conservation. Urban lands are those which are now in urban use and a sufficient reserve area for foreseeable urban growth. Rural areas consist of lands composed primarily of small farms mixed with very low density of not more than one house per one-half acre and a minimum lot size of not less than one-half acre. Agricultural districts include activities or uses characterized by the cultivation of crops, orchards, forage, and forestry; farming, or uses related to animal husbandry, and game and fish propagation... Conservation districts include, areas necessary for protecting watersheds and water sources; preserving scenic and historic areas; providing park lands, wilderness, and beach; conserving endemic plants, fish, and wildlife,forestry, and open space; and preventing floods and soil erosion... Chapter 205's significance lies not only in the establishment of four major land use classifications, but in its division of jurisdiction over the use of these lands among state and county governments. The use of land designated urban is controlled by Hawaii's four county governments through traditional local land use controls. Control over land in agriculture and rural districts is divided between the state and the counties.[27] Land designated conservation is controlled exclusively by the state.

The State Department of Land and Natural Resources (DLNR) has the management and administration responsibility for all conservation lands. This responsibility extends to land areas designated conservation by the State Land Use Commission (SLUC) as well as all coastal areas below the shoreline defined by Chapter 205A, HRS.[28] The landward jurisdiction of this boundary was legally established in 1968 by the Hawaii Supreme Court in the Ashford decision.[29]

The certified shoreline, established pursuant to the procedures contained in Chapter 91, HRS, is the basis used by the DLNR in determining where the state's jurisdiction begins. Coastal areas seaward (makai) of the certified shoreline are under the DLNR's jurisdiction (refer to Figure 3-1).[30] Land areas shoreward (mauka) of the certified shoreline, with the exception of conservation lands, are under the jurisdiction of the SLUC (agriculture or rural lands) or the counties (urban land).[31] Any action landward of the certified shoreline which is not on land designated conservation is outside of DLNR's jurisdictional authority.

Act 258, SLH 1986, authorized the Board of Land and Natural Resources (BLNR) to develop rules for shoreline determinations and appeals which resulted in Chapter 13-222, Hawaii Administrative Rules, "Shoreline Certifications", adopted in 1988. The purpose of Chapter 13-222, HAR, was to standardize the shoreline certification application procedure for the purpose of implementing the shoreline setback law and other related laws. These rules and regulations are applicable to all real properties within the State of Hawaii which border the ocean and became effective on December 10, 1988.

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[27] The counties have jurisdiction over land designated agriculture and rural which is under 15 acres in size (Chapter 15, Land Use Commission Rules).

[28] Chapter 15, Hawaii Land Use Commission Rules, SEC. 15-15-20.

[29] In the Matter of the Application of Clinton Rutledge Ashford and Joan Beverly Schumm Ashford to register title to real property situate at Kainalu, Molokai, State of Hawaii. No. 4516, April 30, 1968.

[30] House Bill 1902, passed by the 1989 Legislature, grants the counties a degree of control over the land seaward of the shoreline by authorizing them to include the area between mean sea level (MSL) and the shoreline for the purposes of enforcing shoreline setbacks.

[31] For purposes of the administration of Chapter 205A, HRS, Parts II and III the counties' jurisdiction also extends to lands under the jurisdiction of the SLUC and the DLNR.

CHAPTER 183, HRS, PART IV, RELATING TO FOREST AND WATER RESERVE ZONES

Chapter 183, HRS, Part IV, grants the DLNR the authority to establish forest and water reserve zones and adopt regulations governing the use of land within the boundaries of these zones. By means of these regulations, the DLNR may establish subzones within any of the reserve zones and specify permissible land uses.

In 1985, critical amendments to Chapter 183, HRS, were passed under Act 221, SLH 1985, regarding accreted land. Any placement of structures or seawalls, grading or dredging, or other uses of accreted land was prohibited. This prohibition refers only to accreted land which was judicially obtained. According to these amendments, a landowner seeking a judicial determination must prove that the accreted land was developed under natural causes and that it has been in a stable condition for at least twenty (20) consecutive years. State and County properties were exempt and all accreted land was considered to be within the Conservation District unless the State Land Use Commission (LUC) designated them otherwise.

CHAPTER 205A, HRS, COASTAL ZONE MANAGEMENT

In accordance with the National Coastal Zone Management Act of 1972, Hawaii's Coastal Zone Management Program (HCZM) outlines objectives, policies, laws, standards and procedures to guide and regulate the use of the State's coastal resources. Administered by the Office of State Planning (OSP), the HCZM encompass broad concerns regarding coastal recreational resources; ecosystems; historic and archaeological resources; scenic and open space resources; economic uses; coastal hazards; and managing development.

Special Management Areas

As part of the HCZM Program, Hawaii's four counties are required to designate Special Management Area (SMA) boundaries and establish a permitting process for development in the SMA, pursuant to Chapter 205A, HRS, Part II. This process is intended to "avoid the permanent loss of valuable resources and the foreclosure of management options, and to ensure adequate access, by dedication or other means, to public owned or used beaches, recreation areas, and natural reserves" (SEC. 205A-21 HRS). SMA boundaries range inland from the shoreline (a line along "the upper reaches of the wash of the waves, other than storm and seismic waves, at high tide during the season of the year in which the highest wash of the waves occurs, usually evidenced by the edge of vegetation growth, or the upper limit of debris left by the wash of the waves") for a considerable distance and are required to include only shoreline or coastal water related land (Att. Gen. Op. 75-18).

Development, as defined in SEC. 205A-21, HRS, may not proceed in an SMA unless an applicant obtains a Special Management Area Use Permit (SMP) from a granting authority.[32] Application for an SMP triggers a review of the proposed development activity by a designated coordinating agency based on the proposed development's valuation and it potential environmental or ecological effects.

Chapter 205A, HRS, Part II, was amended in 1984 by Act 113, SLH 1984, S.B.No. 2180 84. This legislation authorized emergency special management area use permits (SMPs) for the reconstruction of structures to their original form which had been damaged by natural hazards. It also added additional exemptions to the definition of "development" for the SMP process.

Shoreline Setbacks

Chapter 205A, HRS, Part III (the shoreline setback statute), is perhaps the most important legislation in Hawaii affecting shoreline development. Chapter 205A, HRS, Part III, requires the central coordinating agencies of Hawaii's four counties to establish shoreline setbacks of not less than twenty feet and not more than forty feet inland from the shoreline, where activities specified under SEC. 205A-44 are prohibited without a Shoreline Setback Variance (SSV).[33]

Section 205A-46 places the responsibility for administration and enforcement of the shoreline setback requirements with the counties, to be carried out by either county planning departments or, in the case of the City and County of Honolulu, by the Department of Land Utilization (DLU). Rules and regulations concerning shoreline setback have been adopted in the form of County ordinances.

HOUSE BILL 1902 OF THE 1989 LEGISLATURE, RELATING TO COASTAL ZONE MANAGEMENT

In 1989, House Bill 1902 was passed strengthening Chapter 205A, HRS, by clarifying and modifying the roles and responsibilities of the affected agencies participating in the implementation of the Coastal Zone Management Act and providing a comprehensive revision of Chapter 205A, HRS, Part III. Major amendments to Chapter 205A, HRS,

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[32] On Oahu this authority is the Honolulu City Council and on Kauai the granting authority is the Planning Commission of the County of Kauai.

[33] SEC. 205A-45, HRS, permits the counties through adoption of an ordinance to require shoreline setbacks lines be established at distances greater than 40 feet.

contained in House Bill 1902 include:

- o Section 1 relating to Chapter 205A, HRS, Part III, addresses the jurisdictional problems associated with construction of illegal seawalls and other structures in areas where a certified shoreline survey establishing the location of the shoreline has not been conducted. It establishes that "where the shoreline is affected by a man-made structure that has not been authorized with government agency permits required by law, if any part of the structure is on private property, then for the purposes of enforcement of this part, the structure shall be construed to be entirely within the the shoreline area."

- o Section 4 relating to Chapter 205A, HRS, Part I, redefines the "coastal zone management area" to include "the waters from the shoreline to the seaward limit of the State's jurisdiction and all land areas excluding those lands designated as state forest reserves. This extended Chapter 205A's "cause of action provision" (SEC. 205A-6) to include all land areas, with the exception of forest reserves, outside of the SMA.

- o Section 4 relating to Chapter 205A, HRS, Part I, substitutes "seismic" in place of the word "tidal," amending the definition of shoreline to read "the upper reaches of the wash of the waves, other than storm and seismic waves, at high tide during the season of the year in which the highest wash of the waves occurs, usually evidenced by the edge of vegetation growth, or the upper limit of debris left by the wash of the waves."

- o Section 9 relating to Chapter 205A, HRS, Part II and Part III, extended and increased the civil fine penalty procedures to include violations of Part III (shoreline setback area) as well as violations of Part II (shoreline management area).

- o Section 13 relating to Chapter 205A, HRS, Part III, granted the counties through rules adopted pursuant to Chapter 91, HRS, or ordinance to expand the shoreline area to include the area between mean sea level (MSL) and the shoreline. This measure takes the legislative changes made in Section 1 of H.B. 1902 (described above) a step further and allows for overlapping jurisdictions between the DLNR and the counties. Because of their closer knowledge of local (i.e. county) matters, this legislation essentially gives the counties the lead role in regulating development along the shoreline.

3.4 CITY AND COUNTY OF HONOLULU LEGISLATION AND PRACTICE

In 1971, Shoreline Setback Rules & Regulations of the City and County of Honolulu were adopted pursuant to Land Use Law 205-32, HRS. (See Appendix C.) Shoreline setback lines were established at 40 feet inland from the upper reaches of the wash of the waves other than storm or tidal waves (tsunamis). The exception to this setback line was 20 feet inland on any land parcel if one or more of the following conditions existed:

- o If the average depth of the parcel, measured from the shoreline or the seaward boundary of the parcel (whichever was less) was less than 100 feet.
- o If the parcel area was less than the minimum lot area required by Chapter 21, Revised Ordinances (R.O.) of the City and County of Honolulu (1969).[34] This provision was applicable only in zoning districts with minimum lot sizes under the Comprehensive Zoning Code[35] of 7,500 square feet or less.
- o Where the buildable area of the parcel was reduced to less than 50% of the parcel area after application of the 40-foot shoreline setback line.

Even though the Shoreline Setback Rules & Regulations were later amended by Ordinance 4631 (1976) and updated in 1983, the 40-foot shoreline setback and the criteria for the 20-foot setback has not changed.

The Shoreline Setback Rules and Regulations specify that all construction, improvements, grading, clearing, grubbing, filling, and such related activities within the shoreline setback be subject to review and approval of the Director... and prohibit the removal of sand, coral, rocks, soil, shells, or other beach compositions or natural plants within the shoreline setback. The rules also prohibit the changing of the basic topography, physical appearance or configuration of the shoreline setback.

In addition, a different setback is required by zoning ordinance in Oahu's shore areas. This setback is different from the 40-foot established by the 1971 Shoreline Setback Rules & Regulations and is required and administered from a height control

[34] Chapter 21, R.O. 1969 established the Comprehensive Zoning Code for the City and County of Honolulu.

[35] The Comprehensive Zoning Code was replaced by the Land Use Ordinance in 1973. The Shoreline Setback Rules & Regulations have not yet been updated.

perspective. For instance, the Waikiki Special Design District imposes a 100-foot height setback with a building height envelope of one-to-one (45% angle) measured from the shoreline. Height control setbacks are also utilized in other areas on Oahu with different setbacks based on the designated zoning of the area.[36] Although the stated purpose of this regulation is different from those of Shoreline Setback regulations, the end result is to maintain a certain width of shoreline setback.

After the State of Hawaii passed the Interim Shoreline Protection Act (Act 176, SLH 1975), Ordinance 4529 established the interim shoreline protection district for Oahu in the latter part of 1975. The SMA was established as not less than 100 yards inland from the shoreline as defined as the upper reaches of the wash of the waves, usually evidenced by the vegetation line, or if there is no vegetation line, then by debris left by the wash of the waves. Review guidelines were established for review of developments proposed for the SMA. Chapter 33, Revised Ordinance of Honolulu (ROH), established the SMA Rules & Regulations for the City and County of Honolulu in 1978 (Appendix D). Chapter 33 was later amended in 1987 by Ordinance 87-73 with the addition of new definitions, refinement of the fees schedule, and addition of Article 9, Enforcement.

For the City and County of Honolulu, the Department of Land Utilization (DLU) is responsible for the management of all LUC's Urban designated lands on Oahu. This includes all lands landward from the certified shoreline (the upper reaches of the wash of the waves usually evidenced by the edge of vegetation, or by the line of debris left by the wash of the waves) excluding Federally controlled lands and LUC's Conservation designated lands. Included in their management is the Shoreline Setback area. In their administration of the Shoreline Setback Rules & Regulations, the DLU's concern is the high number of seawalls which have been constructed without the proper permits nor proper assessment of their impacts on the neighboring properties.

Monitoring of seawall construction and subsequent enforcement is a problem due to the lack of sufficient budget and personnel. In addition, the complexity of Oahu's overall planning permit process and the time requirements for processing of permits appears to encourage residents on shoreline areas to take individual actions to protect their properties from erosion damage. A good example is the Lanikai shoreline. In a one-third mile stretch of Lanikai consisting of 36 lots, only 3 lots have not built seawalls. Only 2 of the seawalls have the appropriate permits, 9 are non-conforming, and 22 are considered illegal. The erosion process in this area has resulted in little or no beach along this shoreline reach.

[36] The West Beach and Turtle Bay areas each have a height control setback of 200 feet.

3.5 COUNTY OF KAUAI LEGISLATION AND PRACTICE

The Comprehensive Zoning Ordinance (CZO), which was legislated in 1972 and amended in 1976 and 1987, establishes six major Use Districts (Residential, Resort, Commercial, Industrial, Agriculture, and Open) in conjunction with two Special Districts (Special Treatment and Constraint) for the County of Kauai. Of particular concern for the shoreline area is the Constraint District which is further divided into six components. The Shore District (S-SH) is one of the six Constraint District components and regulates development or alterations to the shore and water areas. (A full text of the Shore Districts is included as Appendix E.)

The Shore Districts section defines the shoreline areas as those areas which are specified by the Planning Director as having significant interrelationship between the physical, biologic, or ecologic forms or systems characteristic of the shore area, and the area from the upper reaches of the wash of the waves other than storm or tidal waves (tsunamis) to 40 feet inland, or 20 feet in those cases provided by the rules of the State LUC implementing Chapter 205, HRS. Within five years of the effective date of the 1972 CZO, a Shoreline Special Treatment Zone Plan was to be prepared by the Planning Commission. The boundaries of the Shore District was to be determined upon adoption of the Shoreline Special Treatment Zone Plan by the Planning Commission. The Shoreline Special Treatment Zone Plan has not yet been developed nor is the Shore District used as a planning tool in regulating the shore areas of Kauai.

The Shoreline Setback Rules & Regulations was approved by the Planning Commission in 1971. (See Appendix F.) The shoreline setback line of 40-feet established by the State LUC was adopted by the County of Kauai. A 20-foot setback is acceptable under the following conditions:

- If the average depth of the parcel from the shoreline is less than 100 feet.
- If the parcel is less than one-half (1/2) acre and is less than one-half (1/2) the minimum lot size appropriate for the respective zoning.
- The buildable area of the parcel is less than 50% after applying the 40-foot shoreline setback.

Shoreline setbacks greater than 40 feet may be required by the Planning Commission in accordance with Development Plan Ordinances for multiple-family and resort developments and the SMA Rules & Regulations.

The SMA Rules & Regulations of the County of Kauai were adopted by the Planning

Commission in 1975 in response to Chapter 205-A, HRS, with subsequent amendments filed in 1977, 1979, 1982, and 1984. (See Appendix G.) The SMA for the County of Kauai was established on maps filed with the Planning Commission and the Office of the County Clerk as of June 8, 1977. Boundary amendments to the SMA maps may be initiated by the Planning Director and proceeds through a public hearing process. The SMA includes the Special Treatment Districts as established by the County CZO. The Shore District (S-SH) is, therefore, included within the SMA.

A Special Management Area Use Permit (SMP) defines an action by the Planning Director according to the SMA Rules & Regulations to authorize development which is not in excess of $65,000 and which has no significant adverse environmental or ecological impact. A SMP defines an action by the Planning Commission authorizing development which exceeds $65,000 and which has no significant adverse environmental or ecological impact. In either case, no development is permitted within the SMA without first obtaining the appropriate permit pursuant to these Rules & Regulations.

Emergency situations are handled by the Planning Director in cases requiring immediate action to prevent substantial physical harm to persons or property. In addition, the Rules & Regulations requirements may be waived in State declared emergencies. Such waiver occurred immediately after Hurricane Iwa in 1982.[37]

The organizational structure of the County of Kauai's Planning Department[38] is small and communication problems among agencies is not perceived to be an issue. The Planning Department has always been aware of any State-authorized permits, including emergency permits. Monitoring and enforcement of activities within the Shoreline Setback also is not perceived to be a problem for the Planning Department. The Island of Kauai consists of small, tight-knit communities who seem to be aware of the required permit processes. Because of this awareness and small community size, monitoring is often done by community members. Follow-up enforcement is often easily handled since there seem to be few situations requiring follow-up action. As a result, illegal seawalls and beach access problems have been few and do not appear to be a problem for the Planning Department or the community. Very few applications are received per year for setback variances for shore protection construction as compared to applications received by the Department of Land Utilization of the City and County of Honolulu.

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[37] A County ordinance was enacted immediately after Hurricane Iwa allowing a 6-month grace period to provide for a blanket SMA emergency permit process.

[38] Discussions with the Kauai Planning Department staff members.

TABLE 3-1
SHORELINE SETBACK RULES AND REGULATIONS*
COUNTIES OF HONOLULU AND KAUAI

	HONOLULU	KAUAI
Enabling Legislation	Ch. 205-32 HRS	Ch. 205-32 HRS
Purpose	To regulate the use and activities within the shoreline setback.	
Rules and Regulations Establishing Authority	City Council	Planning Commission
Shoreline Establishing Authority**	State Land Use Commission	State Land Use Commission
Shoreline Setback	40 feet inland from the upper reaches of the wash of waves/ 20 feet for any land parcel of which depth is less than 100 feet; of which area is less than the minimum lot area under less than 7500 s.f. minimum lot zoning; or where buildable area is reduced by 50% after applying 40 ft. setback line.	40 feet inland from the upper reaches of the wash of waves/ 20 feet for any land parcel of which depth is less than 100 feet; of which area is less than 1/2 acre and less than 1/2 of the minimum lot of the zoning lot; or where buildable area is reduced by 50% after applying 40 ft. setback line.
Shoreline Location and Measurement	Instrument survey certified by the Registered Land Surveyor and confirmed by the Chairman of the Board of Land and Natural Resources.	
Effective Duration of Survey	1 year	6 months
(Delayed Case)***	(2 year)	(1 year)
Authority to Waive Instrument Survey	DLU Director with evidence that the proposed construction is located 55 ft. or more from the shoreline for 40 ft. setback or 35 ft. or more for 20 ft. setback area.	Planning Director with evidence that a considerable distance exists between proposed construction and the shoreline.
Activities Subject to the Rules and Regulations	All public and private land subdivision, grading, clearing, grubbing, filling or construction including remodeling, reconstruction or replacement.	

* Each County has yet to revise its Shoreline Setback Rules and Regulations according to the HB 1902 which was signed into Law by Governor Waihee in June 1989.
** Each County Rules and Regulations have not been updated to reflect the shoreline establishing authority as DLNR.
*** Application withdrawn, held in abeyance or government decision delayed.

TABLE 3-1 (CONT'D)

	HONOLULU	KAUAI
Prohibited Actions Within Setback Area	Removal of sand, coral, rocks, soil, shells or other beach compositions for other than reasonable domestic use without changing the basic topography of the area.	
Structures Not Permitted Within Setback Area	No structures permitted without shoreline setback variances.	
Facilities Permitted Within Setback Area	Special structures necessary for safety reasons or to protect property from erosion or wave damages upon compliance with all applicable laws/regulations.	
Permitting Authority	DLU Director w/concurrence of the DPW Chief Engineer & Building Superintendent.	Planning Director w/concurrence of the DPW Chief Engineer.
Certification Necessary for Approval	1) The structure is needed for safety reasons or to protect the property from erosion or wave damage, 2) the proposed construction is the best alternative of several investigated, and 3) the proposed construction will not cause any adverse effect on or significant change to the shoreline.	
Non-Conforming Structure	- Structures existing before June 22, 1970 are permitted as non-conforming structures. - No such non-conforming structure shall be enlarged or altered to another nonconforming use. - No nonconforming use of land shall be enlarged to occupy a greater area of land nor be relocated within the setback area.	
Administration of Rules and Regulations	DLU Director	Planning Director
Variance Granting Authority	DLU Director	Planning Commission
Enforcement	DLU Director	Planning Director
Penalties	Not more than $1,000; plus separate offense provision for continuing violation after conviction.	Not more than $500; plus separate offense provision for continuing violation after conviction.

3.6 OTHER STATES' PROGRAMS RELATED TO EROSION CONTROL AND MANAGEMENT

Of the 29 states with CZM programs, 16 have no setback regulations specifically enacted to set development back from erosion hazard areas. States which have them include: Hawaii, Wisconsin, Michigan, Virgin Islands, South Carolina, Florida, North Carolina, Delaware, Alabama, New Jersey, New York and Rhode Island.[39] In this respect, Hawaii may be among the more progressive states with regard to erosion management.

Based on a review of coastal state erosion management programs and subsequent discussions with federal coastal management agencies, two states--Florida and North Carolina--have been identified as being the states in the U.S. with the most advanced systems for managing coastal erosion.

For a purpose of comparison, each state's measures are briefly described herein and a few pages of each state's publications are included in the Appendix for reference. In addition, Table 3-2 provides a quick comparison of shoreline setback related regimes of Florida, North Carolina, City and County of Honolulu and Kauai County.

FLORIDA[40]

In 1970, the Legislature of the State of Florida passed into law the Beach and Shore Preservation Action (Ch. 161, Florida Statutes), charging the Florida Department of Natural Resources (through the Division of Beaches and Shores) with the responsibility of its administration.

Through the years, beach and coast preservation programs in Florida have reached a high level of specialization with regard to the research done on coastal erosion processes, and in terms of beach management programs which have been established. Presently, major program elements include the establishment of regulatory jurisdictions, construction regulation and enforcement activities, advanced study of coastal erosion in Florida and a funding mechanism for public civil works projects. The cornerstone of the Florida program is, however, the Coastal Construction Control Line Program.

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[39] OCRM, Natural Hazards Issues Study Group. December 1988.

[40] Primary information source is Florida's Beach and Coast Preservation Program: An Overview, James H. Balsillie, Bureau of Coastal Data Acquisition, Division of Beaches and Shores, Florida Department of Natural Resources, February 1988. See Appendix H for selected excerpts.

TABLE 3-2

SHORELINE SETBACK RELATED REGIONS

FLORIDA, NORTH CAROLINA, HONOLULU AND KAUAI

			HAWAII	
	FLORIDA	NORTH CAROLINA	HONOLULU	KAUAI
Enabling Legislation (State)	Ch. 161 F.S.	Coastal Area Management Act (CAMA)	Ch. 205-32 HRS	Ch. 205-32 HRS
Name of Control Line	Coastal Construction Control Lines (CCCL)	Erosion Setback	Shoreline Setback	Shoreline Setback
Control Line Establishing Authority	Bureau of Coastal Data Acquisition	Coastal Resource Commission	State Land Use Commission	State Land Use Commission
Established Line	Variable lines based on erosion rate	Variable lines based on erosion rate	Uniform 20 or 40 ft.	Uniform 20 or 40 ft.
Permit Administering Authority	Division of Beaches and Shores, State Department of Natural Resources	Division of Coastal Management (DCM), State Department of Natural Resources and Community Development	City Department of Land Utilization	County Planning Department
Structure Type Distinction for Permit Purpose	Minor/Major	Minor/Major	No distinction	No distinction

Control Line Program

The establishment of Coastal Construction Control Lines (CCCLs) is administered by the Bureau of Coastal Data Acquisition (Section 161.053, F.S.). Control lines are established, "so as to define that portion of the beach-dune system which is subject to severe fluctuations based on a 100 year storm surge of other predictable weather conditions, and so as to define the area within which special structural design consideration is required to insure protection of the beach-dune system..." Establishment of CCCLs on a county-by-county basis requires field data collection, storm tide and dune erosion modeling, and CCCL restudy and adoption. The Florida law stipulates: "upon the establishment, approval and recordation of such coastal construction control line or lines, no person, firm, corporation, or government agency shall construct any structure whatsoever seaward thereof; make any excavation, remove any beach material, or otherwise alter existing ground elevations; drive any vehicle on, over, or across any sand dune or the vegetation growing thereon..."

In comparison to Hawaii, Florida has established a much more extensive system of beach management. Because of the large number of local governments, the problems of coordination are actually much greater in Florida than in Hawaii. Perhaps it is for this reason that the state government has taken on such a strong leadership in terms of beach management. Because the two states, Hawaii and Florida differ so much in terms of administrative and jurisdictional organizations, it may be difficult to exactly replicate the Florida program in Hawaii. Certainly elements of the program, however, are transferable. Further study of Florida's data collection and data management efforts is likely to strengthen the development of a coastal information system in Hawaii. In addition, permitting procedures, enforcement practices, and penalties for violation of Florida's beach preservation laws would certainly be of interest to Hawaii lawmakers and policy analysts.

NORTH CAROLINA[41]

In North Carolina the Coastal Area Management Act (CAMA) was adopted in 1974. It established a comprehensive regional resource management program for the State's twenty-county coastal area. The framework adopted by CAMA involves State designation and regulation of critical environmental areas and mandatory comprehensive planning of local land use. Overall policy decisions are made by a

[41] Primary information sources are: David W. Owens, "Coastal Management in North Carolina," APA Journal, Summer 1985, pp. 322-329, and A Handbook for Development in North Carolina's Coastal Area, Division of Coastal Management N.C. Department of Natural Resources and Community Development, 1985. See Appendix I for selected excerpts.

citizen Coastal Resources Commission (CRC) appointed by the Governor.

Minimum Oceanfront Setback

Under the provision of the CAMA, a four-part minimum oceanfront setback requirement was adopted and went into effect in 1979. The rule required all new development to be the furthest landward of:

- a distance equal to thirty times the long-term annual erosion rate, measured from the vegetation line;

- the crest of the "primary dune" (defined as the first dune with an elevation to the 100-year storm level plus six feet);

- the landward toe of the "front dune" (defined as the first dune with substantial protective value); and

- sixty feet landward of the vegetation line.

Several changes to the setback rule have occurred. First, an exemption to the setback was adopted to allow low-intensity, non-disruptive uses of the area between the vegetation line and setback line, such as campgrounds, small gazebos, and unpaved parking lots. A second exemption provided limited "grandfathering" of lots subdivided before the setback's original effective date. It allowed single-family residences to be located in front of the erosion-rate setback, provided they met the sixty-foot minimum and dune setback provisions and more stringent construction standards. (This exemption still left some 500 lots unbuildable.) Third, the minimum erosion rate portion of the setback rule was doubled for large structures. This was done because of the high risks and liabilities associated with large oceanfront developments.

Oceanfront Erosion Control

Another significant regulatory initiative has been to ban "shoreline hardening" throughout the state. While setback regulations prevent many of the problems associated with new development, these rules have little effect upon existing oceanfront development. In North Carolina there has been extensive shoreline development in erosion-prone areas and hundreds of existing structures are or will soon be in imminent danger of falling in the ocean. Typical responses to this problem have included the construction of seawalls and bulkheads. These structural remedies have been found to destroy the public beach, increase erosion problems for neighbors, and to be costly. The alternative of abandoning large private investments in beachfront development was politically infeasible. A task force made up of state, local and federal officials was established. The task force concluded that the state should take a policy stand against attempts to permanently stabilize the shoreline, but should instead allow temporary efforts such as beach nourishment and low temporary, sandbag bulkheads. In January 1985 the CRC subsequently adopted regulations to ban shoreline hardening in North Carolina.

Nonregulatory Management Tools

North Carolina has also utilized a number of non-regulatory techniques. Since 1985, local land use plans must contain a post-storm policy section with a pre-storm mitigation program, evacuation plans, and post-storm reconstruction policies. The legislature also established a new beach access program in 1981 and explicitly linked it to the coastal management program in several ways. It assigned responsibility to the CRC for developing implementation standards and required that a priority for acquisition be given to lands that were unsuitable for permanent substantial structures. It is important that this statute includes an explicit legislative recognition that some oceanfront property is unsuitable for development, thereby providing additional legal and political support for the setback concept. Public investment policies likewise have been incorporated into the management program. New growth-inducing public investments, such as water and sewer lines, must be located outside hazard areas.

It has been pointed out that coastal management in North Carolina has achieved a degree of sophistication exceeding most states in the nation including Hawaii. While both the physical and environmental conditions are different from Hawaii, there are some lessons to be learned. First, North Carolina is positive proof of the value of a coordinated management system which has integrated regulations, planning, and public education. Second, compared to many other states, North Carolina has a high degree of citizen involvement in its coastal management program, which is certainly one aspect for Hawaii to consider as it attempts to strengthen its planning and management efforts. Third, North Carolina provides valuable case materials for resolving complex erosion-related problems. The experience of the communities in the Outer Banks region of state may be especially useful to study as an example of severe erosion occurring in developed areas. The difficulties encountered in North Carolina should be a strong inducement for the formulation of erosion management plans for erosion prone areas in Hawaii.

3.7 RECOMMENDATIONS FOR IMPROVING THE EXISTING REGULATORY REGIME IN HAWAII

In reviewing these two states (Florida and North Carolina), it is clear that they are both far ahead of Hawaii in terms of erosion management. This is evident in terms of the magnitude of resources spent on erosion studies and in terms of the efficacy of the regulatory systems in controlling coastal development. Florida, for example, has established within its Department of Natural Resources, a Division of Beaches and Shores with an Office of Erosion Control and Bureau of Coastal Data Acquisition. Florida maintains over 9,800 beach profiles and over 2,300 offshore profiles. This beaches and shores profile data base is one of the most comprehensive and largest of its kind. Historical data from as far back as 1850 are being collected from the various counties to supplement the profiles database.

The philosophy underlying North Carolina's erosion setback program is exemplified by the following general standard, "development should be located as far back from the ocean as possible..." Both North Carolina and Florida attempt to control long-term erosion by utilizing at least a 30-year time horizon. In Florida, erosion rates are predicted for thirty years into the future. The setback line is then based upon this thirty year projection. In North Carolina, the average annual rate of erosion is established, then multiplied by the life expectancy of the structure (30 years for small buildings, 60 years for larger ones) to determine the required setback.

Perhaps the most significant concept to borrow from these two states is the creation of variable setback lines, based on different, site-specific erosion rates.

SHORELINE SETBACKS

Establishment of shoreline setbacks must be based on thorough scientific data analysis. This should involve the following steps:

- data collection and coastal engineering analysis
- determination of erosion rates and setbacks
- impact analysis of the established setbacks
- public participation and adoption

Through the data collection and analysis, appropriate erosion rates for various segments of coastal areas with unstable shorelines can be established. In addition, different life spans must be agreed upon for various types of structures; for example, single-family resident structures versus large structures having more than four (4) units of more than 5,000 square feet of total floor area. In general, a life span of 30 years is reasonable for a single-family structure and 60 years for a large structure (high rise apartment and office building). Assuming an average erosion rate of 2 feet per year for a certain shoreline reach, then the shoreline setback line for a single family residence might be 2 x 30 = 60 feet. For high-density apartment zones, the setback might be 2 x 60 = 120 feet. This method will result in the establishment of different setback requirements for various stretches of coastal areas depending on the zoned uses and erosional processes or rates of erosion.

Another advantage to using a 30 year time horizon is that states which have erosion management systems with 30 year time horizons become eligible for funding under the Upton-Jones amendments which was signed into law in 1988. This amendment provides new erosion coverage under the National Flood Act of 1968 for claims to relocate or demolish buildings subject to damage due to erosion. Further investigation of this amendment and its applicability to Hawaii is warranted, although at present, final regulations regarding administration of this act have not yet been completed.

As long as the shoreline is subjected to erosional processes, there will be an inherent uncertainty regarding the long-term rates of erosion and the movement of the vegetation line. Therefore, it is critical that there be an overall review of the coastal processes and erosion rates a minimum of every eight to ten years, and shoreline setback review and adjustment as necessary.

The setback for rocky shorelines and stable sandy shorelines should have a standard shoreline setback area to provide and maintain unobstructed shoreline access. Expedited procedures can be established for shore protection along these shoreline reaches to facilitate permit processing. General guidelines and standards for acceptable shore protection methods can be developed to aid applicants and agency reviewers.

Because erosion control structures can cross governmental jurisdictional boundaries, a coordinated set of guidelines and standards could resolve problems arising from jurisdictional differences. Coordinated "coastal protection plans" could establish the desired shore protection or stabilization goals. The type of erosion control measure would dictate the lead agency. A reminder clause or check box on the application form can be included in each agency's application form, so that not only the applicants but also the processing staff can be reminded that the other agencies must be notified.

EROSION MANAGEMENT SYSTEM

While numerous government agencies have jurisdiction over coastal areas, and many rules and regulations pertinent to shoreline development have been devised, there is no management system for erosion per se in Hawaii. Compared to the states of North Carolina and Florida, Hawaii has done very little in terms of developing public policies for managing coastal erosion. While there are a few publications about shoreline erosion published by the U.S. Army Corps of Engineers (USCOE), these deal almost entirely with structural remedies associated with erosion management. The neglect of the erosion management problem is evident from the number of illegal seawalls constructed in many areas throughout the state and from improper shore protection structures which have been either ineffective as an erosion countermeasure or have simply transferred the problem to other areas and property owners. The case studies in the next chapter describe typical human responses that have occurred in the absence of an overall system for erosion management. The need for a more rational, comprehensive system continues to grow with increased development of Hawaii's coastlines.

This study recommends that the State and Counties work together to develop a management system for (1) identifying needs and priorities; (2) formulating plans with alternative structural and non-structural remedies; (3) maximizing benefits and minimizing costs associated with various erosion management actions; (4) ensuring coordination between Federal, State, and County agencies as well as between the public and private sectors. A proposed erosion management system is described in greater detail in Chapter 5.

4.0 CASE STUDY SITES

The coastal reaches selected as the case study sites are representative of a range of factors relevant to the evaluation of appropriate erosion management schemes and provide examples of typical problems and successes with regards to the existing shoreline protection and erosion management efforts. Two coastal areas on Oahu and one area on Kauai were selected to represent a range of erosional characteristics, development intensity and uses, and potential erosion control and management methods that may be applicable.

4.1 METHODOLOGY

The methodology used to evaluate the case study sites is intended to provide an example of a recommended approach to the re-evaluation of existing techniques, concepts, regulatory procedures, and management approaches. The methodology involves the following tasks.

<u>ASSESS COASTAL PROCESSES</u>

The coastal processes at any specific site are determined by the wave types affecting the site, the configuration of the shoreline and nearshore bathymetry, the wave transformation processes in the nearshore region, the sediment characteristics, and the influence of existing man-made structures. For the case study sites, the evaluation of coastal processes included:

- Acquisition and review of existing reports, information, and data to determine the wave characteristics, topography, bathymetry and littoral transport characteristics. Federal, State, County, and private sources were utilized as appropriate.

- Application of numerical wave refraction analysis to determine the nearshore wave transformation effects and the wave conditions which contribute to the erosional characteristics. Review of aerial photographs was accomplished to supplement the wave refraction analysis, providing a qualitative understanding of the wave transformation effects over complicated nearshore regions which cannot be effectively quantified using numerical models.

- Analysis of historical aerial photographs to determine the long-term erosion/accretion patterns. The archives of photogrammetry companies were searched to obtain the available aerial photographs. Some photographs were specifically commissioned by governmental agencies to document the coastal characteristics, however, many historical photos were commissioned by private entities for other purposes. Thus, the photos are generally not controlled photos and are of varying quality. Beachlines and other pertinent information from the photos were digitized and computer analyzed to determine the long-term shoreline changes. Chapter 1.4 describes the technique used.

ASSESS EXISTING CONDITIONS

The existing physical condition of the shoreline, the uses and intensity of development, the presence of shore protection structures, and potential problems were characterized to establish the base condition. For the case study sites, this effort included:

- Acquisition and review of existing information from governmental agencies. For some limited areas, the County has undertaken inventories of the existing shore protection structures and has determined whether structures were built with or without permits. Such efforts by the Counties to inventory existing shoreline structures is continuing.

- Digitizing and computer mapping to develop a base map for the area. The information on the base maps include the parcels and zoning from the Zoning Maps; existing buildings and structures near the shoreline from the most recent aerial photo; vegetation line, beach toe line (or waterline), and rocky shorelines from the most recent aerial photo; and the presence of existing shore protection structures. The existence of shore protection structures was field-verified by walking the coastal reach. Detailed characterization of the shore protection structures on the base map was not accomplished.

EVALUATION AND RECOMMENDATIONS

Based on the assessment of coastal processes and the existing condition of the shoreline, the subsequent evaluations attempted to address the effectiveness and impacts of the structural and non-structural measures to date. Recommendations were developed wherever possible to:

- establish new erosion management or regulatory measures,

- establish appropriate erosion control measures or structural measures to prevent erosion damage.

The recommendations include consideration of preferred options for future shoreline management within these areas, with consideration towards balancing:

- o protection of private property,
- o preservation of sandy beach areas,
- o preservation of public access along the shoreline,
- o protection from flood hazard and wave damage.

As a note of caution, the recommendations contained herein are conceptual and intended as planning guidelines. While detailed structural design criteria are beyond the scope of this effort, care must be exercised to ensure that complex coastal engineering requirements are not over-simplified in an attempt to streamline the regulatory process. Coastal engineering expertise is highly desirable within the regulatory review and processing agencies to achieve a cost-effective balance between the reasonable degree of factual data acquisition/analysis demanded of proposed actions and rational judgement based on experience and expertise.

LIMITATIONS OF THE CASE STUDY SITE EVALUATIONS

The shoreline types within the State are varied as are their respective erosion problems. The case study sites represent only a few of these shoreline types, but include some of the more prevalent and problematic types within the context of erosion management concerns. The include:

- o Beaches, exhibiting seasonal and long-term erosion/accretion cycles, or progressive erosion;
- o Low-lying rocky shores, exhibiting stability but susceptible to wave runup and erosion of backshore areas.

The case study sites do not represent the full range of zoning and development intensities, but the land uses within these sites are some of the more common, including:

- o residential
- o resort
- o public facilities (parks)

The case study sites were drawn from only two counties - City and County of Honolulu and County of Kauai. Thus, this study focused on in-depth review of regulatory and erosion management programs of these two counties only. Because of the level of development, the City and County of Honolulu experiences the most problems in regulating and managing shoreline development. On the other hand, the County of Kauai probably experiences the fewest problems because of the relatively low level of development, although pressures for developing shoreline areas are mounting due to the growth of the resort industry.

Given the limitation of funding and time, this study focused on a few case study sites representing a reasonable range of conditions that were considered as generally applicable to the types of erosion management concerns most often encountered within the State. Many of the recommendations can be applied statewide.

Another factor in the choice of case study sites was the availability of existing information and data. This allowed for comprehensive analysis and evaluation of three sites rather than one or two sites. The level of effort expended towards developing new data and analysis for each site varied, depending on the existing database. The Makaha and Kailua-Lanikai case study sites had considerable existing information and data. Thus, the analysis focused on refining and integrating the body of existing information. The Kukuiula-Poipu case study site had the least information and data. For this site, considerable effort was expended towards developing the historical database for estimating long-term erosion.

The methodologies used for estimating long-term erosion trends for each case study site varied, depending on the database. For example, existing transect data for the Makaha case study site was relied upon for estimating long-term erosion trends. As discussed further in the following section, the transect method has shortcomings and does not provide sufficient information to quantitatively describe the coastal processes of the beach area. For the Kailua-Lanikai case study site, continuous beachline data were available from previous studies, and this existing information was used together with the transect method to quantify the long-term erosion trends. Because no existing database for the Kukuiula-Poipu case study site was available for estimating long-term erosion, the recommended method of digitizing continuous beachlines was used to quantify the long-term erosion trends. While every effort was made to develop rational estimates of future erosion tendencies from the respective databases, the degree of confidence of these estimates vary. Obviously, the more complete the database, the better one would expect the estimates to be. This points to the need to expand the database, with as complete and quantitative coverage as possible, so that better knowledge of past history is available in order to make better estimates of future changes. Acts of nature are so highly variable that the concept of the "best" database is primarily constrained by the funding level available for acquiring the data. For practical purposes, the concept of "better" rather than "best" is a reasonable planning approach for developing a database.

4.2 CASE STUDY SITE #1 - MAKAHA, OAHU

GENERAL DESCRIPTION

The first study site is located on the southwest coastline of the island of Oahu (Figure 4-1). This study site at Makaha runs for roughly 2 miles along the leeward coastline from Lahilahi Point to the northern boundary of the residential units at Kepuhi Point. This part of the island is a dry coastal plain running southeast to northwest behind the Waianae Range of volcanic mountains which seals the area off from the moisture of the prevailing northeasterly trade winds. The coastline at Makaha is subjected to deep water ocean wave energy originating anywhere from the south to the northwest. The largest northern swells of the wintertime are also capable of refracting around Kaena Point, located at the northwest corner of the island, and impacting along the coastline at Makaha.

Base maps at a scale of 1 inch = 200 feet are included as Exhibit A in the back of this report. Figure 4-2 shows reduced versions of the base maps for reference.[36] The coastal geology at the Makaha site location alternates between rocky shores along the points of the coast and extensive beach systems at the two large embayments of the shoreline. Lahilahi Point at the southern end of the site is a high, sharply cut headland composed of a raised reef structure.[37] The rocky shores consist of rough limestone shelves which typically have steep faces at the water's edge dropping quickly to depths of fifteen feet and greater. The beaches are composed primarily of calcareous sands of biologic origin. The offshore water depth contours lie roughly parallel to the shoreline at the Makaha site location. As is found at all other shoreline locations of the volcanic Hawaiian islands, the water depths quickly attain magnitudes on the order of the ocean basin floor. Shallow continental shelves which are important features of the coastlines on the mainland are not present in the islands. At Makaha, the 600-foot contour is found approximately one mile offshore and the 6,000-foot contour is found approximately eight miles offshore.

Farrington Highway, Route 90, follows the coastline continuously on this leeward coast. At Makaha, the undivided highway varies in distance to the water's edge from approximately one thousand feet along the rocky shores down to a few hundred feet at the beach areas. Shoreward of the Farrington Highway, single family residences predominate along the rocky coastal sections of Kepuhi Point and the area south of

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[36] The reader is encouraged to use the full scale base maps in Exhibit A for better understanding of the information presented.

[37] R. Moberly and T. Chamberlain, "Hawaiian Beach Systems".

Makaha Beach Park. Of the two extensive beach systems, the northern one contains the Makaha Beach Park just to the south of Kepuhi Point. Only structures for parking and bathing facilities exist at the Makaha Beach Park. The southern beach system, called Papaoneone Beach, which is just above Lahilahi Point, contains two large, multi-story condominium complexes which abut directly on the back edge of the beach.

LAND USE AND DEVELOPMENT

Makaha is one of the four principal communities within the Waianae district on the Leeward side of Oahu. Having good beaches, Makaha is a community with an ocean-based recreational orientation. The General Plan identifies the entire Waianae region as a "rural" area with a 1987 resident population of 34,300.[38] The Makaha area has a 1985 population of approximately 7,874.[39]

The State Land Use designation (SLUD) for the case study area is Urban except for a substantial portion of Lahilahi Point which is designated Conservation. The Urban designation extends from mauka to makai at the shoreline and is under the jurisdiction of the City and County of Honolulu. Seaward of the shoreline is designated Conservation which is under the jurisdiction of the State of Hawaii. Figure 4-3 depicts the Land Use designations for the vicinity.

The intent of the Waianae Development Plan (DP), established under Ordinance 83-11 in 1983, is that the pattern of urban development remain in a linear formation along Farrington Highway with relatively low building heights. No further intensive urban development was to be allowed makai of Farrington Highway other than parks and single-family residences. Most of the area is designated for single-family residences with the exception of two parcels having Mixed Density Apartment (MDA) designation. One of these two parcels is located north of Makaha Beach Park, and the other in the Papaoneone Beach area. Makaha Beach Park and the south portion of Lahilahi Point are designated for Preservation. Figure 4-4 depicts the Development Plan for the vicinity.

[38] *The State of Hawaii Data Book 1988.*

[39] Makaha is included within Census Tract (CT) 98 which also includes all area north to Kaena Point. The majority of the population within this CT is located in Makaha.

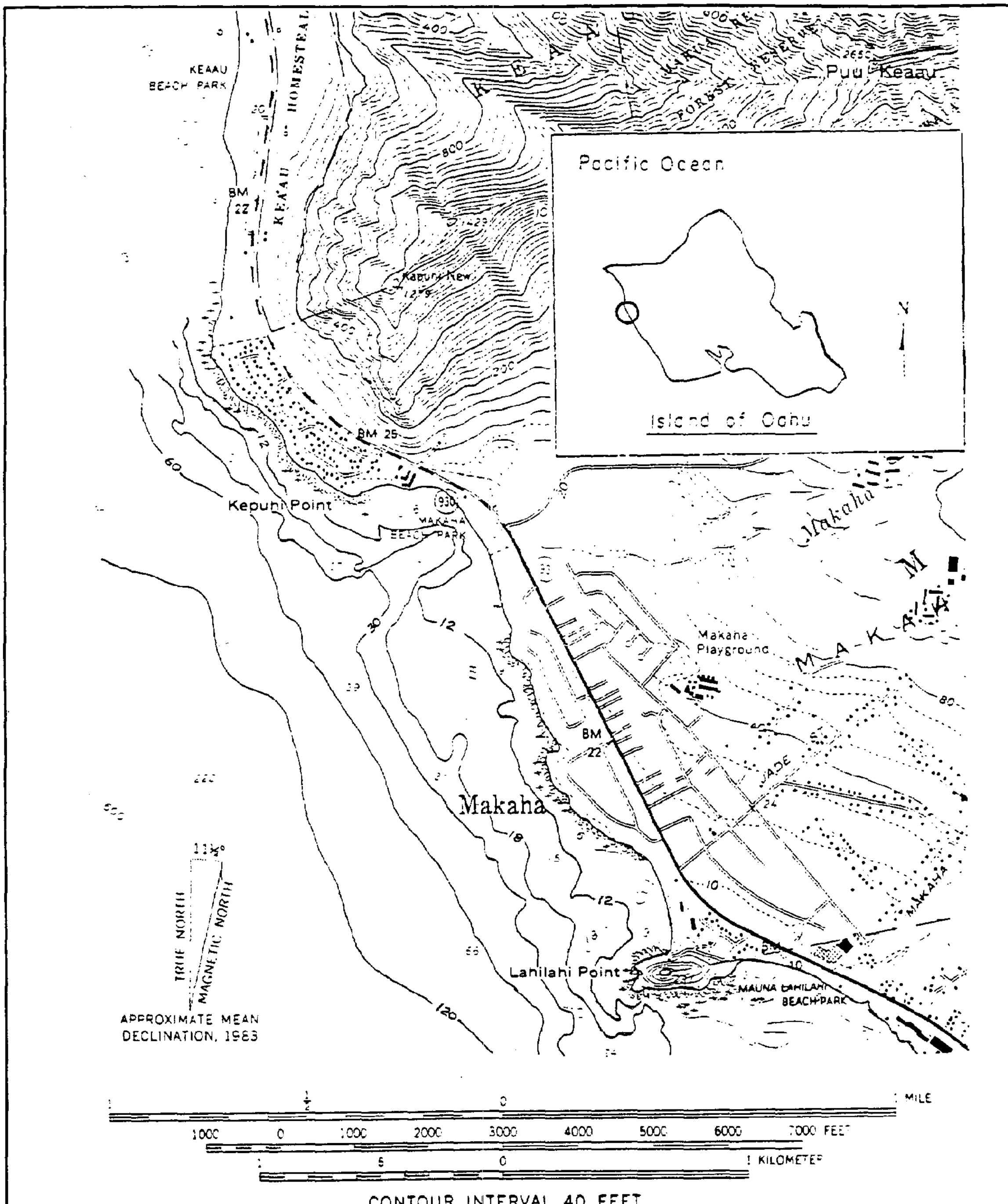

FIGURE 4-1 LOCATION MAP, CASE STUDY SITE #1 - MAKAHA, OAHU

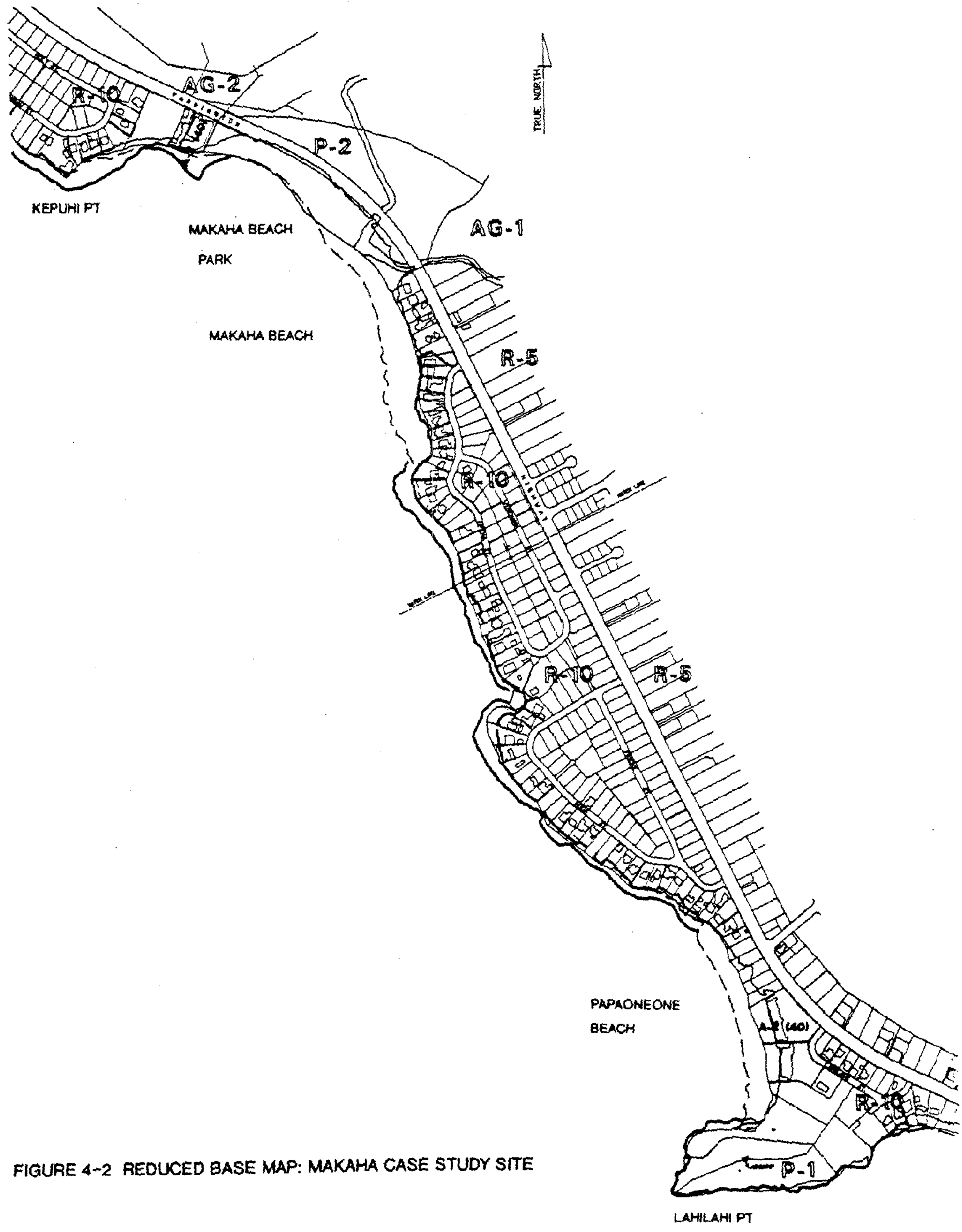

FIGURE 4-2 REDUCED BASE MAP: MAKAHA CASE STUDY SITE

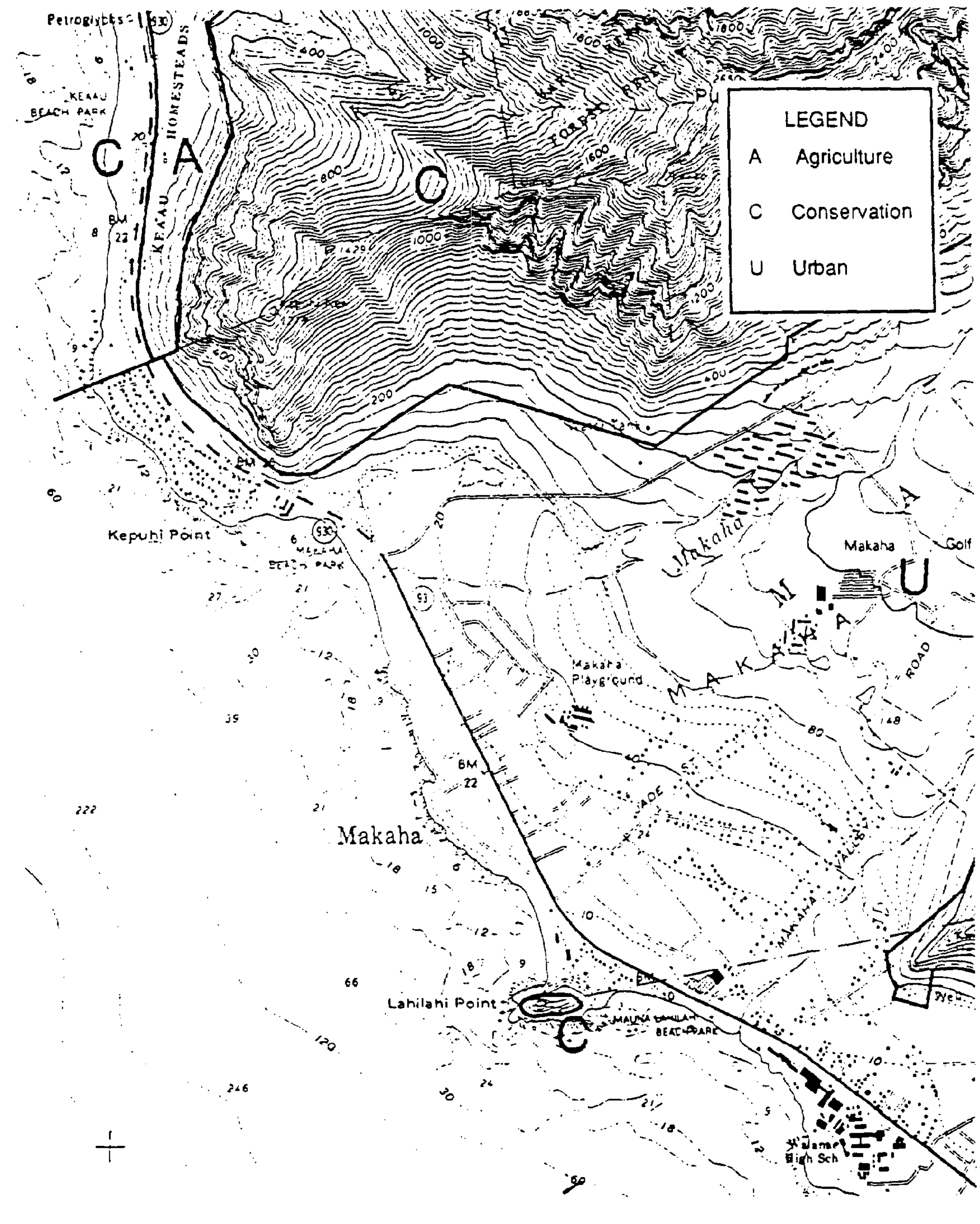

FIGURE 4-3 STATE LAND USE DISTRICT MAP FOR THE MAKAHA VICINITY

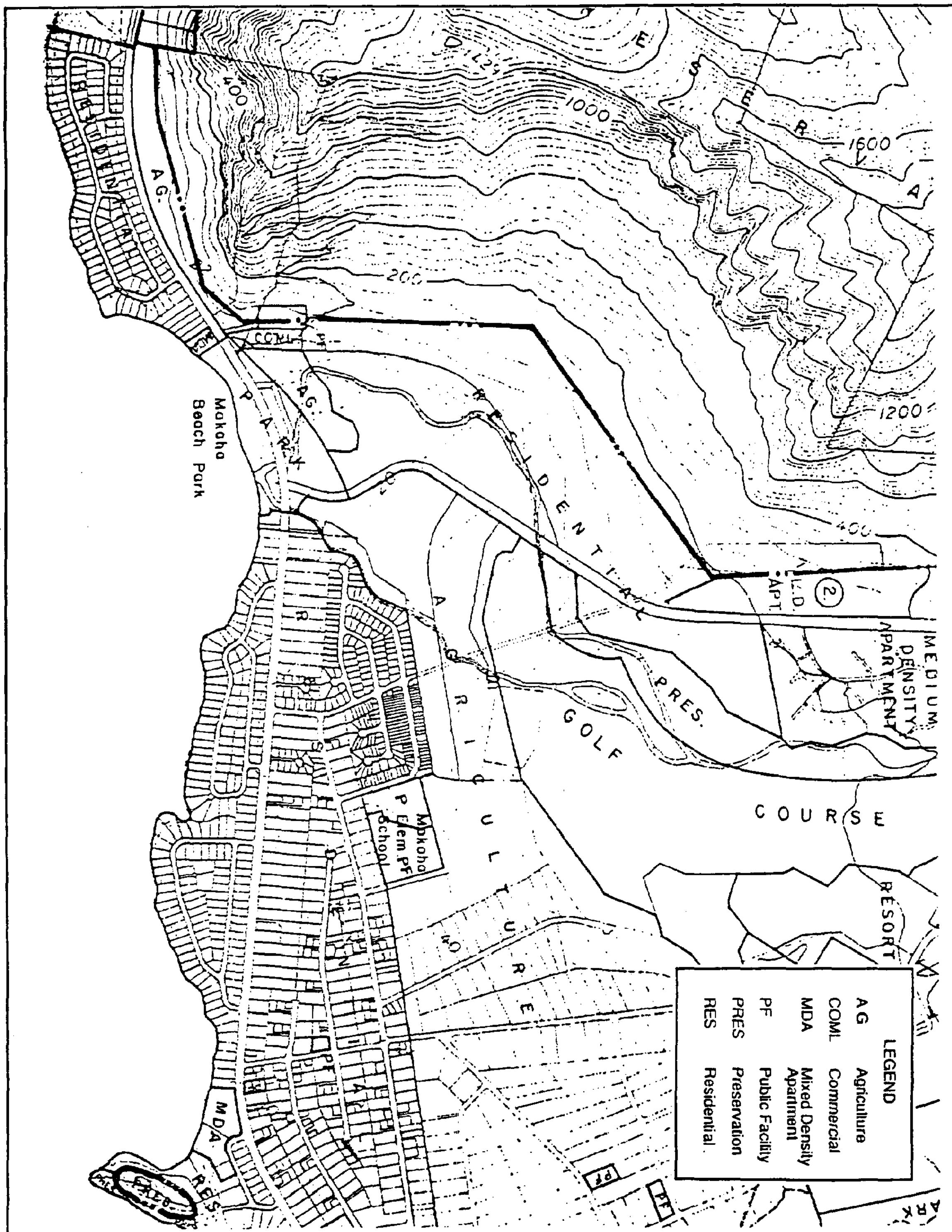

FIGURE 4-4 WAIANAE DEVELOPMENT PLAN (DP) MAP FOR MAKAHA VICINITY

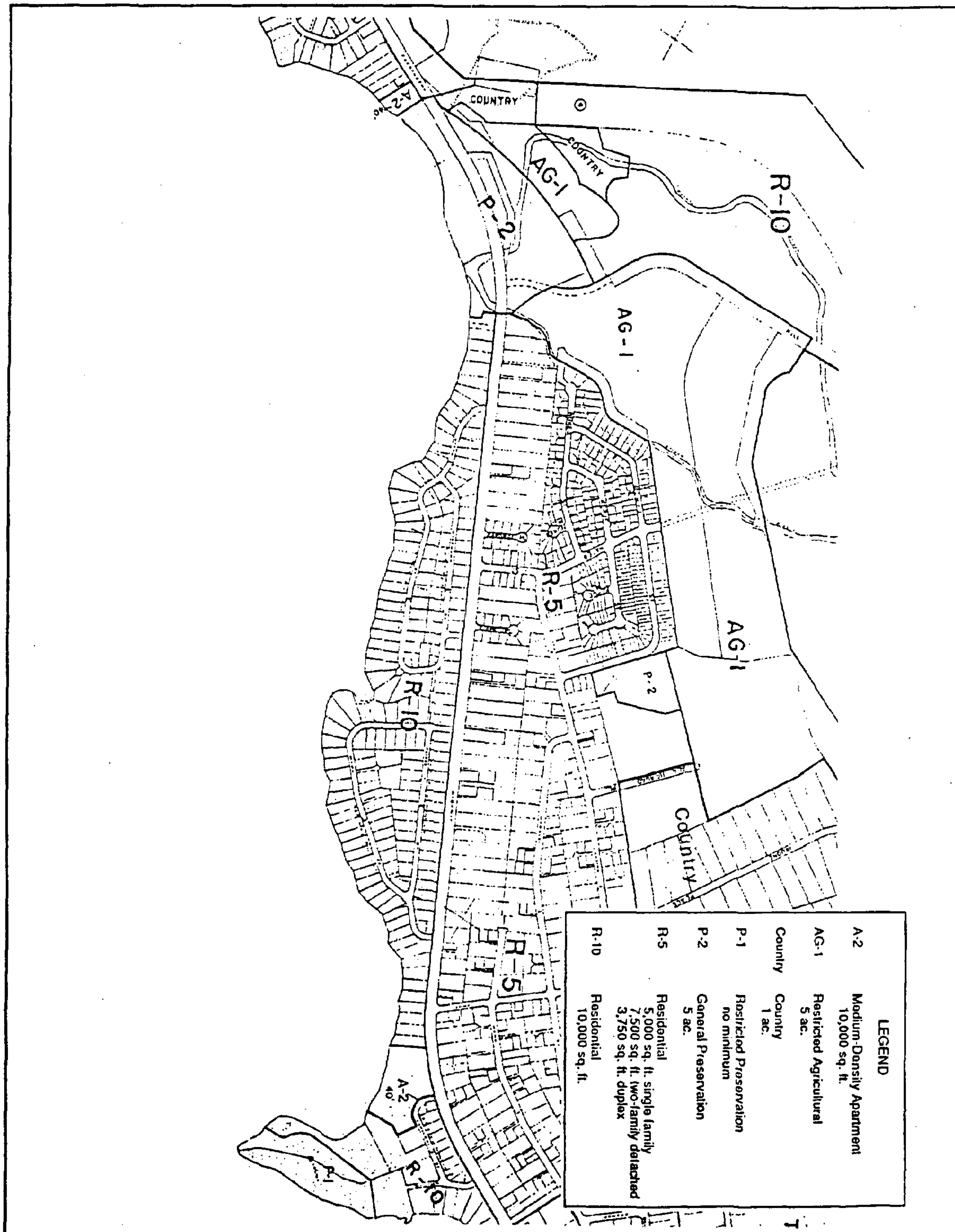

FIGURE 4-5 ZONING MAP FOR MAKAHA VICINITY

Most of the area is zoned for single-family Residential (R-10: a minimum lot area of 10,000 sq.ft.) consistent with the DP designation. The two MDA designated parcels are zoned for Apartment (A-2), and condominiums are constructed on these parcels. Zoning for Makaha Beach Park and most of Lahilahi Point are P-1 and P-2, respectively. The zoning map for the vicinity is presented in Figure 4-5.

There are a total of 64 existing seawalls in the study area with the majority located in the central portion of the study area. Of these 64 seawalls, 17 are legal, 25 are illegal and 22 are considered non-conforming.[40]

NEARSHORE WAVE CLIMATE

As discussed in Section 1.2 of this report, there are five major classifications of ocean waves in the Hawaiian islands: northeast tradewind waves, Kona storm waves, North Pacific swell, South Pacific swell, and hurricane waves. For the Makaha site location, only the northeast trade wind waves are unable to impact the shoreline due to the sheltered position of the site on the southwest coastline of the island of Oahu. Thus, the nearshore wave climate is relatively mild except during the winter months with the arrival of large North Pacific swell. No nearshore wave data are available for this coastal reach. However, wave data are available from a Waverider Buoy located offshore Barbers Point Harbor.[41] Available data from December 1986 through September 1988, with the buoy located in 600-foot water depth, were summarized into monthly and yearly frequency of occurrence statistics of significant wave height versus peak period, as provided in Table 4-1. The Barbers Point Waverider Buoy data can be considered to represent the typical deepwater wave climate for the west coast of Oahu. It may be observed that the Barbers Point Waverider Data does not include any directional information. As with most wave data sets, it can be seen that the information requires interpretation to be performed by those both trained in coastal engineering techniques and familiar with local wind, wave, and weather patterns. From the Table 4-1 data, it is apparent that the winter (North Pacific) swell energy is greater than the summer (southern swell) for this coastal reach.

[40] The available information on seawalls was provided by the Department of Land Utilization (DLU). Seawall definitions used by DLU are as follows: 1) Legal seawall has a permit regardless of when constructed, 2) Illegal seawall did not exist in 1967 DLU aerial photos and has no permit, and 3) Non-conforming seawall may have no record of a permit but is shown in the 1967 or 1969 DLU aerial photos.

[41] The buoy is part of a wave measuring network that is operated and maintained by the Scripps Institution of Oceanography under contract to the U.S. Army Corps of Engineers, as part of the Coastal Data Information Program.

TABLE 4-1
WAVERIDER BUOY DATA OFFSHORE BARBERS POINT HARBOR

% Frequency of Occurrence of Deepwater Waves

Month	Hs(ft)	Peak Period (sec) 4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-22	>22	TOT%
Jan	1.0-2.0	0.0	0.0	0.5	0.9	0.0	0.0	0.0	0.0	0.0	1.4
	2.0-3.0	0.0	7.7	5.0	11.8	7.2	1.4	0.9	0.0	0.5	34.4
	3.0-4.0	0.0	5.0	2.7	6.8	9.0	8.1	1.8	0.0	0.5	33.9
	4.0-5.0	0.5	0.5	1.8	1.4	7.2	2.3	1.8	0.0	0.0	15.4
	5.0-6.0	0.0	0.0	0.9	1.4	1.8	3.6	0.5	0.0	0.5	8.6
	6.0-7.0	0.0	0.0	0.0	0.0	0.5	2.3	0.0	0.0	0.9	3.6
	7.0-8.0	0.0	0.0	0.0	0.5	0.0	0.0	1.8	0.0	0.5	2.7
	TOT. %	0.5	13.1	10.9	22.6	25.8	17.6	6.8	0.0	2.7	100.0
Feb	1.0-2.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.6
	2.0-3.0	0.0	1.7	3.3	6.1	8.3	0.6	0.0	0.0	1.1	21.0
	3.0-4.0	0.6	1.1	0.6	6.6	16.0	6.6	3.9	0.0	0.6	35.9
	4.0-5.0	0.6	0.6	0.6	5.0	12.7	4.4	1.7	0.0	0.0	25.4
	5.0-6.0	0.0	0.6	0.6	2.2	3.3	1.7	0.6	0.0	0.0	8.8
	6.0-7.0	0.0	0.6	0.0	1.7	0.6	1.7	0.0	0.0	0.0	4.4
	7.0-8.0	0.0	0.0	0.0	0.0	0.6	1.1	0.0	0.0	0.0	1.7
	8.0-9.0	0.0	0.0	0.0	0.0	1.1	0.0	0.0	0.0	0.0	1.1
	9.0-10.	0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.0	0.0	1.1
	TOT. %	1.1	4.4	5.5	21.5	42.5	17.1	6.1	0.0	1.7	100.0
Mar	1.0-2.0	0.5	0.5	1.4	1.0	0.5	0.0	0.0	0.0	0.0	3.9
	2.0-3.0	3.9	8.7	3.9	10.6	8.2	1.4	1.0	0.0	0.0	37.7
	3.0-4.0	1.0	6.3	2.9	13.0	6.3	2.9	1.4	0.0	1.0	34.8
	4.0-5.0	0.0	2.4	1.9	3.9	1.9	1.4	0.5	0.0	0.0	12.1
	5.0-6.0	0.0	1.0	0.5	1.9	1.4	1.0	0.0	0.0	0.0	5.8
	6.0-7.0	0.5	1.0	0.5	0.0	1.0	0.0	0.0	0.0	0.0	2.9
	7.0-8.0	0.0	1.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	1.9
	8.0-9.0	0.0	0.5	0.0	0.0	0.5	0.0	0.0	0.0	0.0	1.0
	TOT. %	5.8	21.3	11.1	30.4	20.8	6.8	2.9	0.0	1.0	100.0
Apr	1.0-2.0	0.0	4.7	0.0	0.9	0.5	0.0	0.0	0.0	0.0	6.1
	2.0-3.0	4.2	17.8	7.0	9.3	10.3	4.2	0.5	0.0	0.0	53.3
	3.0-4.0	0.9	10.3	1.9	4.2	4.7	7.9	0.9	0.0	0.0	30.8
	4.0-5.0	0.0	0.5	0.9	0.9	0.9	2.8	0.5	0.0	0.0	6.5
	5.0-6.0	0.0	0.0	0.0	0.0	1.9	1.4	0.0	0.0	0.0	3.3
	TOT. %	5.1	33.2	9.8	15.4	18.2	16.4	1.9	0.0	0.0	100.0
May	1.0-2.0	0.5	0.5	2.6	5.7	11.4	2.1	0.5	0.0	0.0	23.3
	2.0-3.0	3.6	12.4	4.1	10.9	16.6	16.1	2.6	0.0	0.5	66.8
	3.0-4.0	0.0	1.6	0.5	0.5	1.0	4.1	2.1	0.0	0.0	9.8
	TOT. %	4.1	14.5	7.3	17.1	29.0	22.3	5.2	0.0	0.5	100.0
Jun	1.0-2.0	0.0	0.6	0.0	1.1	0.0	0.0	0.0	0.0	0.0	1.7
	2.0-3.0	3.9	26.3	5.6	8.9	11.2	6.7	1.1	0.0	0.0	63.7
	3.0-4.0	1.1	11.7	1.1	1.1	4.5	3.9	1.7	0.0	0.0	25.1
	4.0-5.0	0.0	0.0	0.6	0.0	0.6	6.7	0.0	0.0	0.0	7.8
	5.0-6.0	0.0	0.0	0.0	0.0	0.0	1.7	0.0	0.0	0.0	1.7
	TOT. %	5.0	38.5	7.3	11.2	16.2	19.0	2.8	0.0	0.0	100.0

TABLE 4-2 (CONTINUED)

Month	Hs(ft)	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-22	>22	TOT%
		Peak Period (sec)									
Jul	1.0-2.0	1.8	1.8	13.6	1.8	7.3	3.6	0.9	0.0	0.0	30.9
	2.0-3.0	4.5	2.7	9.1	14.5	17.3	15.5	0.9	0.0	0.0	64.5
	3.0-4.0	0.0	0.9	0.9	0.0	0.0	2.7	0.0	0.0	0.0	4.5
	TOT. %	6.4	5.5	23.6	16.4	24.5	21.8	1.8	0.0	0.0	100.0
Aug	1.0-2.0	0.0	0.5	1.1	3.2	2.7	0.0	0.0	0.0	0.0	7.5
	2.0-3.0	1.1	16.0	18.7	13.9	14.4	8.0	2.7	0.0	0.0	74.9
	3.0-4.0	0.0	4.3	2.7	1.1	1.1	6.4	1.6	0.0	0.0	17.1
	4.0-5.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.5
	TOT. %	1.1	20.9	23.0	18.2	18.2	14.4	4.3	0.0	0.0	100.0
Sep	1.0-2.0	0.0	2.3	3.3	1.9	0.0	0.5	0.0	0.0	0.0	8.0
	2.0-3.0	1.4	24.4	16.0	12.2	10.8	0.9	0.0	0.0	0.0	65.7
	3.0-4.0	0.0	6.6	4.7	3.3	3.8	3.8	0.0	0.0	0.0	22.1
	4.0-5.0	0.0	0.0	0.9	0.5	0.0	0.0	0.0	0.0	0.0	1.4
	5.0-6.0	0.0	0.0	0.9	1.9	0.0	0.0	0.0	0.0	0.0	2.8
	TOT. %	1.4	33.3	25.8	19.7	14.6	5.2	0.0	0.0	0.0	100.0
Oct	1.0-2.0	3.7	2.8	0.9	0.9	0.0	0.0	0.0	0.0	0.0	8.4
	2.0-3.0	1.9	14.0	12.1	17.8	17.8	13.1	2.8	0.0	0.0	79.4
	3.0-4.0	0.0	0.0	0.0	3.7	1.9	3.7	1.9	0.0	0.0	11.2
	4.0-5.0	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.9
	TOT. %	5.6	16.8	13.1	22.4	19.6	17.8	4.7	0.0	0.0	100.0
Nov	1.0-2.0	0.0	1.7	0.9	0.0	0.0	0.0	0.0	0.0	0.0	2.6
	2.0-3.0	0.0	1.7	6.0	1.7	17.1	9.4	3.4	0.0	2.6	41.9
	3.0-4.0	1.7	1.7	4.3	1.7	10.3	5.1	7.7	0.0	2.6	35.0
	4.0-5.0	0.0	0.0	2.6	1.7	5.1	4.3	2.6	0.0	0.0	16.2
	5.0-6.0	0.0	0.0	0.9	0.0	0.9	1.7	0.9	0.0	0.0	4.3
	TOT. %	1.7	5.1	14.5	5.1	33.3	20.5	14.5	0.0	5.1	100.0
Dec	1.0-2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	2.0-3.0	0.0	5.9	6.9	4.9	5.4	3.4	1.0	0.0	0.0	27.6
	3.0-4.0	1.0	7.9	10.8	4.4	9.9	6.4	1.0	0.0	0.0	41.4
	4.0-5.0	0.0	3.4	2.5	1.0	2.5	7.9	1.5	0.0	0.0	18.7
	5.0-6.0	0.0	3.0	1.5	1.5	0.5	0.0	0.0	0.0	0.5	6.9
	6.0-7.0	0.0	2.0	1.5	0.0	0.0	0.0	0.5	0.0	0.5	4.4
	7.0-8.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.5
	8.0-9.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
	TOT. %	1.0	22.7	23.6	11.8	18.2	17.7	3.9	0.0	1.0	100.0
Annual (1987)	1.0-2.0	0.5	1.3	2.1	1.5	1.9	0.5	0.1	0.0	0.0	7.8
	2.0-3.0	2.0	11.6	8.1	10.2	12.0	6.7	1.4	0.0	0.4	52.6
	3.0-4.0	0.5	4.8	2.8	3.9	5.7	5.2	2.0	0.0	0.4	25.2
	4.0-5.0	0.1	0.6	1.0	1.2	2.6	2.6	0.7	0.0	0.0	8.8
	5.0-6.0	0.0	0.4	0.4	0.7	0.8	0.9	0.2	0.0	0.1	3.5
	6.0-7.0	0.0	0.3	0.2	0.1	0.2	0.3	0.0	0.0	0.1	1.3
	7.0-8.0	0.0	0.1	0.0	0.0	0.1	0.1	0.2	0.0	0.0	0.6
	8.0-9.0	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.2
	9.0-10.	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1
	TOT. %	3.2	19.1	14.6	17.7	23.4	16.4	4.6	0.0	1.0	100.0

Wave refraction analysis was conducted for the Makaha site location for characteristic wave periods of 10, 14 and 18 seconds and with deep water wave propagation directions originating from 180 degrees true (south), 270 degrees true (west), and 315 degrees true (northwest). The area encompassed by the numerical model extended west roughly 7,000 feet from Kepuhi Point to a north-south line lying roughly 13,000 feet west from Lahilahi Point. The bathymetry for the Makaha site location was obtained from a 1 inch = 500 meter scale map with 5 meter depth contours.[42] A grid was superimposed over this area and bathymetric data input to the model using a grid size of 100 meters to a side. The analysis results and output from the refraction model are provided in Appendix J, as well as a technical discussion of the technique. Figures 4-6 through 4-8 have been included herein to cover the important points of the analysis. The three outputs from the refraction calculations display deep water wave energy propagating from the northwest with a 14 second period, from the west with a 10 second period, and from the south direction with an 18 second period. For each wave approach direction, the period selected here best represents typical wave periods for the predominant wave types affecting this coastal reach.

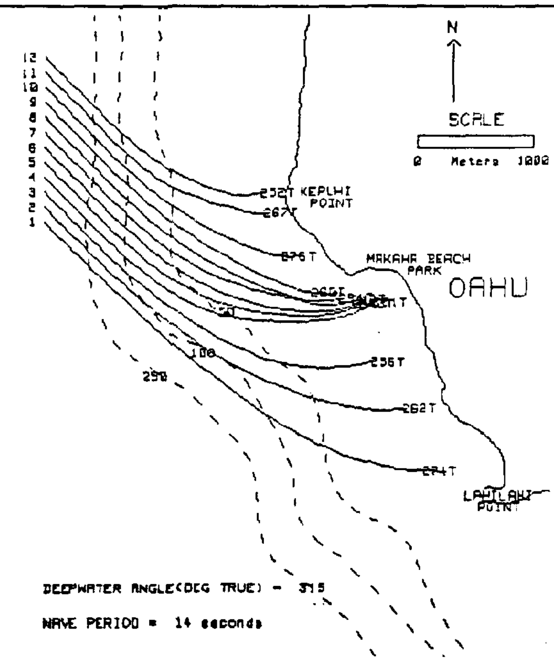

FIGURE 4-6 MAKAHA REFRACTION ANALYSIS, 14 SEC WAVE PERIOD FROM NW DIRECTION

[42] Pararas-Carayannis, George (1965), "The Bathymetry of the Hawaiian Islands, Part 1. Oahu", Hawaii Institute of Geophysics, University of Hawaii, HIG-65-15.).

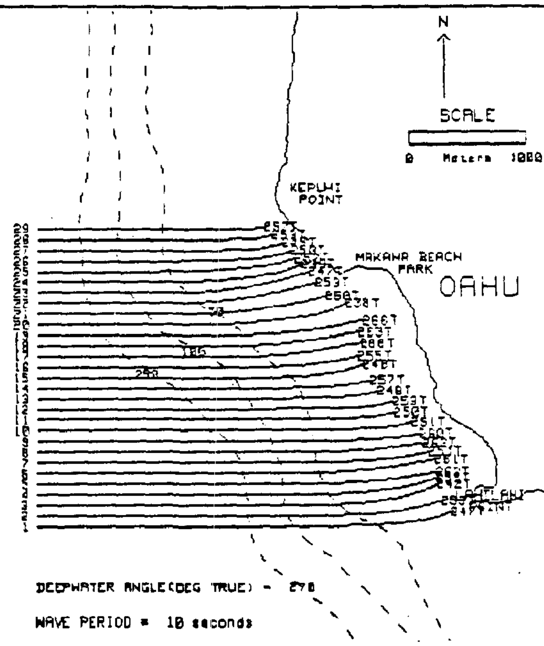

FIGURE 4-7 MAKAHA REFRACTION ANALYSIS, 10 SEC WAVE PERIOD FROM W DIRECTION

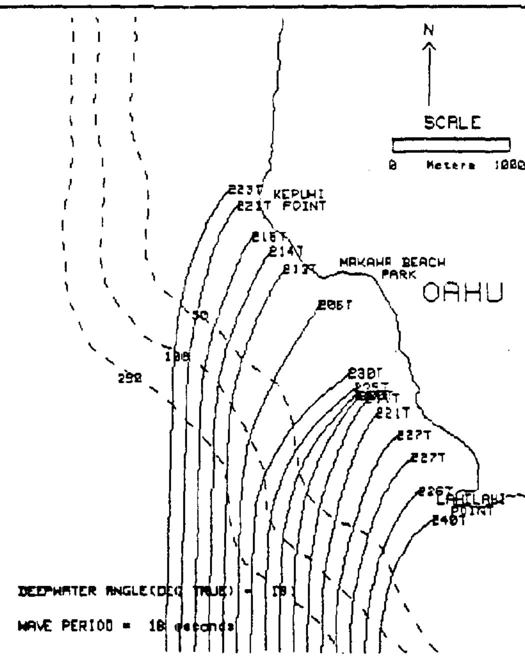

FIGURE 4-8 MAKAHA REFRACTION ANALYSIS, 18 SEC WAVE PERIOD FROM S DIRECTION

From inspection of the wave ray diagrams for the different wave approach directions, three facts are quickly evident. First, waves from the northwest, west and south directions will all significantly impact the shoreline along the site area at Makaha. Second, the manner in which the waves impact the site area from any one of the three source directions is far from uniform along the stretch between Lahilahi Point and Kepuhi Point. This is due to the variations in the nearshore bathymetry. Third, the specific positions of the convergence zones, where wave energy is concentrated along the shore, vary significantly depending on the wave approach direction; this translates to significant variation in the position of wave energy concentration from one season to another when the different wave approach directions predominate.

The most dramatic convergence zone occurs with ray numbers 4-9 in the 14 second wave period output from the northwest direction. The output displays the focusing of wave energy in the area offshore from the Makaha Beach Park just to the south of Kepuhi Point. The reef area closer to shore at this location harbors one of the more famous surf breaks on the island of Oahu, and it is no surprise that local knowledge confirms that most fun is had when the northwest swell rises. The convergence at this location has important implications to the nature of erosion in the area.

The output for the 10 second wave period from the west shows significant convergence of wave energy at Kepuhi Point and at the area offshore from Papaoneone Beach. This output represents typical conditions when local Kona storms or hurricanes hit the islands. It can also be noted that the wave rays from the west direction undergo the least amount of transformation when compared to the northwest and southerly wave approach directions. This is due to the fact that the offshore contours are relatively parallel to the shoreline and that the wave crests for the westerly approach direction are the most parallel to the bottom contours.

The significant convergence area for the 18 second south swell occurs on the north end of the rocky shore between Papaoneone Beach and Makaha Beach approaching the southern end of the Makaha Beach system. North of this convergence zone, there is a significant divergence zone. From review of the data outputs for the 14 and 10 second wave periods propagating from the south (see Appendix J), it can be seen that the pattern of wave transformation for the shorter wave periods are similar in form but less severe in degree to the outputs for the longer wave periods from the same direction. Generally, similar rays converge or diverge but to a lesser extent.

Typical maximum deep water wave heights for the southern swell can be anticipated at approximately 5 feet and for the other swell directions at approximately 10 feet, excluding the rare event hurricane. Shoaling and refraction effects for the Makaha site can lead to an approximate doubling of the deep water wave heights before breaking occurs in those areas shoreward of convergence zones. This leads to approximate maximum breaking wave heights of 10 feet for the southern swell and 20 feet for the west and northwest swell directions at the Makaha site location. The physical complexity of breaking waves must be emphasized. Breaking wave heights are a function of bottom slope, water depth, and wave characteristics. In most areas, including the site location, water depths vary so greatly, both spatially with the reef structures, as well as temporally with the movement of sand on and offshore, that the position and form of breaking waves would be difficult to calculate for all wave conditions. Inspection of the site area during different wave conditions can qualitatively reveal the wide range of breaking conditions on or near the shoreline. The estimate of 10-20 feet maximum breaking wave heights is intended to provide an order-of-magnitude understanding of the high energy regime which can be experienced at the Makaha site location especially during winter high swell conditions. This is in contrast to the calm conditions which prevail during most times of the year due to sheltering from the prevailing northeast trade winds.

COASTAL PROCESSES: ROCKY POINTS

The dominant feature along the rocky headland and sections of rocky shores at the Makaha site location is the hard rock, flat-topped, limestone terrace which acts as a buffer at the water's edge between the backshore areas and the violence of the ocean waves. Rough and wave-cut from the pounding of ocean waves, the limestone platforms typically lie 1-3 feet above MSL (mean sea level) and form the bedrock of the upland areas. MSL is determined from a long term average of the tidal range which is only about two feet in the Hawaiian islands. The seaward rim of the limestone terraces have typical widths of less than 15 feet before rising in one or more steps to approximately 5 feet above MSL. The wave-cut limestone terraces are extremely stable buttresses in regards to the erosional processes of the ocean and the land, showing no observable landward retreat in their position.

An important characteristic of the limestone platform is the near vertical face at the water's edge which drops immediately to water depths between 10 and 15 feet. The ocean quickly attains much greater depths in the nearshore area - 600 foot depths can be found just one mile offshore. The steepness of the platform's face at the water's edge plays a significant role in reflecting a large part of the incoming wave energy back offshore. Instead of turbulent rolling breakers typical of high surf conditions along gently-sloping sandy shores, the high energy conditions in front of the limestone terraces are better characterized by a surging swell. Only a portion of the incoming wave energy is transmitted landward as run-up towards existing houses and other structures. On the south side of Kepuhi Point, the data output from the refraction analysis shows a convergence zone for the 10 second westerly wave period. If it were not for the fronting limestone platforms, the oceanfront residential dwellings would not survive deepwater wave conditions approaching 10 feet in the winter.

FIGURE 4-9 KEPUHI POINT SHORELINE
Representative of rocky limestone terrace shoreline with seawalls protecting oceanfront residential lots

The residential dwellings, having often been constructed at less than 100 feet from the water's edge in such areas, are not without need for protection however. With approximate shorefront slopes ranging near 1V:5H, landward lot elevations of only 10-15 feet above MSL are common. Unchecked wave run-up may reach 30-40 feet inland from the water's edge as evidenced by surface scour, cobble placement and debris lines on open lots. Although calculations for the required height of seawalls for protection against wave run-up are difficult to estimate in such an environment, coastal engineering analyses have been conducted for homeowners at such locations within the Makaha study reach.[43] Such analyses agree with the judgement of previous construction to build the seawalls up to elevations of roughly 15-17 feet above MSL at the shorefront of the residential properties. Roughly 95% of such residential lots along the rocky shoreline areas within the Makaha study site have constructed seawalls. On most lots, the seawalls stand 5-8 feet above the limestone base, they are typically of

[43]Edward K. Noda and Associates, Inc., "Coastal Engineering Evaluation and Environmental Assessment for Construction of Shore Protection at Makaha, Oahu, Hawaii (TMK: 8-4-10:9), September 16, 1989; and "Coastal Engineering Evaluation and Environmental Assessment for a Seawall at Makaha, Oahu, Hawaii (TMK: 8-4-05:7), February 1989.

cement-rubble-masonry (CRM) construction, and they are in good structural condition.

An important feature of the three rocky point areas within the Makaha study site is the manner in which they isolate the two extensive beach systems: Makaha Beach and Papaoneone Beach. Each beach system, along with its adjacent rocky shorelines, may be considered as an independent littoral cell in regards to its sediment budget. More simply, the supply and transport of beach material at one location may be considered to not affect the supply and transport of beach material at the other. Littoral transport features of the two beach systems are discussed below.

COASTAL PROCESSES: BEACH SYSTEMS

There are numerous similarities in both the physical structure and the coastal processes at the two extensive arcuate beach systems within the Makaha study site: Makaha Beach and Papaoneone Beach. For this reason the two systems will be presented at the same time. Although susceptible to great seasonal variation, both beaches are wide, 50-200 feet, and composed of fine to medium grained calcareous sands of biological origin. Makaha Beach is the larger of the two beach systems, roughly 2000 feet in length, while Papaoneone Beach is about 1000 feet in length. Both systems are located at sizable embayments of the coastline, Makaha Beach to the south of Kepuhi Point and Papaoneone Beach to the north of Lahilahi Point.

The nearshore ocean bottoms of both embayments are composed of mixed reef and sand structures. Relative to the nearshore bathymetry offshore of the rocky points, the bathymetry inside the embayments remains shallow. Typical water depths are less than twenty-five feet at distances less than 1500 feet from the sandy beaches. At both ends of the two beaches, the sandy shores merge into the limestone platforms of the adjacent rocky points. The first rocky areas usually appear intermittently in the wave run-up zone on the beach and gradually rise in elevation to become continuous with the formation of the rocky point. Such transition zones are subject to tremendous seasonal variation in sand cover.

The combination of refraction effects leading into the breaker zones and bathymetry of the coastal embayments where the ocean waves actually break at the Makaha Beach and Papaoneone Beach areas lead to dynamic conditions at these beach shores. The refraction output for the northwest swell and west swell showed a significant convergence zone towards the north end of Makaha Beach and Papaoneone Beach, respectively. With the shallow reefs immediately adjacent to the shoreline in these areas, the larger winter swells with breaking wave heights at 10-20 feet and periods at 10-15 seconds break as plunging waves with their turbulent white-water boars extending all the way to the beach front. Smaller swells may break as only partial

FIGURE 4-10 MAKAHA BEACH
Note multi-story building towards Kepuhi Point with seawall at foundation level.

FIGURE 4-11 PAPAONEONE BEACH
Directly fronting shorefront condominium.

plungers on the reefs with secondary wave formation (3-4 feet) inside the reefs, expending all the remaining energy directly on the beach front. This activity scours and suspends sediment at the north end of the two beach systems and transports the sediment southward during the wintertime when the northwest and west swells occur.

Waves from local Kona storms during the winter season exhibit 5-15 feet breaking wave heights with shorter periods (5-10 seconds) and steeper faces than the North Pacific swell. The steep Kona waves more directly assault the entire length of the beach front at Makaha and Papaoneone. This action scours large volumes of sand from the beach and transports the sediment directly offshore onto the nearshore reef flats in the coastal embayments. This process is accelerated in areas of rip-current formation where return-flow occurs between breaker zones at the beachfront. The scouring of sand from the beach causes the beach slope at the water's edge to steepen dramatically. This effect, when coupled with rip-current formation, creates dangerous hazards to unwary swimmers.

The depreciations and accumulations of sediment due to erosion in the winter season vary from year to year, swell to swell, storm to storm, even day to day as the wave patterns, reef areas, and changes in bottom bathymetry continuously interact throughout the coastal embayments. It can be said with certainty, however, that two erosional processes will occur in every winter season. First, significant volumes of sand will be scoured at the north end of the two beach systems and transported toward the southern reaches of the beach systems. This process will lay bare reef formations in the wave run-up zone, which were completely covered with sediment in the summer season, along possibly hundreds of feet of shoreline at the northern end of the two beaches. Additionally, the process will increase the wave exposure of structures which are constructed on the hard rock base near the areas scoured of beach sediment. Second, sediment will be transported directly off the beach and onto the nearshore reef flats throughout the length of the two beach systems. This process can narrow the beach width by a third to one half of its summertime width and create added wave exposure for structures near the landward edge of the beach systems.

The coastal processes which occur during the summer months act to restore the effects of the winter season. The longer period southern swell predominates with little or no swell activity from the west and northwest. The longer period waves with less steep faces act to transport the sediment from the offshore reef flats within the coastal embayments towards shore, depositing the sand back onto the beach slopes at Makaha and Papaoneone. Within the beach systems, the beach widths are built back out seaward attaining a flatter sloped beach front at the water's edge. In addition to this offshore-onshore transport, there is a shifting of sediment back toward the northern reaches of the beach systems. The southern swell approaches the shorelines at Makaha maintaining a southerly component of approach. As the swells break within the embayments, their angle with the beach sets up a northerly longshore transport toward the rocky points on northern flanks of the beach systems. This transport replenishes the severe scouring which occurs during the winter season in these areas.

In addition to the above discussed features, in the Makaha Beach system another important process occurs. Near the middle of the beach span, a channel mouth is present where two streams converge before draining beneath the Farrington Highway. This channel mouth is most often dry at the beachfront, but during periods of heavy rain the fresh water run-off will erode through the beach front as it joins the sea. The position where the channel mouth crosses the beach varies laterally on the order of several hundred feet. This variation occurs due to the different relative discharges from the two streams entering the channel mouth and the continually varying nature of the beach front undergoing the erosional processes discussed above.

During periods of heavy rain in the winter, a significant volume of sand is scoured off the beach by this stream discharge. Most of this sand is immediately deposited in the form of a small delta at the ocean's edge, but some is carried further out onto the reef flats of the coastal embayment. There is not an indication that the stream discharge is causing beach sediment to be permanently lost from the littoral cell; it is likely that there is a net input to the littoral cell as the rain run-off carries sediment in suspension from the drainage basin area. Nevertheless, this rapid scouring of the beach from the stream discharge occurs during the winter season when the Makaha Beach system is already undergoing extensive erosion as discussed above. Previous investigations[44] have noted as large as 145 feet seasonal variations in beach width, leading to damage of Makaha Beach Park facilities where a revetment was constructed to protect the public bathhouse.

[44] R. Moberly and T. Chamberlain, "Hawaiian Beach Systems".

FIGURE 4-12 TRANSITION AREA AT NORTH END OF PAPAONEONE BEACH
Photo date December 1988: Note the depth of sand cover over the limestone terrace and the escarpment due to scouring from winter surf activity.

FIGURE 4-13 SAME AREA AS FIGURE 4-12, NORTH END OF PAPAONEONE BEACH
Photo date May 1989: Note the accretion of sand over the rocky limestone terrace due to summer swell activity, creating a gently sloping beach face.

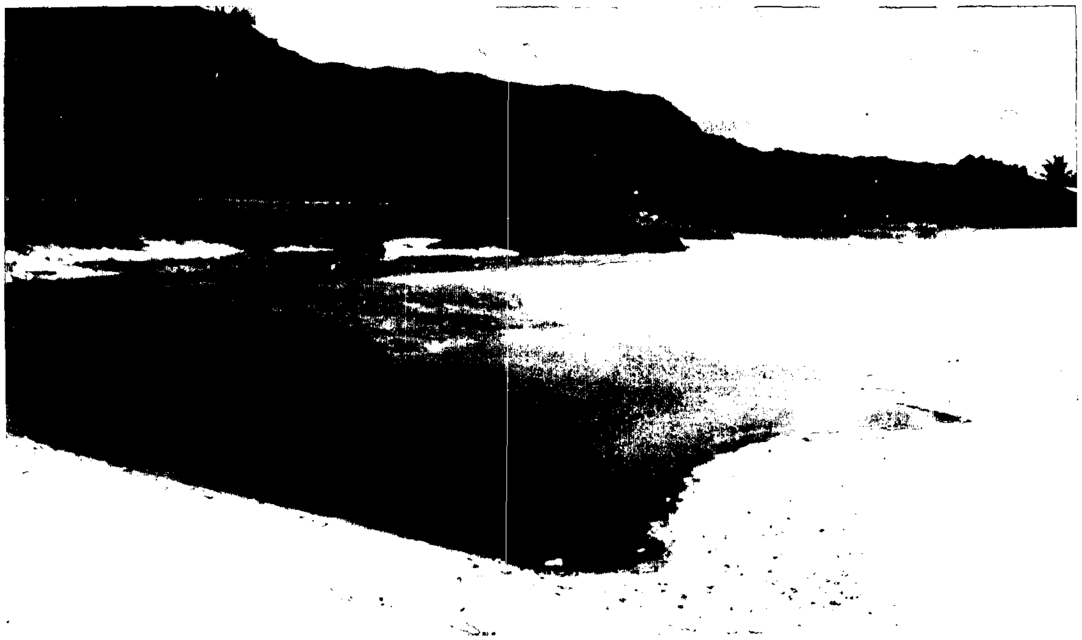

FIGURE 4-14 PLUGGED STREAM MOUTH IN CENTRAL PART OF MAKAHA BEACH

LONG-TERM SHORELINE CHANGES

Along the rocky sections of shoreline at Lahilahi Point, Kepuhi Point, and the long stretch between Makaha Beach and Papaoneone Beach, there has been no observable long-term shoreline change. These stable areas are naturally protected by the fronting limestone platforms discussed earlier. For the two large pocket beaches, Makaha and Papaoneone, an estimate of long-term shoreline change is difficult to determine. Previous studies of these beaches were accomplished based on analysis of historical aerial photos.[45] These studies documented the changes in position of the vegetation line along just a few transects at each beach. Seven historical aerial photos over a forty year period were used in the analysis. The positions of the transects, which were established by Hwang and added on to by Sea Engineering, Inc., are shown in Figure 4-15. Time series for the changes in position of the vegetation line at

[45] Dennis Hwang, "Beach Changes on Oahu as Revealed by Aerial Photographs", prepared for the State of Hawaii Dept. of Planning and Economic Development, prepared by the Urban and Regional Planning Program and the Hawaii Institute of Geophysics, University of Hawaii, Technical Report HIG-81-3, Cooperative Report UNIHI-SEAGRANT-CR-81-07, July 1981.
Sea Engineering, Inc., "Oahu Shoreline Setback Study", prepared for the City and County of Honolulu, Dept. of Land Utilization, November 1988.

each transect are shown in Figures 4-16 and 4-17. The plots show the cumulative loss or gain of the vegetation line along each transect relative to the earliest photo date.

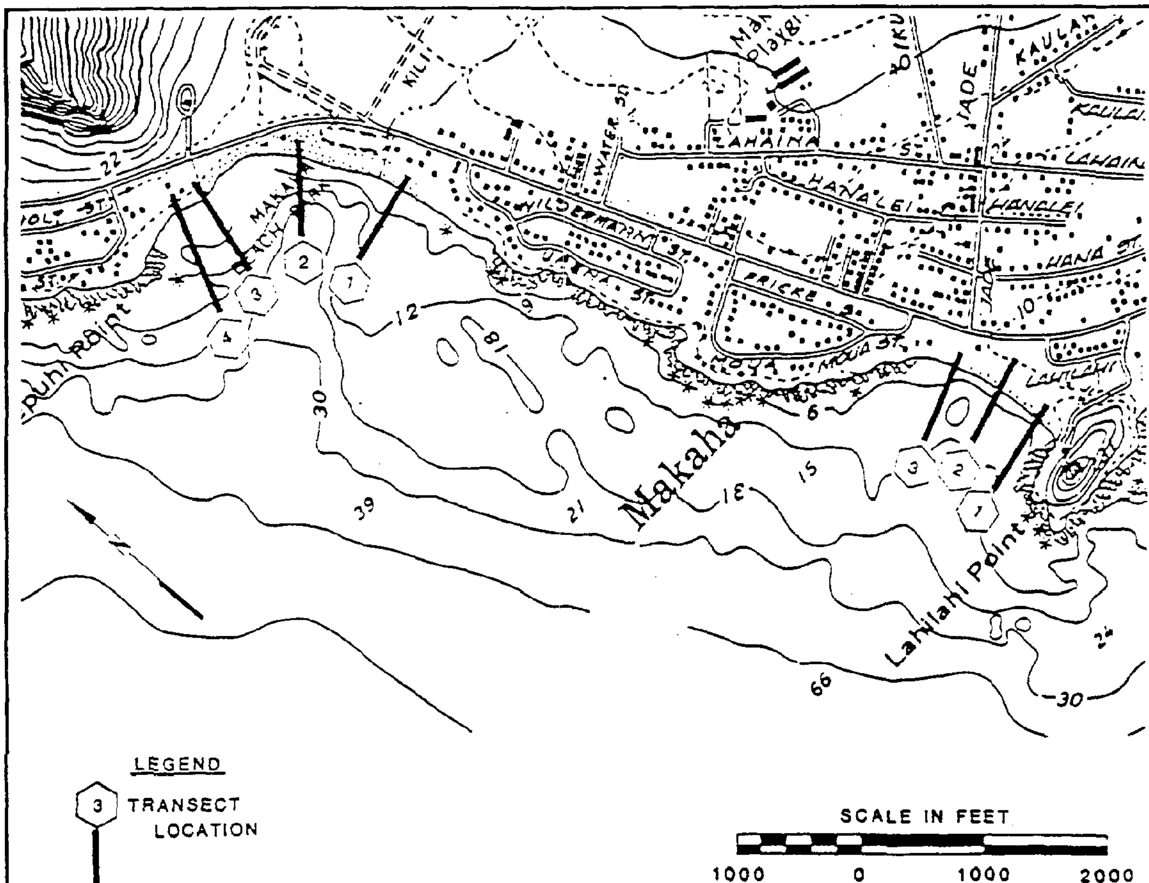

FIGURE 4-15 TRANSECT LOCATIONS FROM PREVIOUS STUDIES
(Adopted from Sea Engineering, Inc. Study)

The transect time series for Makaha Beach display a net long-term accretion of the vegetation line along Transects 1 and 2 at the south and middle positions of the beach. At the north end of the beach, Transects 3 and 4 display significant erosion. It can also be seen that since 1975, the vegetation line at Transect 2, through the middle of the beach, has been eroding at nearly the same rate as along Transects 3 and 4. This is also near the location of the Makaha Beach Park bathhouse facility which has been damaged in winter storms. The previous studies conclude that the southern shoreline area at Transect 1 is stable but susceptible to episodic severe erosion due to extreme storms. The rest of the shoreline area at Transects 2-4 were classified as unstable with long-term erosion history.

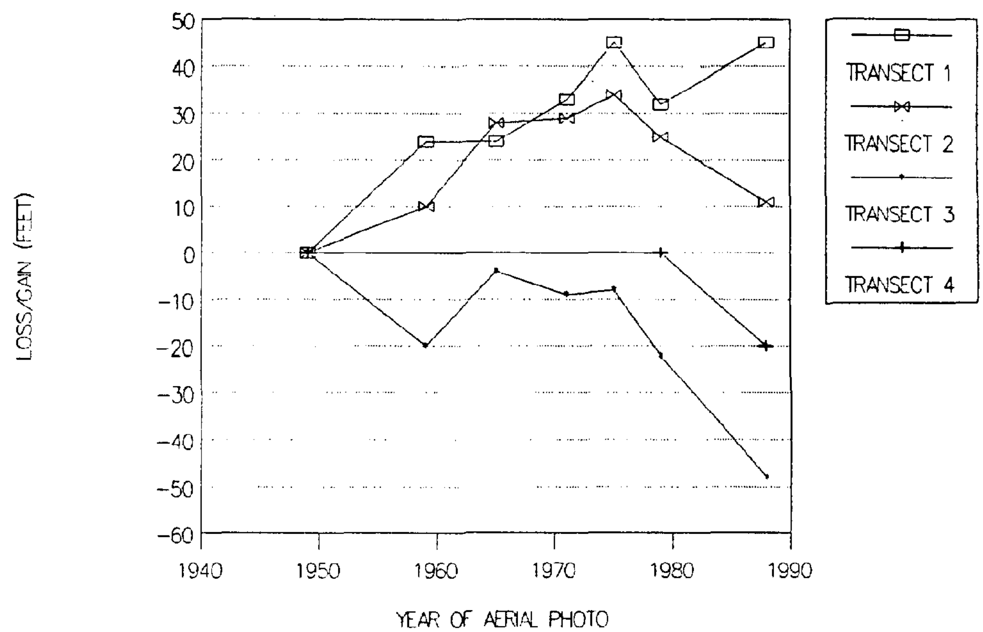

FIGURE 4-16 MAKAHA BEACH CUMULATIVE SHORELINE CHANGES

The time series for Papaoneone Beach shows a net long term accretion in the position of the vegetation line for Transects 1 and 3 at the south and north sections of the beach. Before the condominium units were built, Transect 2 in the middle of the beach showed a recession in the vegetation line. After construction of the tall buildings, the vegetation line was obscured by the buildings and no data were obtained for this transect. The previous studies conclude that Papaoneone Beach is stable based on the transect data. However, the incidence of run-up and flooding of these buildings during winter storm periods would seem to indicate a possible eroding trend as opposed to a stable trend at the location of the condominiums. However, no quantitative data are available to substantiate this hypothesis.

Use of the technique of digitizing the vegetation and beach toe lines as described in Section 1.4 of this report may provide more detailed information regarding the long-term changes of the entire shoreline reach within the beach littoral cells. The vegetation line could be interpolated across the buildings in a consistent manner, with no loss of data from the particular aerial photo and subsequent photos because of it

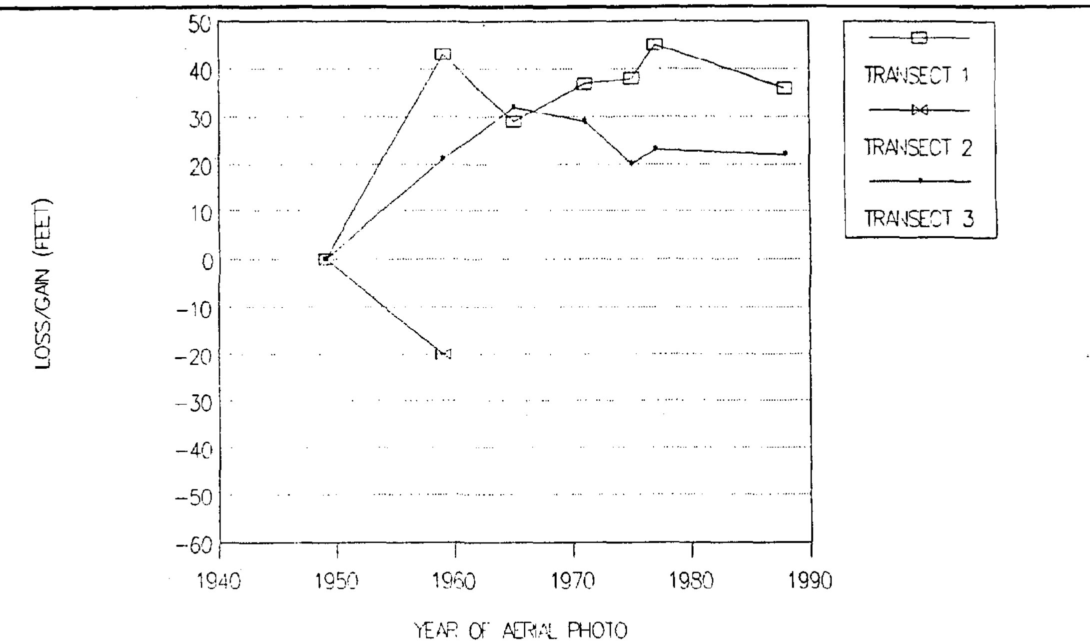

FIGURE 4-17 PAPAONEONE BEACH CUMULATIVE SHORELINE CHANGES

being hidden by the tall buildings. This technique of obtaining continuous data representing the entire shoreline, as opposed to the transect technique of obtaining point data at only discrete locations, was accomplished for the other case study sites. This is an example of how the digitizing of continuous beachlines can mitigate the shortcomings of the transect technique.

The opposite trends along different transect lines within the same beach system, the lack of historical data along the whole continuous length of the beach systems, and the great seasonal variation in the width of the beaches at Papaoneone and Makaha Beaches, all point to the need for more frequent data and more detailed data to more definitively describe the long-term trends of erosion or accretion within such dynamic seasonal beach systems.

The large seasonal fluctuations in beach widths, the history of erosion or storm wave-related problems at the two beaches, and the possible incidence of rare storm events such as Hurricane Iwa in 1982, all warrant a conservative approach towards the estimate of the long-term shoreline change at Papaoneone and Makaha Beaches. While stressing the need for continual monitoring of such coastlines through controlled aerial photography, two possible approaches to estimating the long-term erosion potential are discussed below.

The first approach is based upon the observation that the maximum deviation from the 1949 base line, in both the erosion and accretion directions, for position of the vegetation line is close to 50 feet over the last forty years at both beaches. Since 50 feet is the natural bound to the fluctuation in both directions, there is reasonable likelihood that the position of the vegetation line will not recede more than 50 feet from its present position, at all locations, over a similar time period in the future.

The regulatory appeal of the second approach for a long-term estimate of shoreline change at the Papaoneone and Makaha Beach areas lies in conforming to a previously determined standard, as opposed to creating new standards based on narrow data sets. This second approach utilizes the boundaries from the Flood Insurance Rate Map (FIRM) established by the Federal Emergency Management Agency (FEMA) under the National Flood Insurance Program. As can be seen from Figure 4-18, it appears that the boundary between ZONE VE[46] and ZONE AE[47] at the two beaches lies near a line located 50 feet inland from the present vegetation line. From the standpoint of familiarity alone, use of the FIRM zones to estimate the potential for long-term erosion impacts may more easily gain acceptance as a regulatory approach for managing development in erosion-prone shoreline areas. Use of the FIRM zones could not unilaterally be applied for all coastal areas since some shoreline areas are susceptible to tsunami inundation for hundreds of feet inland. However, for areas such as Makaha and Papaoneone, where lack of detailed information make the estimate of long-term shoreline changes difficult to predict, use of the FIRM zones may have applicability as an initial basis for establishing erosion hazard zones. However, more detailed study of erosion processes and historical rates is the preferable method for estimating future long-term shoreline changes and erosion hazard.

A final note to the long-term estimates of shoreline change at the Makaha site location concerns the transition zone between the rocky shoreline areas and the beach areas. The rocky shores are stable in the long-term while the beach areas are suggested as having a long-term erosion potential of approximately 50 feet. The beach areas merge into the rocky point areas gradually. An appropriate division between the two areas lies at the location where the rocky shore adjacent to a beach system becomes unaffected by the seasonal processes of sediment transport within the beach system, during any time of the year.

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[46] Zone VE is within the Special Flood Hazard area inundated by the 100-year flood, and is defined as a coastal flood zone with velocity hazard (wave action), where the base flood elevation is determined. These zones represent the limits of tsunami wave flooding.

[47] Zone AE is within the Special Flood Hazard area inundated by the 100-year flood, where base flood elevations are determined. These zones at the coast represent the limits of flooding due to storm wave inundation.

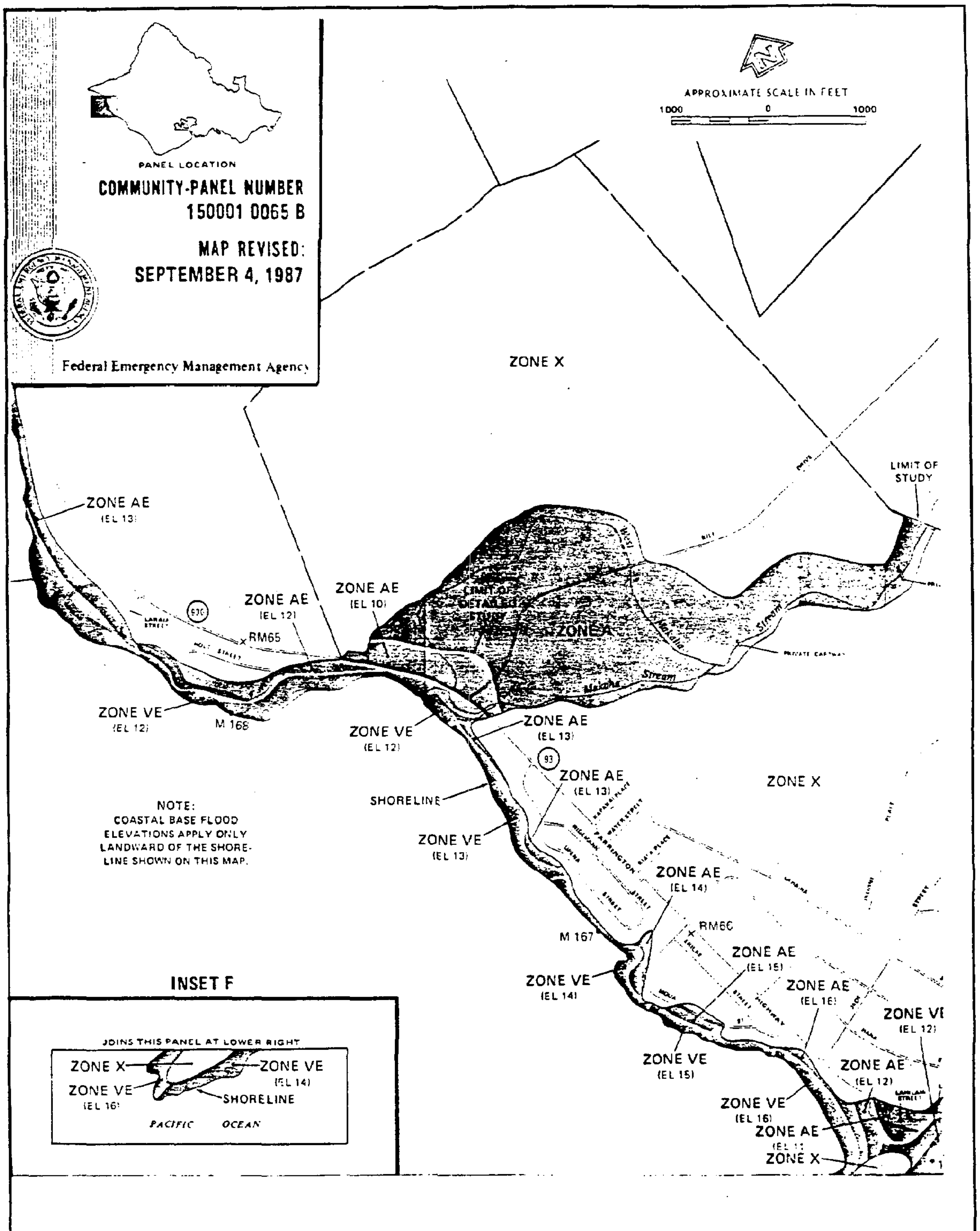

FIGURE 4-18. PORTION OF FLOOD INSURANCE RATE MAP FOR MAKAHA STUDY SITE

APPROPRIATE SHORE PROTECTION MEASURES

In the case where structural shore protection measures are required at the Makaha site location, only two methods are appropriate: seawalls along the rocky shore areas and buried revetments in the sandy beach systems. In the rocky areas, vertical seawalls are the most cost-effective measure. The hard limestone platforms provide a good foundation for the structure, and the seawalls can be built in the dry at elevations above the high water line. Vertical seawalls take up less space, thus maximizing use of the shoreline by the public as well as by the landowner. The seawalls should be placed sufficiently landward of the waterline to permit public access along the rocky shore. This minimum distance may vary depending on the shoreline elevations. Within the sandy beach systems, sloping rubble revetments are the most appropriate measure. The revetments should be buried at the edge of the vegetation line to protect existing improvements, serving as a last line of defense during extreme storm wave events. During the typical seasonal wave conditions, the beaches would be expected to build back. The permeability of the revetment would allow the sand to accrete and re-bury the revetment. Selection of the most appropriate option in the transition areas between the beaches and the rocky points should be based on the pertinent features such as depth to a hard substrate and maintenance of sufficient public shoreline access.

Groins are not functionally suitable for the beach areas since they may aggravate the offshore transport of sediments from the beach during high surf conditions. Groins are more suited to long shoreline reaches with relatively mild wave conditions. Offshore breakwaters are functionally suitable but may likely affect the offshore surf sites. The breakwaters would also be much more expensive to construct and maintain than shoreline structures.

EROSION MANAGEMENT RECOMMENDATIONS

Within the Makaha case study area are two large pocket beaches, Makaha Beach and Papaoneone Beach, with different land uses. Specific recommendations for these pocket beach areas are as follows.

Papaoneone Beach:

- o Based on the analysis of historical shoreline changes described herein, a 50-foot shoreline setback should be established for the entire sandy beach area extending from Lahilahi Point to a portion of rocky shore to the north.[48]

- There should be constant monitoring of the two parcels with the apartment buildings. These two parcels were spot zoned for an A-2 designation which is different from the surrounding R-10 parcels. Because the land use of these parcels may have changed historic erosion/accretion patterns, detailed information should be collected and maintained to document future changes. This is especially true since there are no seawalls or revetments built on the major portion of Papaoneone Beach and the surrounding parcels are vacant. This clearly presents a management opportunity to control further development which may affect erosion/accretion patterns, for example, through the establishment of special overlay zoning designation or redesignation as Conservation District. A sufficient data base and analysis should be required before any permits are considered for a shoreline setback variance for shore protection. Shoreline surveys should be conducted over a minimum number of years, say 6-8 years. If possible, the entire Papaoneone beach area should be surveyed consistently twice during a year (summer and winter season) at approximately the same time periods to ensure consistency in the data.

<u>Makaha Beach</u> is a similar beach physically to Papaoneone Beach without the presence of large structures or a higher-density spot-zoning on the sandy beach area. An apartment structure is on a rocky parcel at the north end of the sandy beach area and is within the transition zone between the beach area and the rocky shore. This apartment zoned parcel already has a shore protection structure. Recommendations for Makaha Beach include:

- Based on the analysis of historical shoreline changes described herein, it is recommended that a 50-foot shoreline setback be established for the entire Makaha Beach littoral cell.

- Revetments should be the only shoreline protection structure permitted in the beach area if shore protection is determined to be necessary. However, since major portions of Makaha Beach are as yet undeveloped, management or regulatory controls would be preferable to prevent need for shore protection of future structures and improvements.

[48] The shoreline setback area should encompass the transition zones between the sandy beach and rocky shore. The transition zone on the rocky shore includes that portion affected by seasonal erosion-accretion patterns.

4.3 CASE STUDY SITE #2 - KAILUA-LANIKAI, OAHU

GENERAL DESCRIPTION

The second study site is located on the windward side of Oahu as displayed in Figure 4-19. Below the protruding Mokapu Point, Kailua Bay extends south meeting the Lanikai coastline north of Waimanalo Bay. This study site includes the stretch of coastline at Lanikai, located between Wailea Point and Alala Point, along with the southern third of Kailua Bay to the north of Alala Point. The shoreline faces northeast into the prevailing northeasterly tradewinds. Base maps at a scale of 1 inch = 200 feet are included as Exhibit B in the back of this report. Figure 4-20 shows a reduced version of the base maps for reference.[49]

The site area, located adjacent to the town of Kailua, lies in two distinct coastal reaches separated by Alala Point. The Lanikai developed area lies along a thin strip, typically less than 2000 feet wide, in front of the Kaiwa Ridge which rises up to an elevation of 600 feet behind the coastline. The Lanikai shoreline extends over a length of roughly 1 mile bounded by the rugged rocky Wailea and Alala Points. The two points jut out from headlands composed of basaltic volcanics along the seaward extensions of the Kaiwa Ridge behind Lanikai.

The Kailua portion of the site area, extending into the middle segment of the 2 mile long beach system at Kailua Bay, lies on a broad 1-2 mile wide barrier beach deposit in front of inland lagoonal marshes. Landward from the existing beach at the shoreline, this deposit is largely vegetated and presently supports the population in the town of Kailua. Both the Lanikai and Kailua segments have been fully developed with residential units built right to the shoreline except for the Kailua Public Beach Park area just to the north of Alala Point. This park extends above Alala Point for a distance of roughly 1/2 mile and extends inland over distances varying between a few hundred feet and 1/4 mile. Near the middle of this beach park, the mouth of the Kaelepulu stream interrupts the shoreline.

[49] The reader is encouraged to use the full scale base maps in Exhibit B for better understanding of the information presented.

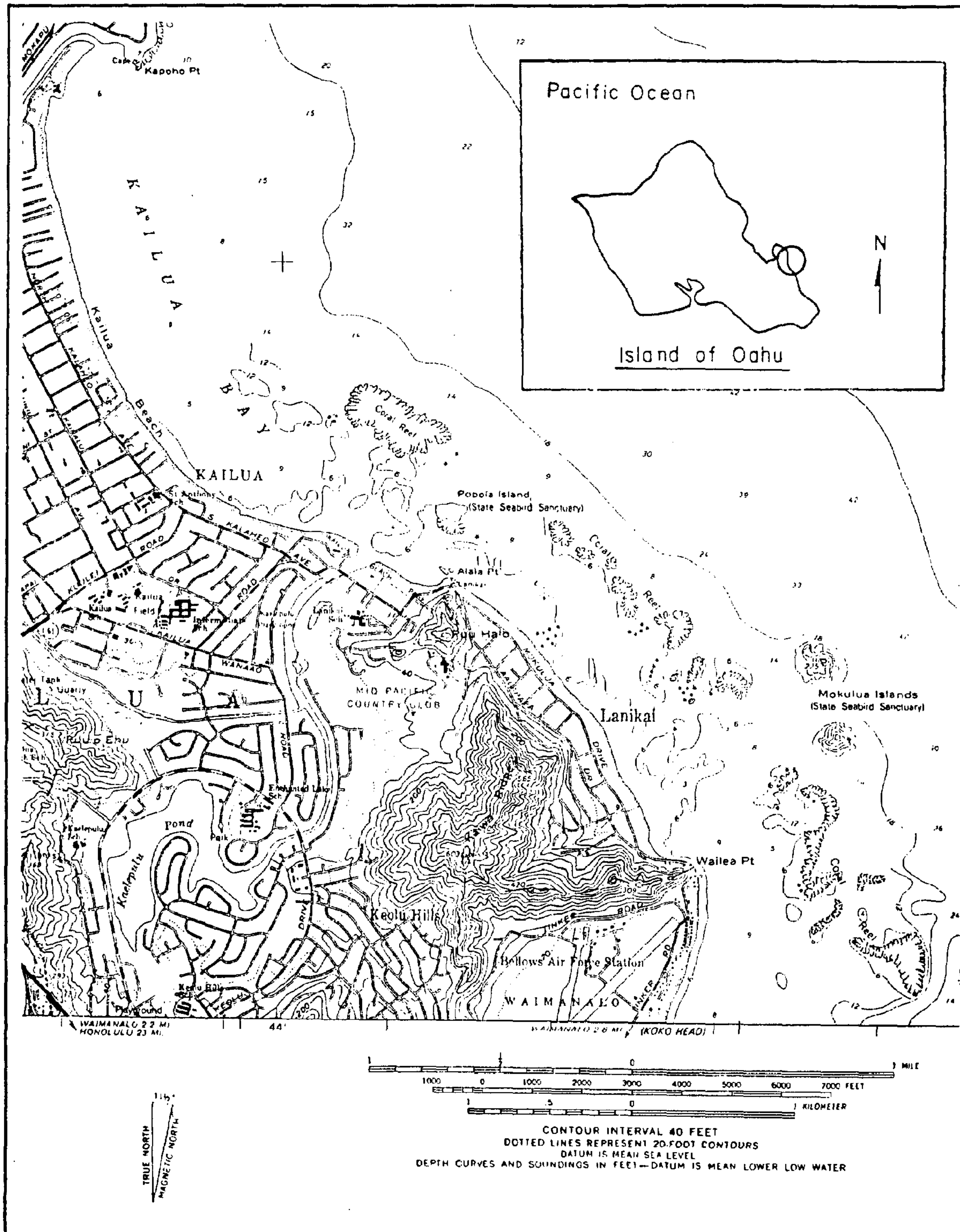

FIGURE 4-19 LOCATION MAP, CASE STUDY SITE #2 - KAILUA-LANIKAI, OAHU

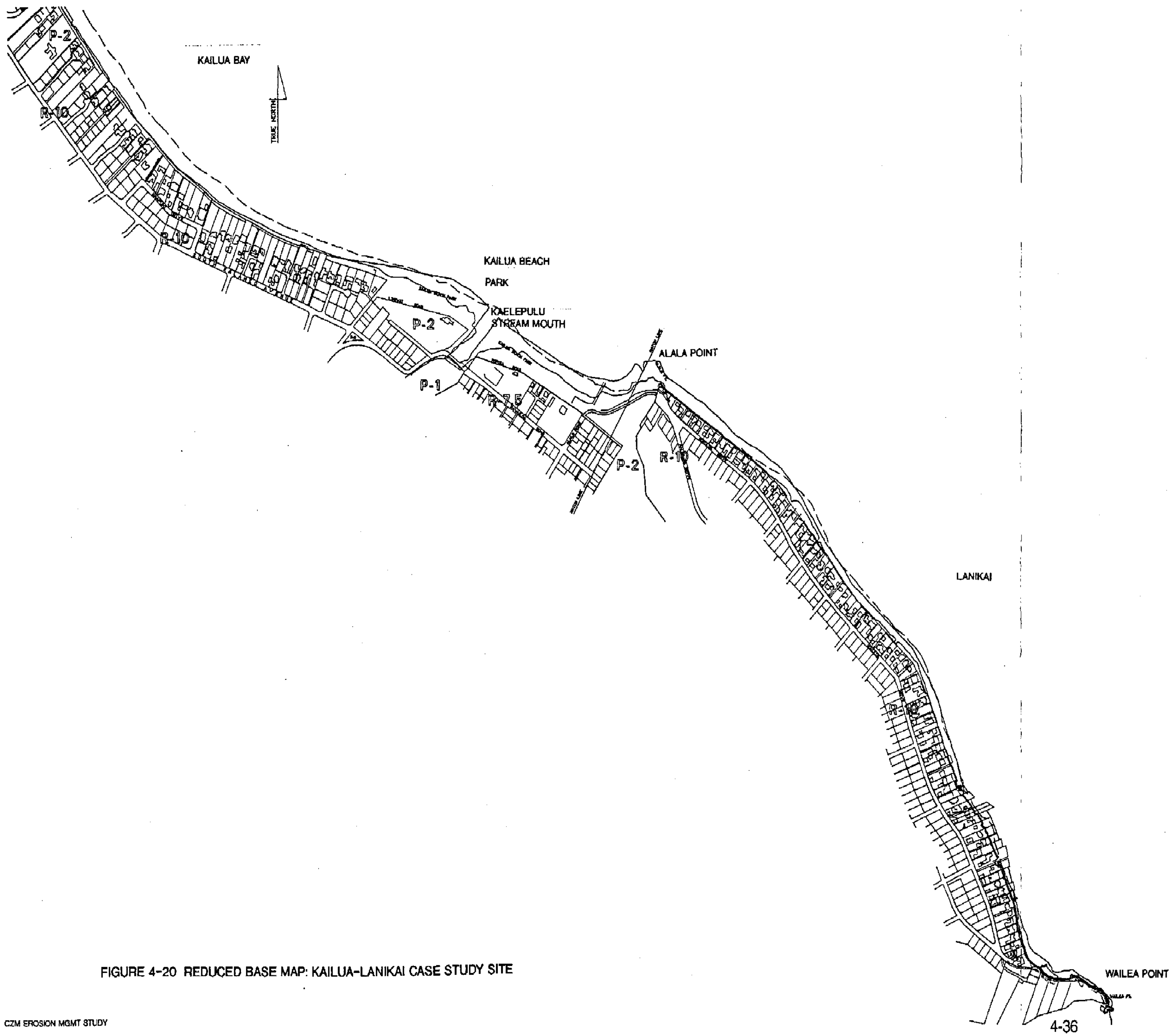

FIGURE 4-20 REDUCED BASE MAP: KAILUA-LANIKAI CASE STUDY SITE

The beaches of the site area at both Lanikai and Kailua are composed of fine to medium grained calcareous sands of biologic origin. The beaches are generally narrow with low elevations and flat slopes which extend seaward onto a wide, shallow and continuous fringing reef. In many areas, the fringing reef is covered with sand channels and pockets. The edge of the reef lies roughly 3/4 of a mile offshore with typical water depths ranging from 6-10 feet over the reef. At numerous locations near the offshore edge of the reef, coral structures rise to within 1 feet or less of MSL (mean sea level). In the central and northern sections of Kailua Bay, outside the case study site area, the water depths are deeper on top of the reef and reef structures are less exposed. Three small islands supporting permanent vegetation lie within the site area upon the fringing reef. Popoia ("Flat") Island is located on the reef offshore from the Kailua Beach Park. The two Mokulua Islands lie offshore from Wailea Point at the outer edge of the fringing reef near the southern limit of the site area. All three of these islands are State Seabird Sanctuaries without structures or development. The water depths drop off rapidly beyond the fringing reef. The 600 feet contour is found approximately 2.5 miles offshore and the 6000 feet contour is found roughly 12 miles offshore.

FIGURE 4-21 SHALLOW FRINGING REEF AND MOKULUA ISLANDS AS SEEN FROM THE BEACH AT LANIKAI

LAND USE AND DEVELOPMENT

The Kailua-Lanikai area is one of the principal population areas located within the Koolaupoko district on the Windward side of Oahu. This area serves as a "bedroom" community for the Honolulu area since most residents of this district work in Honolulu. The population growth in this district was substantial between 1960 and 1970, representing 24% of the total increase on Oahu for this time period. Kailua experienced the highest growth with a population increase from 34,809 in 1960 to 47,003 in 1970.[50] Population growth slowly leveled off increasing to 52,906 in 1980 and to 53,620 in 1985.[51] This was a 1.3% increase between 1980 and 1985.[52]

The Kailua Beach Park is considered by many to have one of the finest beaches and family recreation areas on the Windward side of Oahu. The area is used by residents from the area and from neighboring communities.

The State Land Use designation for the entire study area is Urban, as depicted on the Land Use District map of the vicinity (Figure 4-22). This designation extends to the shoreline and is under the City and County of Honolulu jurisdiction.

The intent of the Koolaupoko Development Plan established under Ordinance 83-8 in 1983 is to encourage suburban single-family development as the predominant residential use surrounded by substantial amount of open space and agricultural land. Limited apartment uses are permitted in close proximity to regional commercial and industrial centers and will be low-rise. Most of the study area is designated for single-family residences with the exceptions of a Public Facility designation for the Kalama Community Trust parcel, a Park designation for the Kalama Beach Park parcel, and Park designation for the Kailua Beach Park. The Kalama Community Trust parcel and the Kalama Beach Park are located towards the north portion of the study area while the Kailua Beach Park is centrally located in the study site. Figure 4-23 provides the Koolaupoko Development Plan map for the vicinity.

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[50] "Kailua Beach Park Erosion Control Environmental Impact Statement", U.S. Army Corps of Engineers.

[51] The State of Hawaii Data Book 1988.

[52] Kailua and Lanikai are located within CT 31 which also includes the Kaneohe and Mauanawili areas.

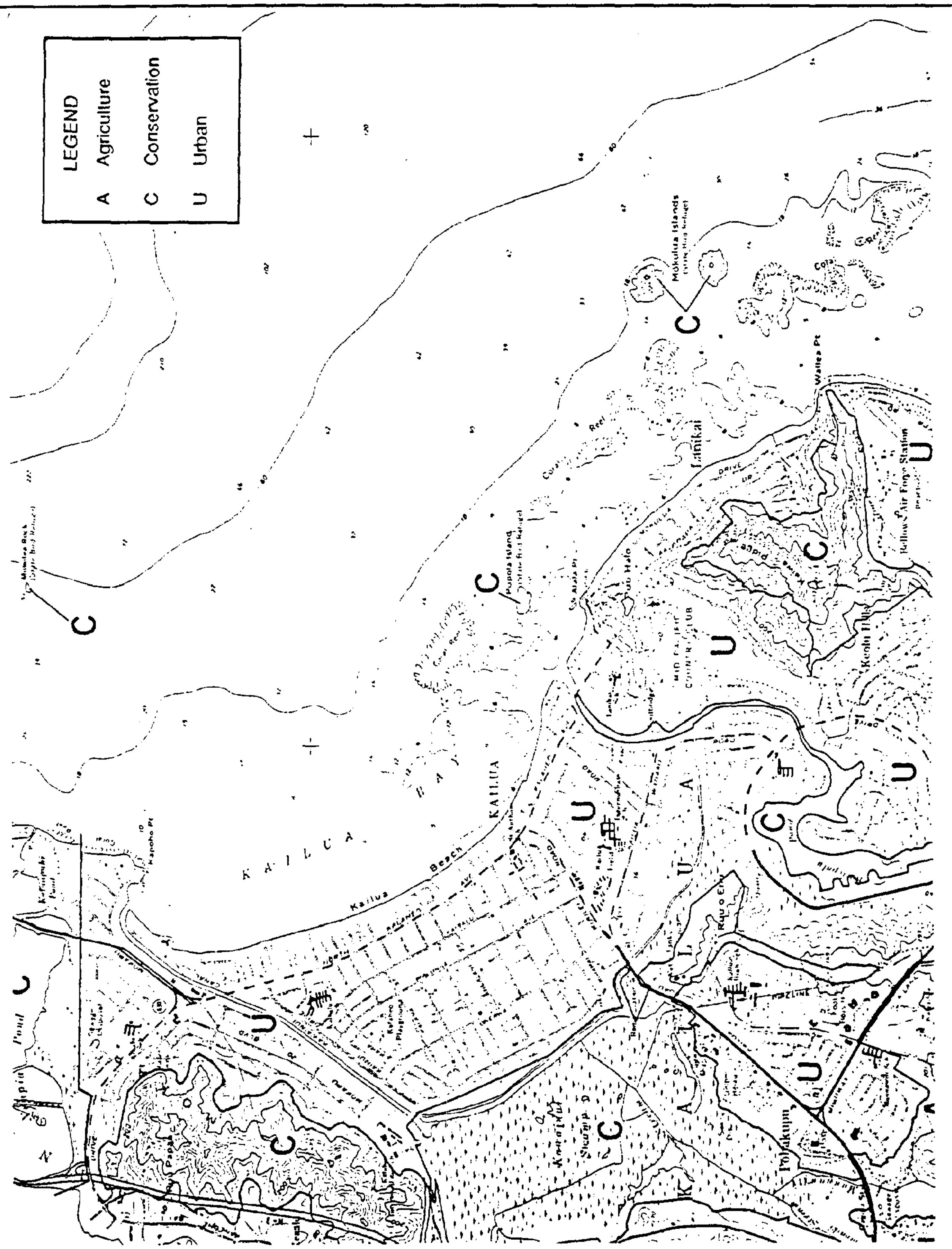

FIGURE 4-22 STATE LAND USE DISTRICT MAP FOR KAILUA-LANIKAI VICINITY

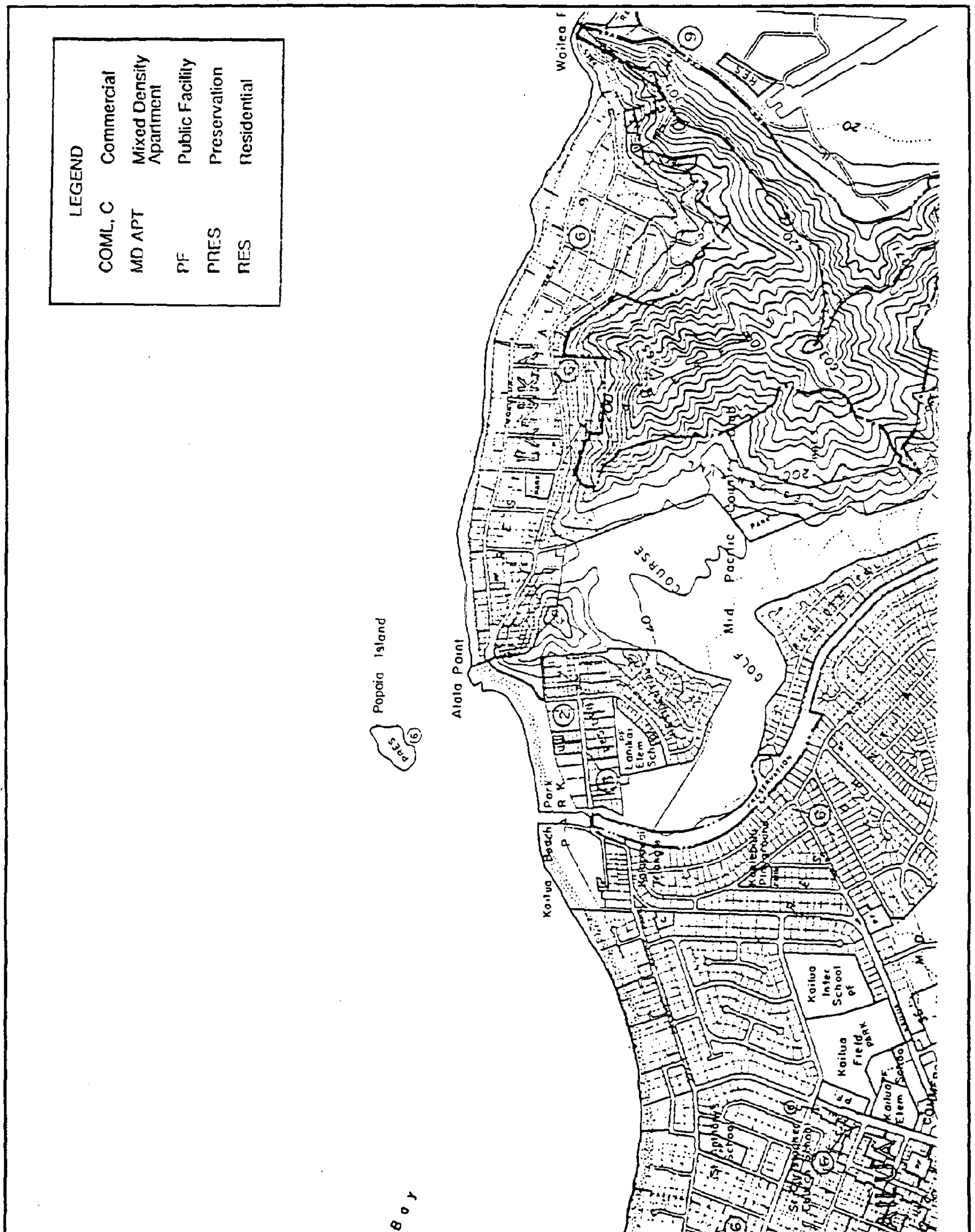

FIGURE 4-23 DEVELOPMENT PLAN MAP FOR KAILUA-LANIKAI VICINITY

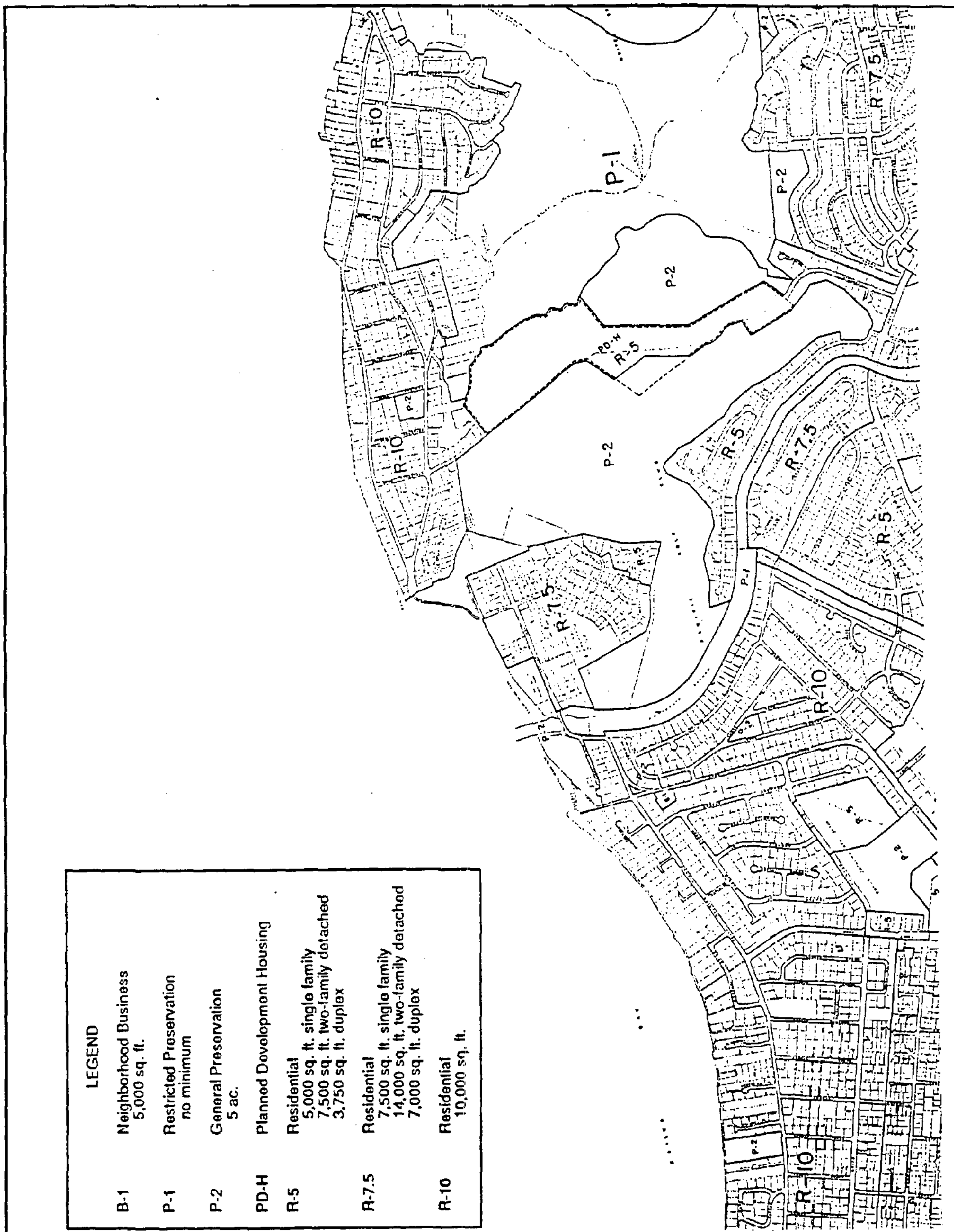

FIGURE 4-24 ZONING MAP FOR KAILUA-LANIKAI VICINITY

The majority of the case study area is zoned for single-family Residential (R-10: a minimum lot area of 10,000 sq.ft.) consistent with the DP designation. The two beach park areas (Kalama Beach Park and Kailua Beach Park) are zoned for Preservation (P-2). Figure 4-24 provides the zoning map for the vicinity.

The Kailua-Lanikai case study area presents a contrast in the number of existing seawalls along the Kailua Beach area and the Lanikai Beach area. The north portion of the study site south to Kailua Beach Park has only two seawalls. There is no information available from the DLU regarding the legality of these seawalls. On the other hand, from Kailua Beach Park south to Wailea Point at the southern tip of Lanikai, there are 70 seawalls or revetments. Of these 70 seawalls and revetments, 2 are legal, 21 are illegal, 10 are considered to be non-conforming and 37 have no information available on them in the DLU file.[53]

NEARSHORE WAVE CLIMATE

The location of the Kailua-Lanikai site area on the windward coast of Oahu gives open exposure to only the north through southeast quadrants. The island mass blocks all deep water wave energy from the south, west and northwest directions. The wave characteristics at the site area are dominated by the northeast tradewinds which persist throughout the year and the northern swells which propagate down from the North Pacific during the winter season of October-April. Deep water wave statistics for a typical year applicable to the site area are provided in Table 4-2[54]. The data were generated by means of hindcast techniques over the 1964-1977 time period using atmospheric pressure fields to project wind-generated wave fields. This data from the Spectral Ocean Wave Model (SOWM) is especially applicable to windward coasts in the Hawaiian islands. The Table 4-2 data present the annual percent frequency of occurrence for specific wave period and wave height classes from the north, northeast and east directions, which are the specific direction sectors of wave approach at Kailua-Lanikai. Based on the data, wave refraction analysis was accomplished for wave periods of 8 and 12 seconds propagating from the north, northeast and east directions.

The bathymetry for the refraction analysis was obtained from a 1 inch = 500 meter

[53] The available information on seawalls was provided by the Department of Land Utilization (DLU). Seawall definitions used by DLU are as follows: 1) Legal seawall has a permit regardless of when constructed, 2) Illegal seawall did not exist in 1967 DLU aerial photos and has no permit, and 3) Non-conforming seawall may have no record of a permit but are shown in the 1967 or 1969 DLU aerial photos.

[54] National Climatic Center, "Spectral Ocean Wave Model (SOWM) Data", NOAA.

TABLE 4-2
ANNUAL PERCENT FREQUENCY OF OCCURRENCE OF SIGNIFICANT WAVE HEIGHT VERSUS WAVE PERIOD FOR SPECIFIC DIRECTION SECTORS OF WAVE APPROACH AT KAILUA-LANIKAI FROM THE SPECTRAL OCEAN WAVE MODEL (SOWM)

PCT FREQ OF WAVE PERIOD(SEC) VERSUS WAVE HEIGHT(FT)

TOTAL OBS: 2181
WAVE SECTOR: NORTH — PEAK PERIOD

HGT	<2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	>=20	TOTAL PCT
<1	0.0	.0	0.0	.0	.0	.1	.1	.0	.0	.0	.0	.4
1-2	0.0	.1	0.0	.2	.2	.2	.4	.1	.1	.1	.0	1.5
2-3	0.0	0.0	.0	.5	.4	.2	.4	.2	.1	.1	.0	1.8
3-4	0.0	0.0	.0	.4	.3	.2	.5	.2	.1	.1	0.0	1.7
4-5	0.0	0.0	.0	.3	.3	.2	.4	.1	.1	.0	.0	1.5
5-6	0.0	.0	0.0	.3	.4	.2	.3	.1	.1	.0	.0	1.5
6-7	0.0	0.0	0.0	.2	.3	.2	.3	.1	.1	.0	.0	1.3
7-8	0.0	0.0	0.0	.1	.3	.2	.3	.1	.1	.0	.0	1.1
8-9	0.0	0.0	0.0	.0	.1	.1	.2	.0	.1	.0	0.0	.6
9-10	0.0	0.0	0.0	.0	.1	.1	.2	.1	0.0	.1	.0	.6
10-11	0.0	0.0	0.0	0.0	.0	.1	.2	.1	.1	.0	.0	.4
11-12	0.0	0.0	0.0	0.0	.0	.0	.1	.1	.0	.0	.0	.3
12-13	0.0	0.0	0.0	0.0	0.0	.0	.1	.1	.0	.0	0.0	.2
13-14	0.0	0.0	0.0	0.0	0.0	.0	.1	.0	.0	.0	0.0	.2
14-15	0.0	0.0	0.0	0.0	0.0	0.0	.0	.0	.0	0.0	0.0	.0
15-16	0.0	0.0	0.0	0.0	0.0	0.0	.0	0.0	.0	.0	0.0	.1
16-17	0.0	0.0	0.0	0.0	0.0	.0	.0	.0	.0	.0	0.0	.1
17-18	0.0	0.0	0.0	0.0	.0	0.0	0.0	.0	.0	0.0	0.0	.1
18-19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.0	.0	0.0	.0
19-20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.0	.0	0.0	0.0	.0
>=20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.1	.1	.0	.2
TOT PCT	0.0	.1	.1	2.1	2.4	1.7	3.8	1.3	1.3	.6	.1	13.4

TOTAL OBS: 10025
WAVE SECTOR: NORTHEAST — PEAK PERIOD

HGT	<2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	>=20	TOTAL PCT
<1	0.0	.1	0.0	1.1	.4	.1	.1	.0	.1	0.0	0.0	1.8
1-2	0.0	.6	0.0	5.4	1.8	.3	.6	.2	.1	.0	0.0	9.1
2-3	0.0	.1	.3	9.4	1.7	.3	.5	.2	.2	.0	.0	12.7
3-4	0.0	0.0	.8	7.1	1.9	.3	.5	.2	.1	.0	.0	10.8
4-5	0.0	0.0	.0	6.3	2.4	.3	.6	.1	.1	.0	.0	9.8
5-6	0.0	0.0	0.0	3.8	1.9	.2	.4	.0	.0	.0	0.0	6.4
6-7	0.0	0.0	0.0	2.2	1.4	.2	.2	.0	.0	.0	.0	4.2
7-8	0.0	0.0	0.0	1.1	1.3	.1	.1	.1	.0	.0	0.0	2.8
8-9	0.0	0.0	0.0	.6	1.1	.1	.1	.0	0.0	.0	0.0	1.8
9-10	0.0	0.0	0.0	.0	.9	.1	.1	.0	0.0	.0	0.0	1.2
10-11	0.0	0.0	0.0	0.0	.5	.1	.0	.0	0.0	.0	0.0	.6
11-12	0.0	0.0	0.0	0.0	.1	.0	.0	0.0	0.0	0.0	0.0	.2
12-13	0.0	0.0	0.0	0.0	.0	.0	.0	0.0	0.0	0.0	0.0	.1
13-14	0.0	0.0	0.0	0.0	.0	.1	.0	0.0	0.0	0.0	0.0	.1
14-15	0.0	0.0	0.0	0.0	.0	.0	.0	0.0	0.0	0.0	0.0	.0
15-16	0.0	0.0	0.0	0.0	0.0	.0	.0	0.0	0.0	0.0	0.0	.0
16-17	0.0	0.0	0.0	0.0	0.0	.0	.0	0.0	0.0	0.0	0.0	.0
17-18	0.0	0.0	0.0	0.0	0.0	.0	.0	0.0	0.0	0.0	0.0	.0
18-19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19-20	0.0	0.0	0.0	0.0	0.0	0.0	.0	0.0	0.0	0.0	0.0	.0
>=20	0.0	0.0	0.0	0.0	0.0	0.0	.0	0.0	0.0	0.0	0.0	.0
TOT PCT	0.0	.7	1.2	37.1	15.4	2.4	3.4	.9	.6	.1	.0	61.7

TOTAL OBS: 2916
WAVE SECTOR: EAST — PEAK PERIOD

HGT	<2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	>=20	TOTAL PCT
<1	0.0	.1	0.0	.3	.1	.0	.0	.0	.0	.0	0.0	.6
1-2	0.0	.7	.8	1.1	.5	.1	.2	.0	.1	.0	0.0	2.7
2-3	0.0	.0	.6	1.2	.6	.0	.1	.0	.0	.0	0.0	2.6
3-4	0.0	0.0	1.0	1.1	.4	.0	.0	.0	.0	0.0	0.0	2.6
4-5	0.0	0.0	.1	2.0	.4	.0	.0	.0	.0	.0	0.0	2.5
5-6	0.0	0.0	0.0	1.7	.4	.0	.0	.0	.0	0.0	0.0	2.2
6-7	0.0	0.0	0.0	1.3	.3	.0	.0	.0	0.0	.0	0.0	1.6
7-8	0.0	0.0	0.0	.7	.3	.0	.0	0.0	0.0	0.0	0.0	1.1
8-9	0.0	0.0	0.0	.2	.5	.0	.0	0.0	0.0	0.0	0.0	.7
9-10	0.0	0.0	0.0	.0	.4	.0	.0	0.0	0.0	0.0	0.0	.5
10-11	0.0	0.0	0.0	0.0	.5	0.0	.0	0.0	0.0	0.0	0.0	.5
11-12	0.0	0.0	0.0	0.0	.2	.0	.0	0.0	.0	0.0	0.0	.3
12-13	0.0	0.0	0.0	0.0	.1	.0	0.0	0.0	0.0	0.0	0.0	.1
13-14	0.0	0.0	0.0	0.0	.0	.0	0.0	0.0	0.0	0.0	0.0	.1
14-15	0.0	0.0	0.0	0.0	.0	0.0	.0	0.0	0.0	0.0	0.0	.0
15-16	0.0	0.0	0.0	0.0	0.0	.0	.0	0.0	0.0	0.0	0.0	.0
16-17	0.0	0.0	0.0	0.0	0.0	.0	0.0	0.0	0.0	0.0	0.0	.0
17-18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18-19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19-20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
>=20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOT PCT	0.0	.8	1.7	9.4	4.0	.4	.5	.1	.1	.0	0.0	18.0

scale map with 5 meter depth contours.[55] The included area extended as much as 4 miles offshore from south of Wailea Point nearly up to Mokapu Point north of Kailua Bay. A grid was superimposed over this area and bathymetric data input to the model using a grid size of 150 meters to a side. The output from all the refraction calculations and wave ray diagrams are included in Appendix J. Several of the wave ray diagrams which are significant and most typical of site conditions have been included here for the purposes of discussion. The following discussion pertains especially to those wave rays which end within the site area; it can be seen in the accompanying figures that many wave rays terminate in the northern reaches of Kailua Bay north of the site area.

It is important to observe two points from the wave ray diagrams in Figures 4-25 to 4-27. First, from Figure 4-25, rays originating from the northeast terminate in the site area with very little convergence or divergence maintaining their original propagation direction. Second, from Figures 4-26 and 4-27 with the north and east approach directions, the rays from the north finish with a dominant northern component to the shoreline just as the rays from the east finish with a dominant eastern component to the shoreline; however, compared to their initial orientations which lie 90 degrees apart, most rays from the north and east both finish in a rather similar orientation which would best be categorized as northeast. Because the shoreline faces towards the northeast, small changes in mean wave approach direction can result in opposite longshore components in the nearshore area. The longshore components of wave approach near the shoreline determine the direction of sediment transport. As the tradewinds continually vary in direction between north-northeast and east-northeast throughout the year, and as northern swells mix with tradewind waves in the wintertime, the mean longshore component of wave approach may easily reverse itself during both the summer and winter season. Subsequently, the direction of sediment transport along the shoreline may also reverse itself.

[55] G. Pararas-Carayannis,"The Bathymetry of the Hawaiian Islands, Part 1. Oahu".

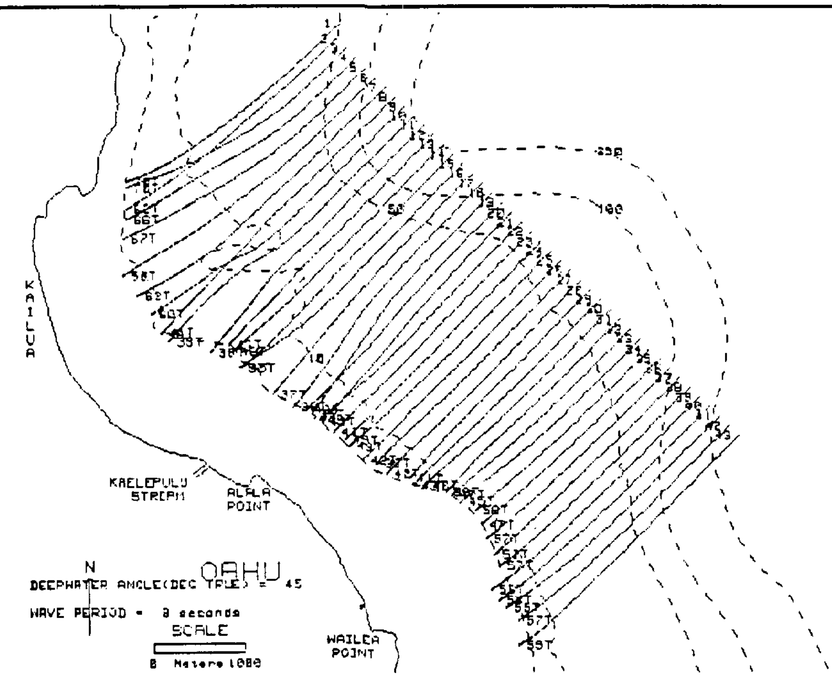

FIGURE 4-25 KAILUA REFRACTION ANALYSIS, 8 SEC WAVE PERIOD FROM NE DIRECTION

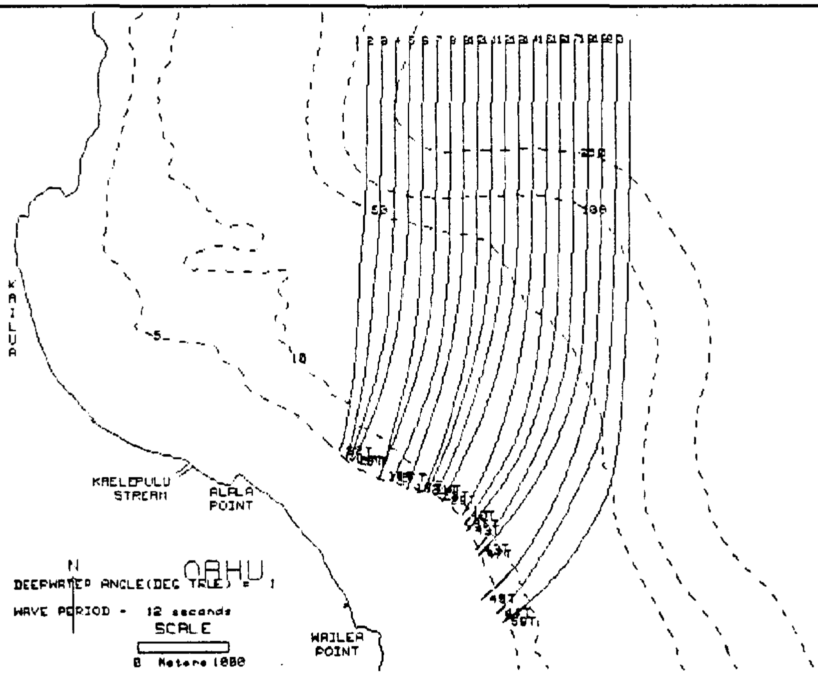

FIGURE 4-26 KAILUA REFRACTION ANALYSIS, 12 SEC WAVE PERIOD FROM N DIRECTION

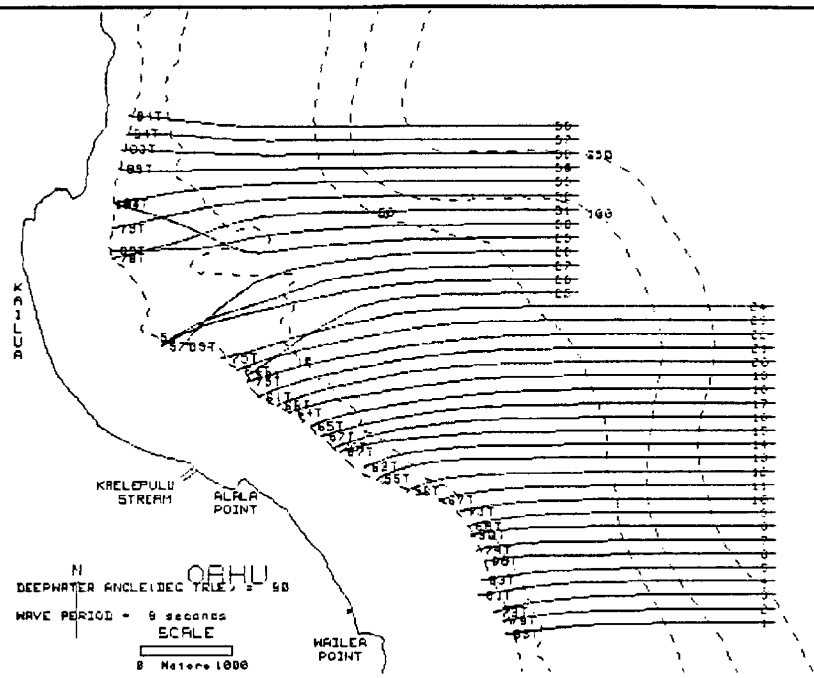

FIGURE 4-27 KAILUA REFRACTION ANALYSIS, 8 SEC WAVE PERIOD FROM E DIRECTION

The aerial photograph in Figure 4-28[56] provides a clear view of the fringing reef structure offshore from the study site. Running from south of Wailea Point, past the Mokulua and Popoia Islands, and into the Kailua Beach system, the fringing reef is identified by the mottled sand and coral structures inshore from the deep blue of the deeper offshore waters. The numerous bright white splotches near the outer edges of the reef identify areas that are so shallow the incoming waves become unstable and turn into breaking waves. Zones of low wave height and low wave energy exist in the shadows of the outer reef areas where breakers occur as well as inshore from the three islands on the reef. Higher wave energy passing between the islands and reefs is reduced shoreward due to diffraction effects, where wave energy is spread laterally along wave crests.

Dynamically linked to the shallow barriers along the reef edge, the propagation of wave energy towards shore results in a high degree of lateral variation in the amount and

[56] Edward K. Noda and Associates, Inc., "Lanikai Flood Control Project- Assessment of Impacts Related to Offshore Extension of Drain Pipe and Open Channel", prepared for Kwock Assoc. and the C & C of Honolulu DPW, included in Lanikai Flood Control Project DEIS, Feb 1989.

FIGURE 4-28 TYPICAL NEARSHORE WAVE PATTERNS DUE TO NE DEEPWATER WAVE APPROACH

direction of wave energy finally dissipated along the beachfront. In general, this accounts for the strangely convex and wavy nature of the beachfront at Lanikai between Wailea and Alala Points. The physical processes at the beachfronts in the site area are discussed in greater detail in the following section.

One important aspect of the Kailua-Lanikai case study site is the perhaps misleading protection of the shallow fringing reef from the perspective of littoral transport processes. In a previous study of the area[57], theoretical maximum wave heights were calculated for the nearshore water depths on top of the fringing reef. With 50-100 year maximum deep water wave heights of 20-25 feet directed at the site area, maximum tide levels, and super-elevation of water level due to wave-breaking processes, nearshore wave heights on top of the fringing reef were calculated to be less than 6 feet. Maximum annual wave heights are in the 3-4 feet range and typical wave heights are 1 foot or less on top of the fringing reef. While the nearshore wave climate is mild along the case study reach, the longshore transport processes and small volume storage within the beaches have resulted in substantial fluctuations of the shoreline over the past 40 years.

COASTAL PROCESSES

The influence of coastal processes at the shoreline dictate the supply of sediment to the beaches. Inputs of sediment to the beaches include generation and transport of calcareous sand from the offshore reef, as well as deposition of suspended sediment in run-off from the heavy winter rains at the location of various drainage structures and the Kaelepulu Stream mouth in the Kailua Beach Park. Losses of sediment from the beaches may occur with transport of sediment directly offshore onto the reefs along with longshore transport of sediment along the beach fronts.

Previous engineering efforts[58] have come to several conclusions about sediment transport processes at the site area. First, there is not evidence for significant longshore transport in either direction around Alala Point which implies that Lanikai and Kailua are independent littoral cells. Also, within the Kailua littoral cell, which includes the northern reaches of Kailua Bay outside the case study site area, there is not a significant onshore/offshore transport of sediment. In the Kailua part of the site area, the longshore sediment transport process dominates.

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[57] Edward K. Noda and Associates, Inc.,"Lanikai Flood Control Project- Oceanographic Design Considerations for Drainage Discharge Structures", prepared for Kwock Assoc. and C & C of Honolulu DPW, August 1987.

[58] Edward K. Noda and Associates, Inc.,"Beach Processes Study- Kailua Beach, Oahu, Hawaii", prepared for U.S. Army Corps of Engineers, September 1977.

LANIKAI:

The dominant sediment transport processes at Lanikai can be visualized with the aid of Figures 4-30 and 4-31.[59] Wave crest lines have been included between the intermittent shadow zones representing wave patterns due to typical tradewind wave approach directions. Sediment transport directions follow the centers of high wave energy towards the shoreline as the wave motions suspend sediment off of the reef flats and carry the sediment towards the beach. The sediment transport directions also follow the component of wave direction along the shoreline and follow an offshore direction

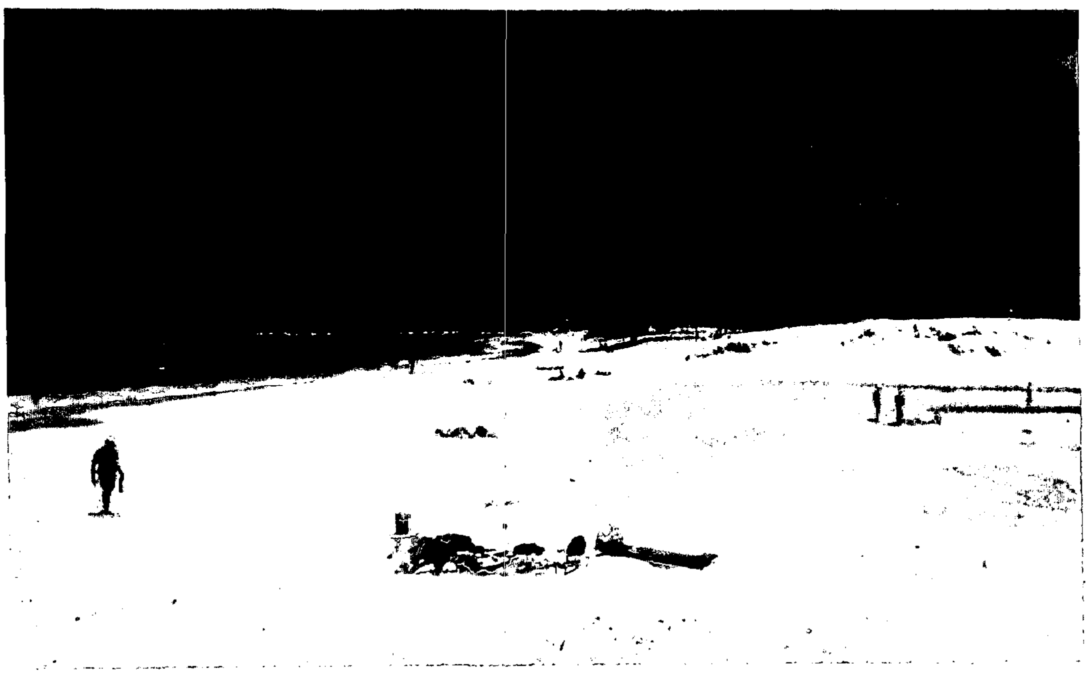

FIGURE 4-29 ALALA POINT AS VIEWED FROM KAELEPULU STREAM MOUTH AT KAILUA BEACH PARK
(One of Mokulua Islands in background)

[59] Edward K. Noda and Associates, Inc."Lanikai Flood Control Project- Assessment of Impacts Related to Offshore Extension of Drain Pipe and Open Channel".

component at locations where longshore sediment transport currents converge. The offshore direction of sediment transport occurs in a manner similar to the more easily visible rip-currents in higher wave energy locations around the islands. It is important to understand, first, that sediment transport processes may be occurring in all the indicated directions simultaneously. Second, the sediment transport processes typically will not achieve an equilibrium in the cell. Net transport of sediment creates accumulations and depreciations in different parts of the Lanikai cell over different time periods. Such mechanisms allow for the observed accretion and erosion of the shoreline over long time periods as significant imbalances of the transport processes occur, carrying sediment onto and off of the beach faces and reef flats at Lanikai.

The two different scales of detail are intended to show the two different scales of beach changes which can occur from the sediment transport processes. At the larger scale in Figure 4-30, wave approach at the reef edge drives sediment onshore and alongshore towards the center of the Lanikai shoreline reach between Alala and Wailea Points. This process has resulted in several prominent features at Lanikai. The beach is typically thinnest at the boundaries of this littoral cell near the headland locations. Also, it has a convex shape with the widest part of the beach at the center of the shoreline, offshore from which lies the largest sand deposit on top of the fringing reef flat. On the smaller scale in Figure 4-31, more detail has been given to the wave crest and transport directions over the reef flat. The smaller scale sediment transport cells provide definition to the small number of beach arcs, minor sandy points and depressions, which exist throughout the length of shoreline at Lanikai.

As discussed earlier, seasonal variations exist in the local wind and wave patterns at the site area. Northeast tradewinds and waves are strongest in the summer season while north swell is only present in the wintertime. During the summer season, the direction of winds and waves can switch from being northeasterly to more northerly or easterly. In general, with the site area facing so directly towards the northeast and the summer season with a mean wind/wave direction east of northeast, the larger net transport occurs alongshore from Wailea Point towards Alala Point. Conversely, the winter season drives a net transport alongshore from Alala Point towards Wailea Point. This accounts for the greatest seasonal loss and gain of beach cover at the endpoints of the Lanikai littoral cell at both Wailea and Alala Points. However, other signatures of such seasonal trends in transport become lost in the more complex interactions of the mini-cells mentioned above.

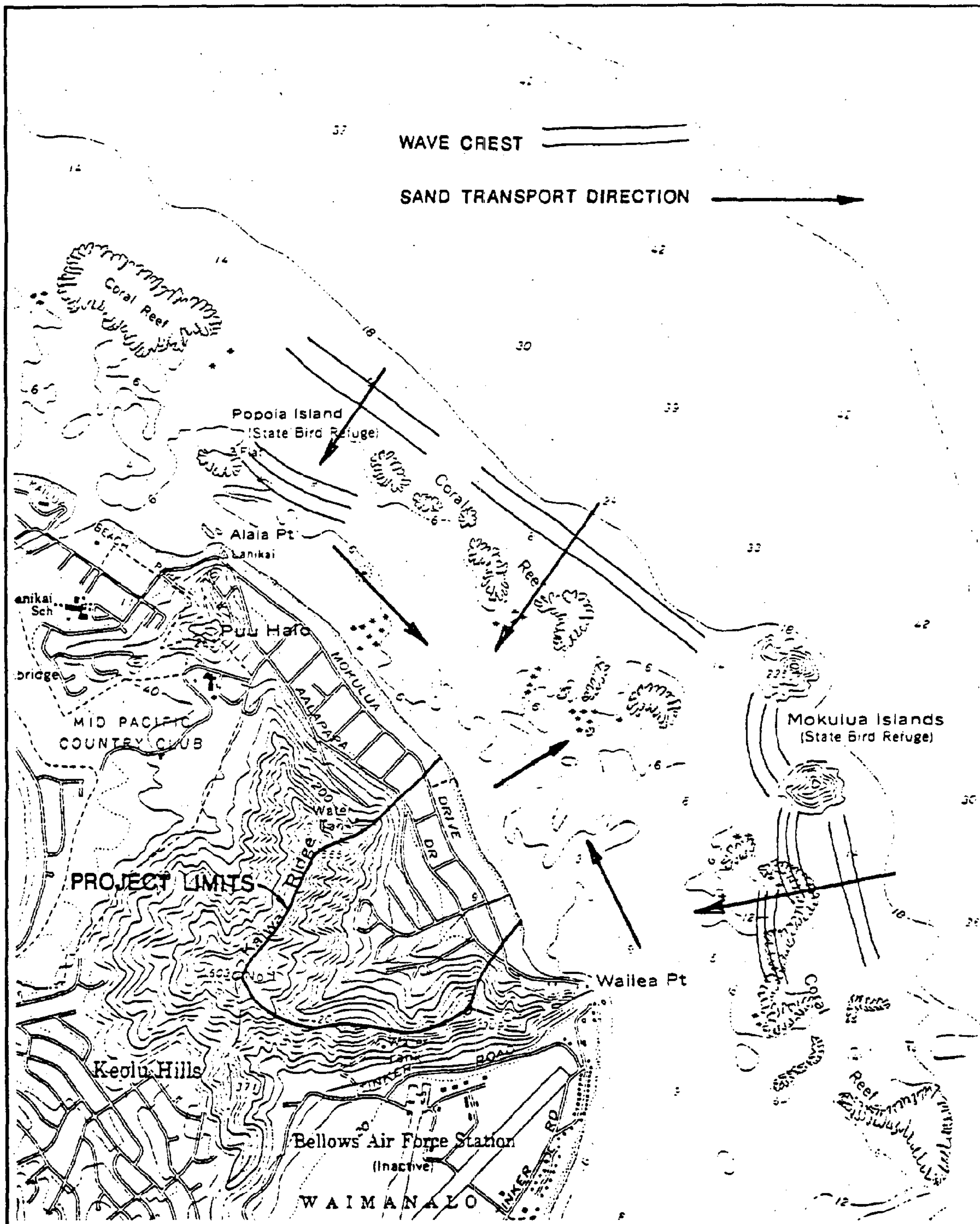

FIGURE 4-30 GENERAL NET SAND TRANSPORT PATTERN ALONG LANIKAI SHORELINE

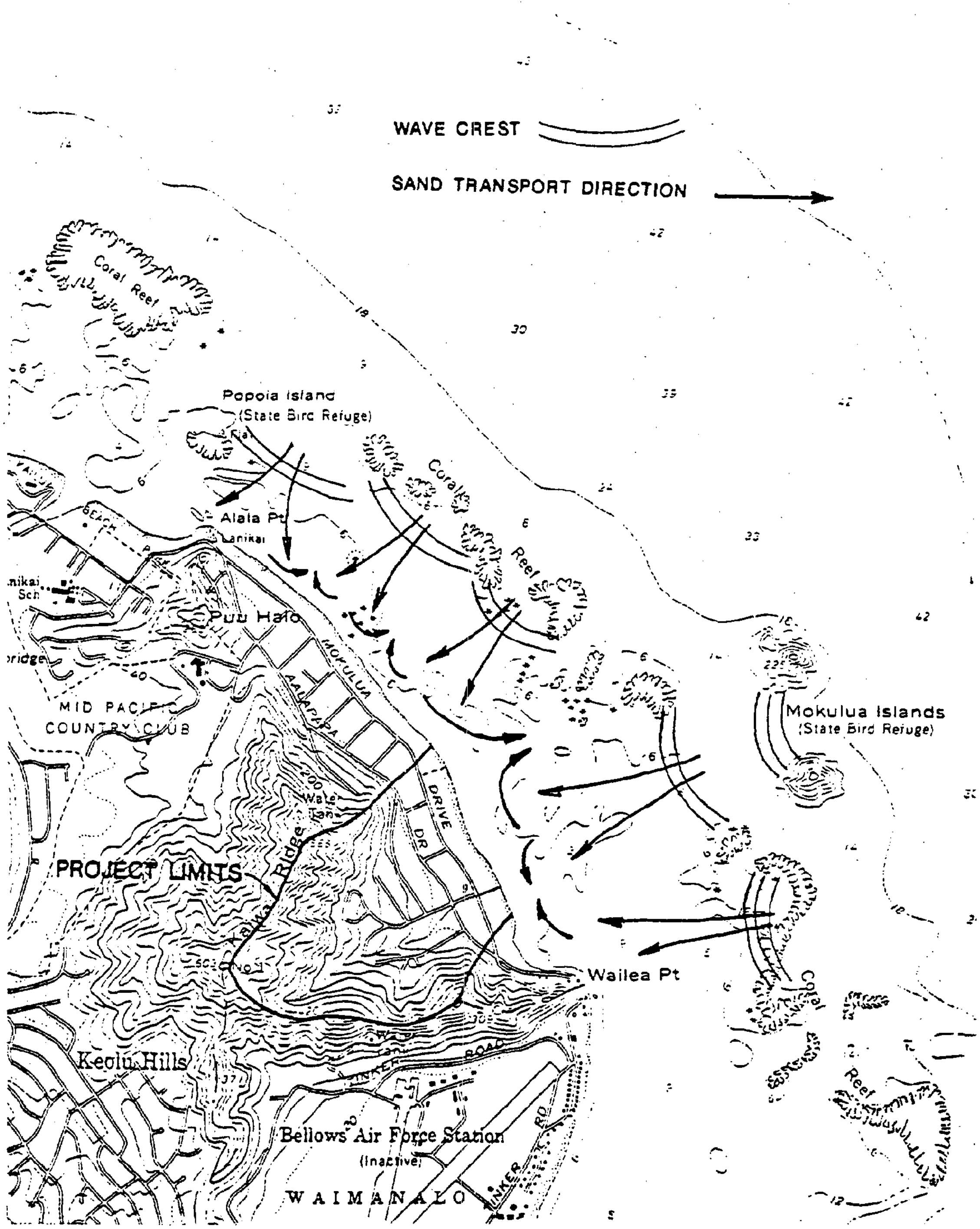

FIGURE 4-31 MICRO-SCALE SAND TRANSPORT PATTERNS DUE TO TYPICAL NE WAVE APPROACH

FIGURE 4-32 BEACH ARC FORMATION IN MINI-LITTORAL CELL, MID-COAST, LANIKAI

FIGURE 4-33 KAILUA BEACH PARK

KAILUA:

At the Kailua Beach Park within the Kailua littoral cell, the seasonal variation of longshore transport is also observed. The shoreline here faces more northward than at Lanikai, which results in a greater longshore component towards the north for the northeast tradewind waves. Such sediment transport dynamics at the Kailua part of the site area are evident in a series of beach profiles accomplished during a previous study[60].

The profiles displayed in Figures 4-35 to 4-37, were taken at Kailua Beach at the locations displayed in Figure 4-34. Location A lies near the northern boundary of the study site; location B lies near the northern boundary of Kailua Beach Park and location C lies closest to the southern end of the beach near Alala Point. The profiles were taken at monthly intervals during the summer of 1977. As the figures indicate, at location C nearest to Alala Point, the whole beach profile was eroded, receding landward between 15 and 30 feet over a less than three month period. Meanwhile, at locations B and A further along the beach at Kailua Bay, there was little or no change by comparison.

The processes indicated here represent the classic phenomenon where one end of a littoral cell is seasonally attacked due to a wave approach direction which is non-parallel to the shoreline. The more easterly summer tradewind waves drive sediment northward along Kailua Bay. With the rocky Alala Point serving as the southern boundary of the littoral cell, location C shows the depletion of sediment from the beachfront due to the northward longshore transport. Downstream from location C, locations B and A are able to maintain in equilibrium as enough sediment, originally derived from the head of the littoral cell, is deposited to replace sediment transported northward from their own beach fronts. This transport process is confirmed by the historical record which indicates greater problems of beach erosion observed at Kailua Beach Park than to the immediate north even though the beach is actually wider at the Beach Park. With northern swells mixed in with more northerly tradewind waves during the wintertime, the transport direction may reverse as Kailua Beach accretes in the public beach park area.

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[60] Edward K. Noda and Associates, Inc.,"Beach Processes Study- Kailua Beach, Oahu, Hawaii".

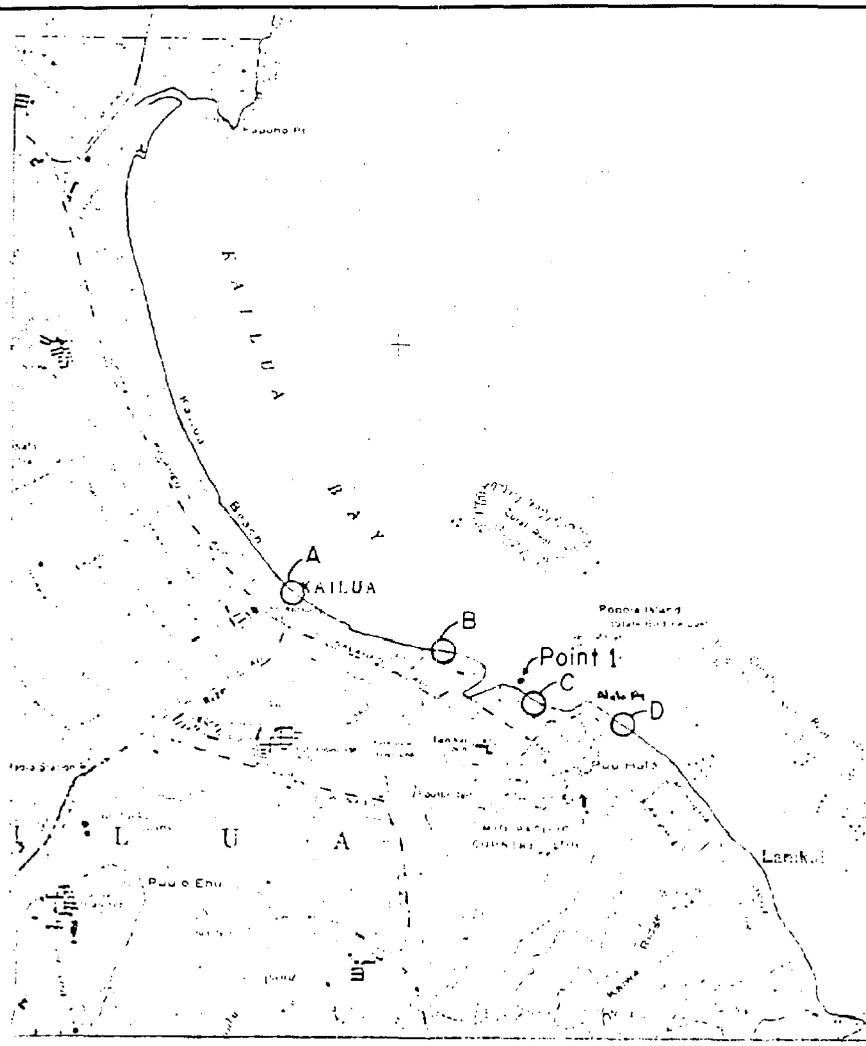

FIGURE 4-34 BEACH PROFILE LOCATIONS: A,B,C
(From Edward K. Noda and Assoc., "Beach Processes Study-Kailua Beach", 1977)

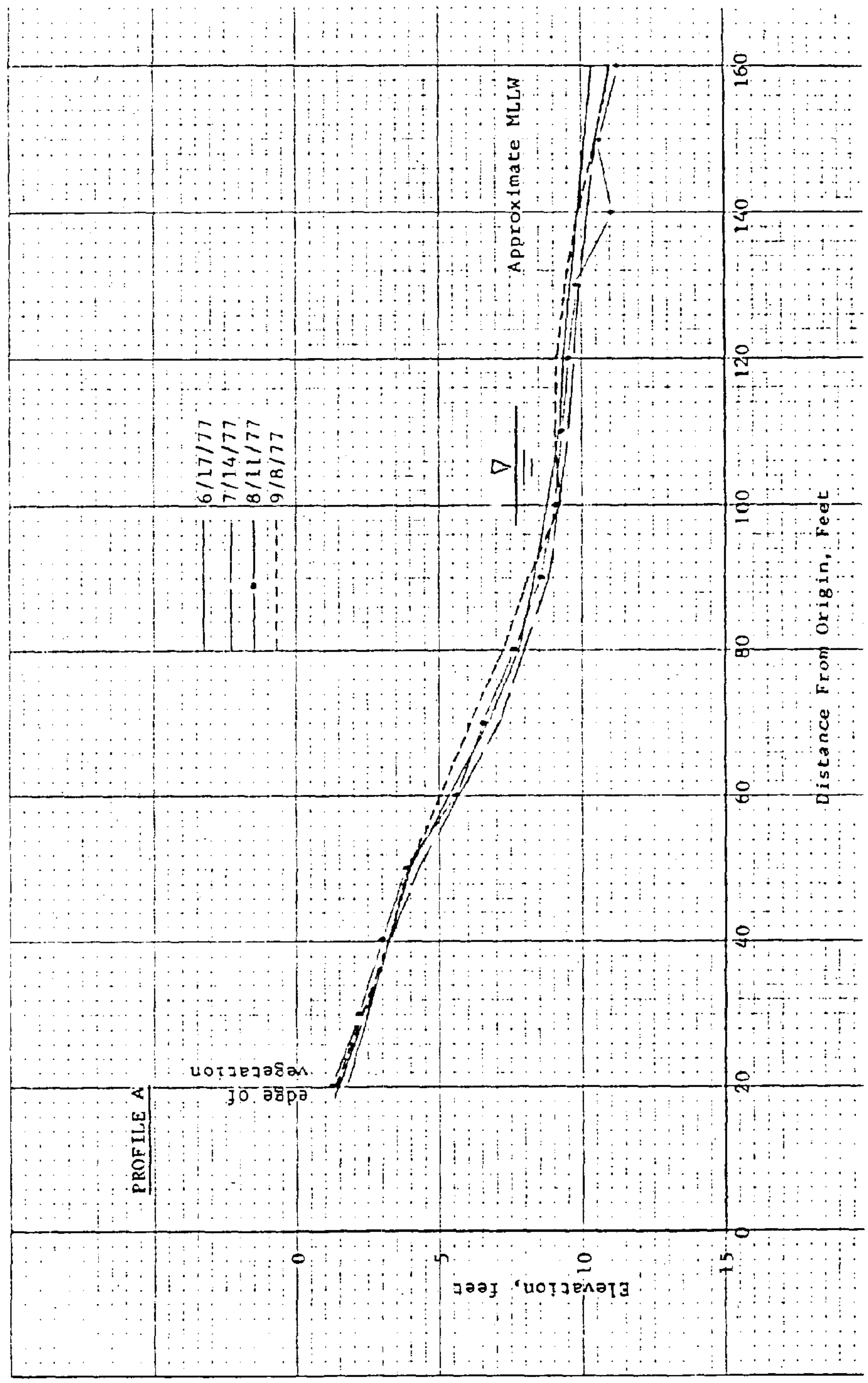

FIGURE 4-35 BEACH PROFILES AT STATION A, KAILUA BEACH
(From Edward K. Noda and Assoc., "Beach Processes Study-Kailua Beach", 1977)

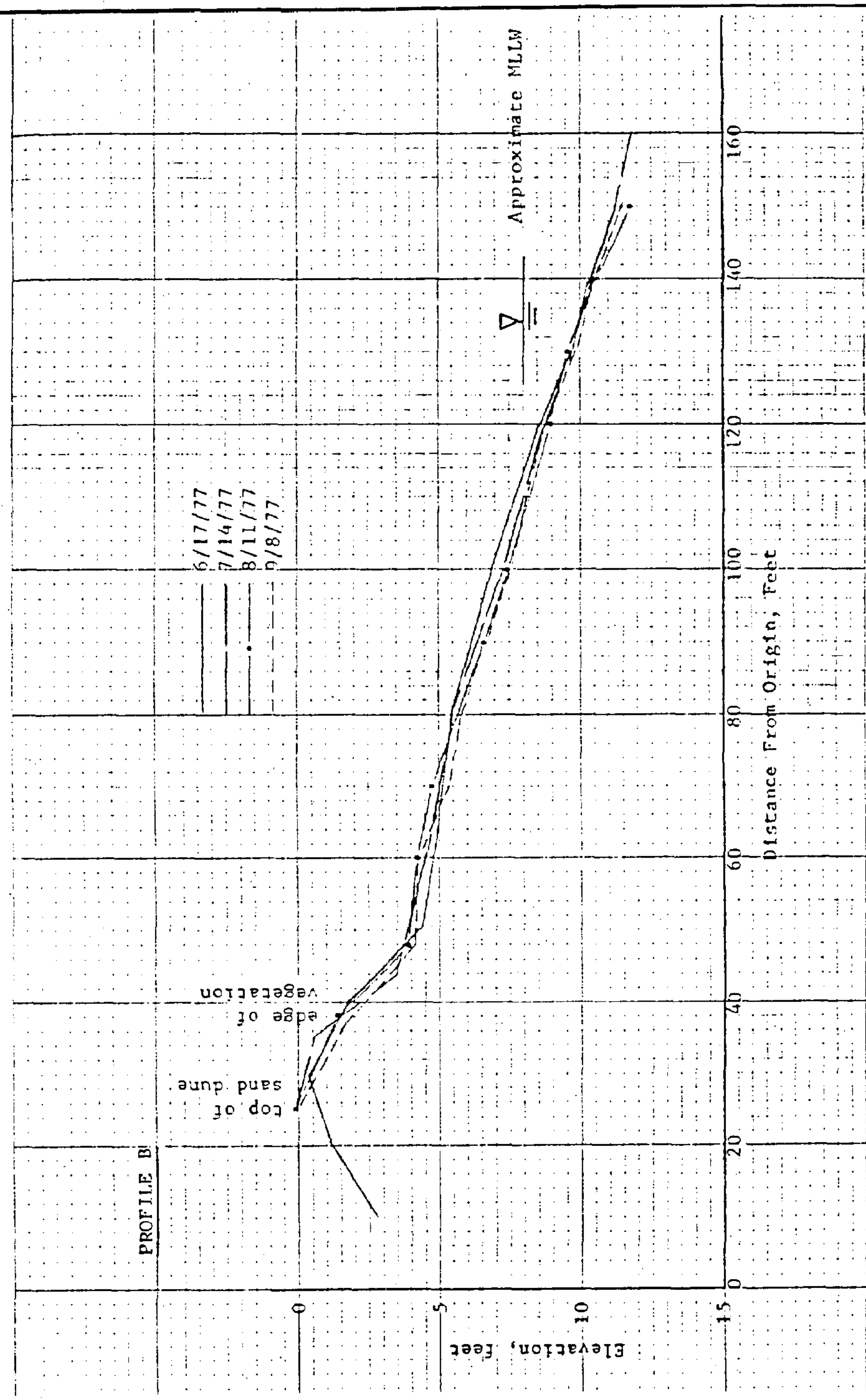

FIGURE 4-36 BEACH PROFILES AT STATION B, KAILUA BEACH
(From Edward K. Noda and Assoc., "Beach Processes Study-Kailua Beach", 1977)

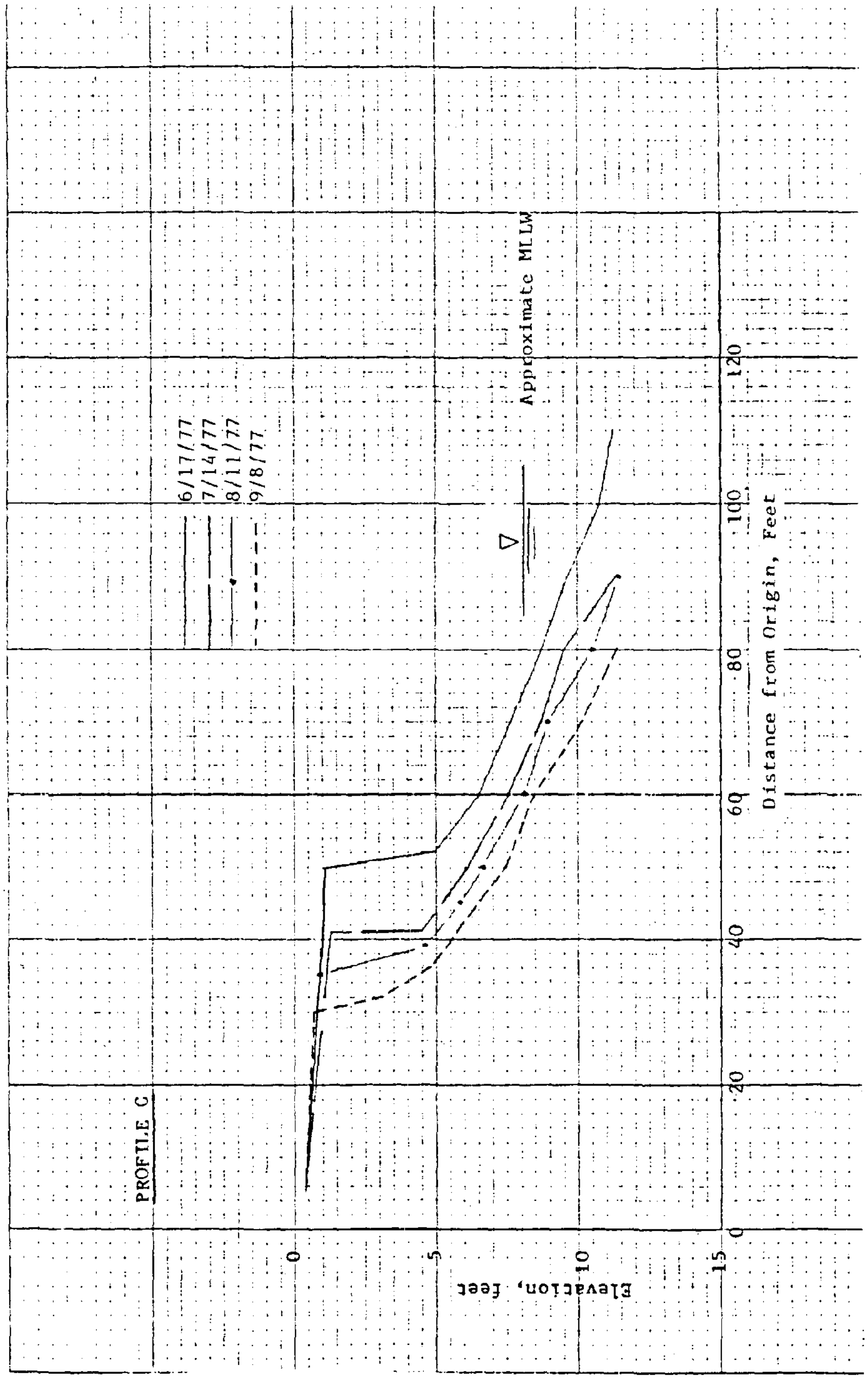

FIGURE 4-37 BEACH PROFILES AT STATION C, KAILUA BEACH
(From Edward K. Noda and Assoc., "Beach Processes Study-Kailua Beach", 1977)

The seasonal erosion patterns exhibit a tremendous degree of variation due to combined effects of the varying meteorological conditions, the orientation of the shoreline being so nearly perpendicular to the prevailing wave approach directions, and the complexity of nearshore interactions between the waves and the reef structures. Figure 4-38 displays the results from a computer modelling effort, conducted under a previous study[61], to simulate beach erosion at the Kailua Beach Park. Using physical parameters from the site, including wave characteristics and shoreline orientation, seasonal shoreline movements were simulated with random variables incorporated to represent meteorological variability. Seasonal accretion or erosion are plotted on the bar graph and the cumulative position of the shoreline relative to the base year is shown as the dashed line. As can be seen, the model does not simply predict net erosion in the summertime followed by net accretion in the wintertime. The simulation generates numerous periods with consecutive seasons of either accretion or erosion throughout the thirty years of the simulation period. However, the cumulative changes indicate a long-term cycle of accretion and erosion on the order of ±90 feet from the baseline. The period of this cycle is 30 years, in which one complete cycle of accretion and erosion occurs. This long-term fluctuation of shoreline position is consistent with the historical record of shoreline change ascertained from historical aerial photographs.

LONG-TERM SHORELINE CHANGES

KAILUA:

Whereas seasonal changes in shoreline position of ±20 feet are typical from the computer simulation for Kailua Beach Park, the cumulative long-term changes from Figure 4-38 indicate possible ranges of ±100 feet for the longer time scale of decades. This implies a maximum range of fluctuation in shoreline position on the order of 200 feet. This value from the simulation is in excellent agreement with the record from historical photographs of the Beach Park displayed in Figure 4-39[62]. Beachlines from aerial photos from 1949 to 1977 are plotted on this figure. The boat ramp presently acts as a groin in stabilizing the shoreline on the Alala Point end of the beach, but north of the boat ramp the variation in shoreline position has been approximately 200 feet between the position of maximum recession in 1949, and the position of maximum accretion in 1970. After 1970, the shoreline rapidly eroded, placing the 1977 shoreline position back near the 1949 position. Inspection of today's shoreline at the beach park appears to indicate slight accretion has occurred since 1977.

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[61] Edward K. Noda and Associates, Inc.,"Beach Processes Study- Kailua Beach, Oahu, Hawaii".

[62] Edward K. Noda and Associates, Inc.,"Beach Processes Study-Kailua Beach, Oahu, Hawaii".

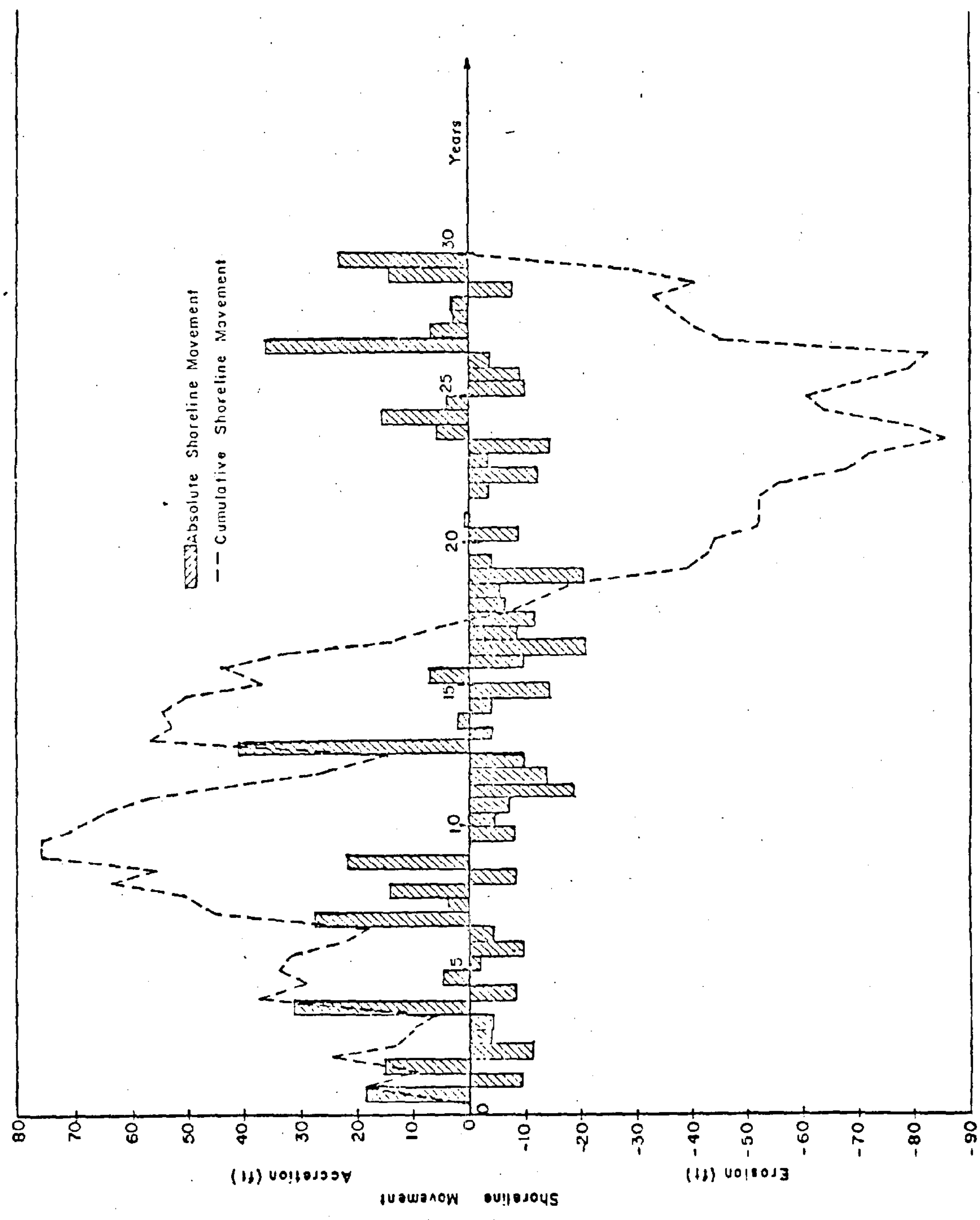

FIGURE 4-38 COMPUTER SIMULATION OF KAILUA BEACH SHORELINE MOVEMENT
(From Edward K. Noda and Assoc., "Beach Processes Study-Kailua Beach", 1977)

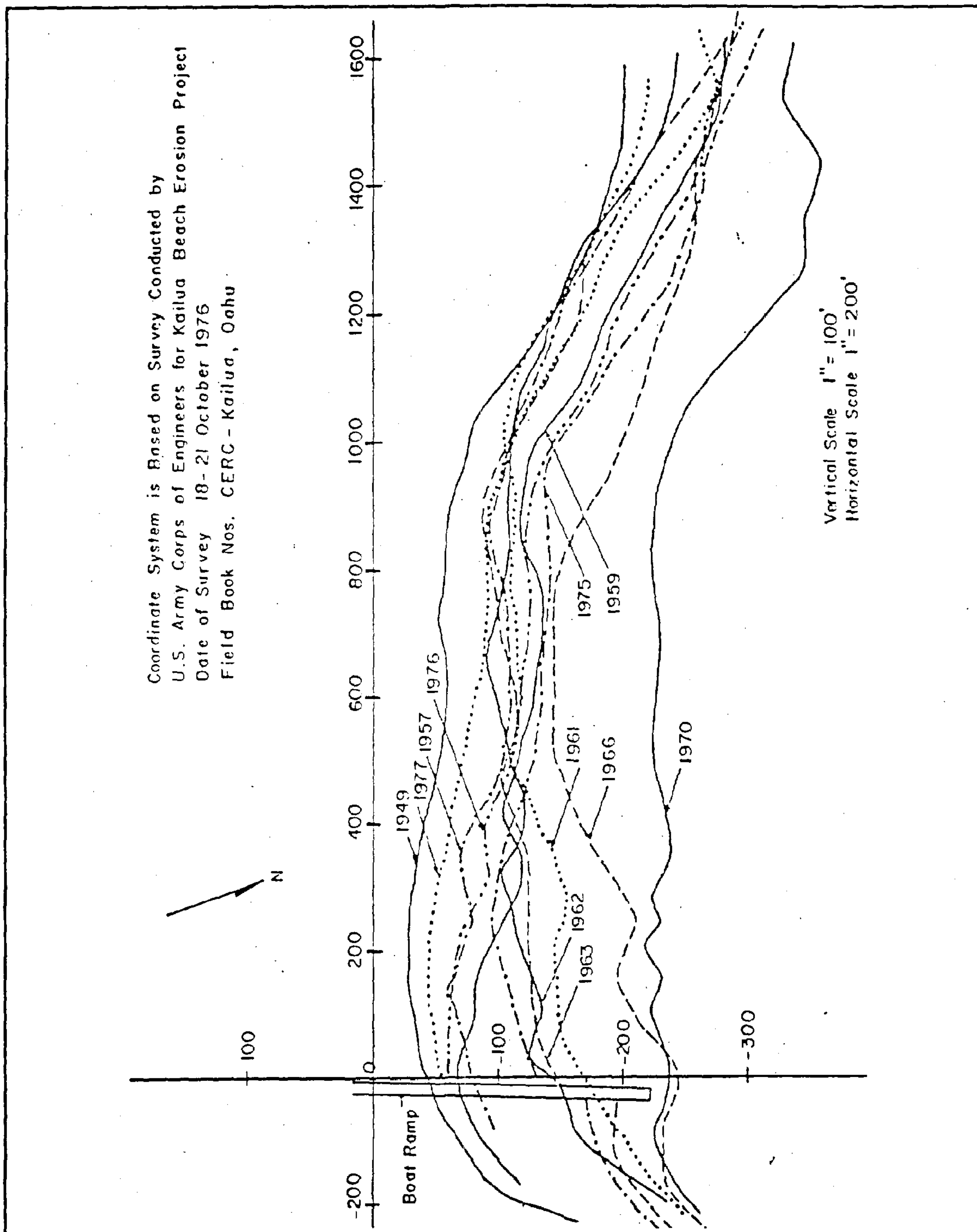

FIGURE 4-39 HISTORIC SHORELINE MOVEMENT NEAR BOAT RAMP AT KAILUA BEACH PARK
(From Edward K. Noda and Assoc., "Beach Processes Study-Kailua Beach", 1977)

Figure 4-40 shows the plot of cumulative shoreline movement at two transect locations from Figure 4-39. These locations are at distances of 200 feet and 800 feet from the boat ramp. Note that the periodicity of the accretion/erosion cycle correlates well with the computer simulation, on the order of 30 years.

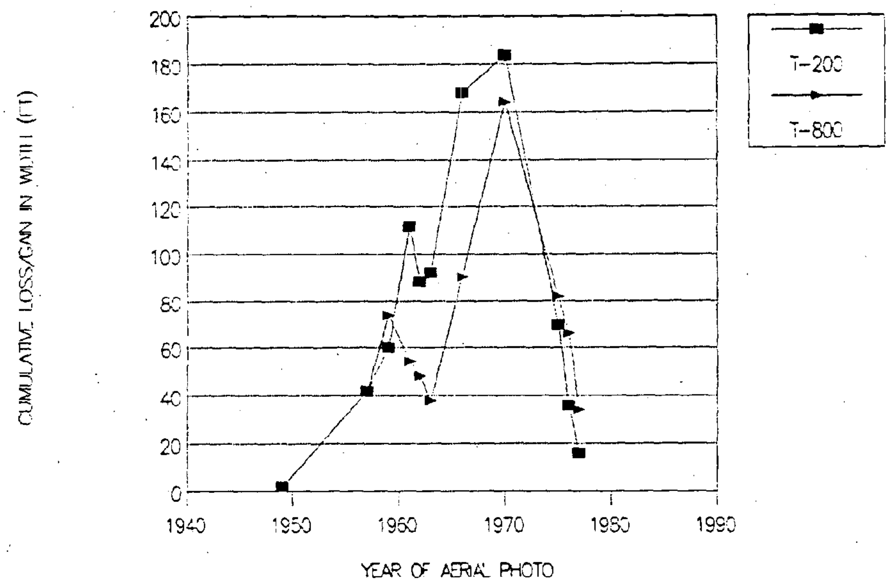

FIGURE 4-40 CUMULATIVE SHORELINE MOVEMENTS AT TRANSECTS 200 AND 800: KAILUA BEACH PARK

The loss of beach during the early to middle 1970's was a cause of great concern at the Kailua Beach Park, but it can be seen that the 1977 shoreline position was not unprecedented in the historical record. The intermediate shoreline movements between the extreme positions of 1949, 1970 and 1977 can be found to follow rather regular incremental changes between the extremes without wild fluctuations. The observed movements of the shoreline are representative of long term cycles with periodicities on the order of a number of decades. In general, long-term cycles have been observed in meteorological trends and previous investigations[63] have postulated that there is a cycle with an appropriate period involving the variation in mean direction of the tradewinds near the Hawaiian islands.

The historical record at Kailua Beach is not long enough to be certain that the present shoreline, near the 1977 shoreline position, is close to the maximum limit of erosion with a period of significant accretion to follow in the near future. The range of

[63] Wyrtki, K. and G. Meyers, (1975),"The Trade Wind Field Over the Pacific Ocean - Part 1. The Mean Field and the Mean Annual Variation", Hawaii Institute of Geophysics Report HIG-75-1.

shoreline fluctuations from the numerical simulation would suggest this, however these results incorporate random processes. From the existing historical record, which is only a little longer than one cycle period, it is not possible to be confident that, indeed, the cycle is in the accretion phase. An appropriate estimate of long term erosion from the present shoreline position at Kailua Beach Park should attempt to moderate in a conservative manner between the best and worst case scenarios. The best case envisions a return to an accretionary period of shoreline movement, with gain of about 200 feet in the next 15-20 years. If we assume that the present shoreline represents the starting point of another accretion/erosion cycle, then over the next 30 years or so, the shoreline would return to about its present location, with zero net movement. The worst case might expect erosion at the rate of earlier trends, with shoreline recession on the order of 200 feet in 15-20 years, then a subsequent return to its present location to complete the 30 year cycle. Thus, an appropriate estimate for long term erosion of the present shoreline position at the Kailua Beach Park might be 100 feet of recession during the next thirty years.

FIGURE 4-41 NARROW BEACH JUST TO THE NORTH OF KAILUA BEACH PARK IN KAILUA BAY

Over the same time period, shoreline recession of 50 feet would be an appropriate conservative estimate for the rest of Kailua Beach within the site area north of the Beach Park, since it is less susceptible to large fluctuations in net sediment transport than the head of the littoral cell at Kailua Beach Park. In addition, previous studies[64] indicate that this reach has been generally stable or slightly accretionary. It should be noted that, in the past, few shore protection structures have been needed along this shoreline reach immediately north of Kailua Beach Park. However, the dry beach here is only approximately 10 feet wide, making the area susceptible to future change, especially if the Kailua Beach Park shoreline enters into another erosion cycle.

LANIKAI:

Between the stable rocky headlands at Alala and Wailea Points, the coast at Lanikai presents significant features which correspond to the history of shoreline change at the Kailua Beach Park. Figure 4-42[65] plots the position of the water line (at the beach toe) and the position of the vegetation line (at the back of the beach) for the entire coast at Lanikai from eight aerial photographs between 1950 and 1982. The distance between the vegetation line and the beach toe define the usable beach width and so provides one measure of erosion over the time period. The two structures identified on the plot include a drainage pipe and open drainage channel. Over the whole span of Lanikai, inspection of this data for the beach system will confirm the general trend of erosion in the 1950's time frame when the beach was narrow, accretion in the 1970's time frame when the beach was widest, and erosion again in the most recent time frame. One can see that, at any one time, the state of erosion is not consistent along the entire Lanikai shoreline. This is due to the presence of the mini-littoral cells discussed earlier which form through the complex interactions between wave energy propagating shorewards and the reef structures in the near shore zone.

A different perspective of the same data from the aerial photographs is shown in Figure 4-43. On this plot, first the vegetation lines and then the beach toe lines have been plotted on top of each other as measured from a fixed reference line. The change in position of both the vegetation and beach toe lines is clearly evident. With the aid of colored lines on the original work, the accretion and erosion trends are able to be confirmed. It is also possible to see that these trends were not uniform over the entire Lanikai coast.

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[64] Dennis Hwang, "Beach Changes on Oahu as Revealed by Aerial Photographs", 1981; and Sea Engineering Inc., "Oahu Shoreline Setback Study", 1988.

[65] Edward K. Noda and Associates, Inc.,"Lanikai Flood Control Project- Oceanographic Design Considerations for Drainage Discharge Structures". Work accomplished as part of the study but not reproduced in entirety in the referenced report.

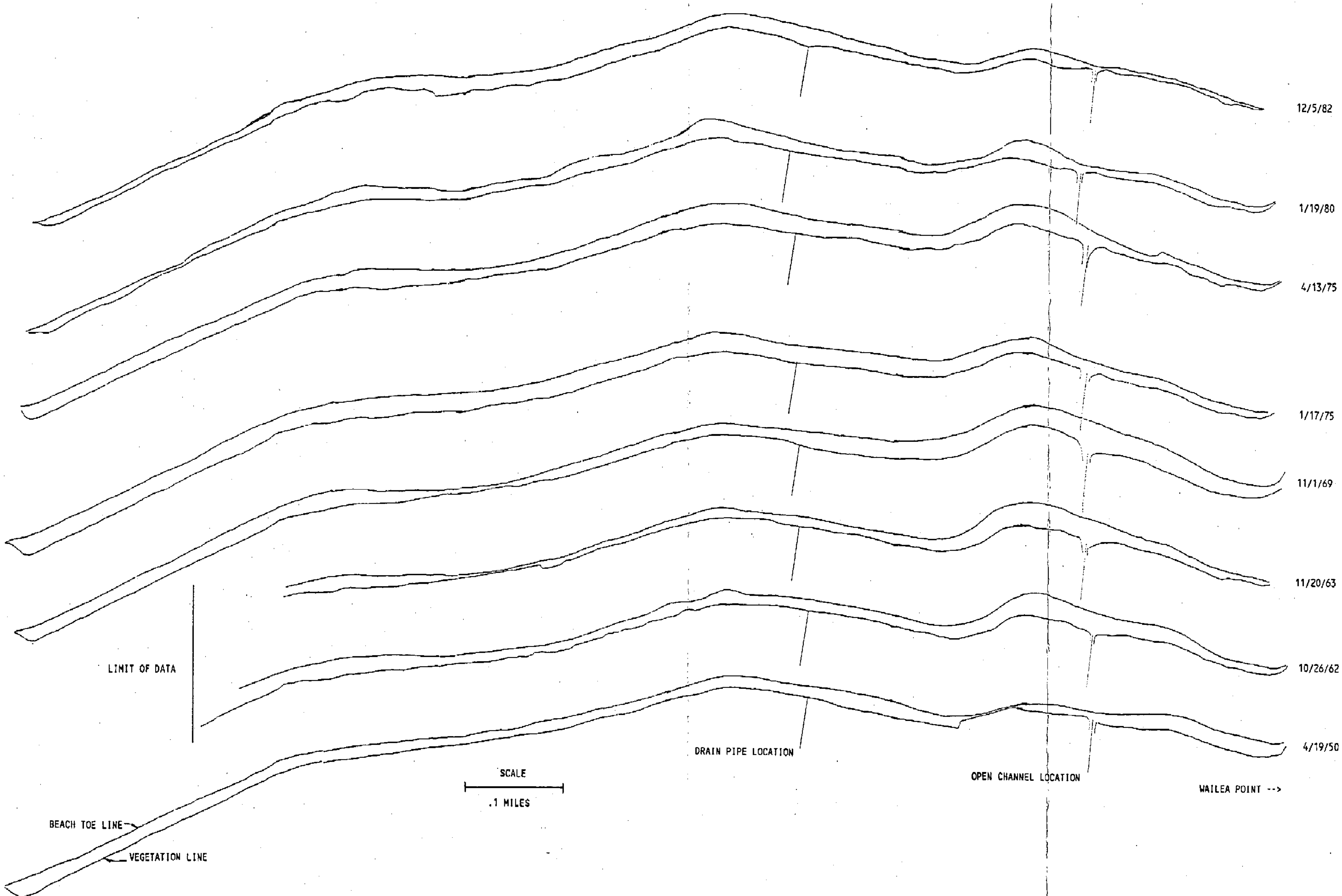

FIGURE 4-42 BEACHLINES AT LANIKAI FROM AERIAL PHOTOS, 1950-1982
(Developed from study by Edward K. Noda and Assoc., "Lanikai Flood Control Project, Oceanographic Design Considerations", 1987)

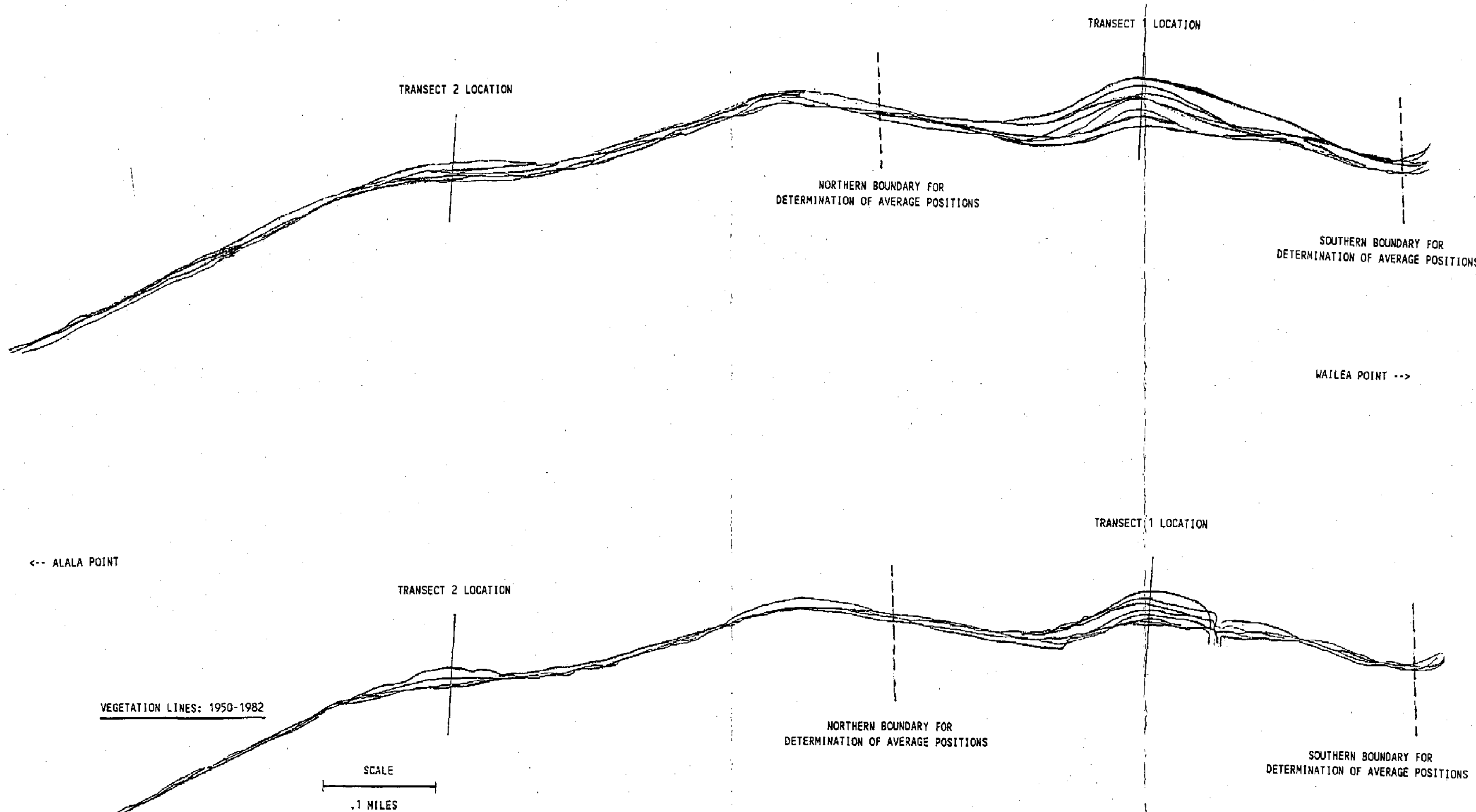

FIGURE 4-43 VEGETATION AND BEACH TOE OVERLAYS AT LANIKAI: 1950-1982
(Developed from study by Edward K. Noda and Assoc., "Lanikai Flood Control Project-Oceanographic Design Considerations", 1987)

From 1950 to 1982, it is possible to account for the net movements of sediment which occur between the beach and the fringing reef flats by accurately determining the changes between consecutive photographs. Over a 2500 feet length along the southern third of the Lanikai coastline where the range of fluctuation was the greatest, the average change in position of the beachlines relative to the earliest photo was determined for each photograph. Figure 4-44 graphically depicts the average erosion (-) or accretion (+) of the vegetation line and beach toe line along the 2500-foot long beach segment. The average change in beach width could also be calculated, with beach width defined as the horizontal distance between the vegetation and beach toe lines. Figure 4-45 depicts the average change in beach width relative to the earliest photo. From the plots, it can clearly be seen that this beach segment was in an erosive phase during the earliest time period around 1950, as well as at the present time, and in an accretionary phase during the 1970 time frame. The ranges of fluctuation over the designated reach were 90 feet for the beach toe line, 50 feet for the vegetation line, and 50 feet for the change in beach width.

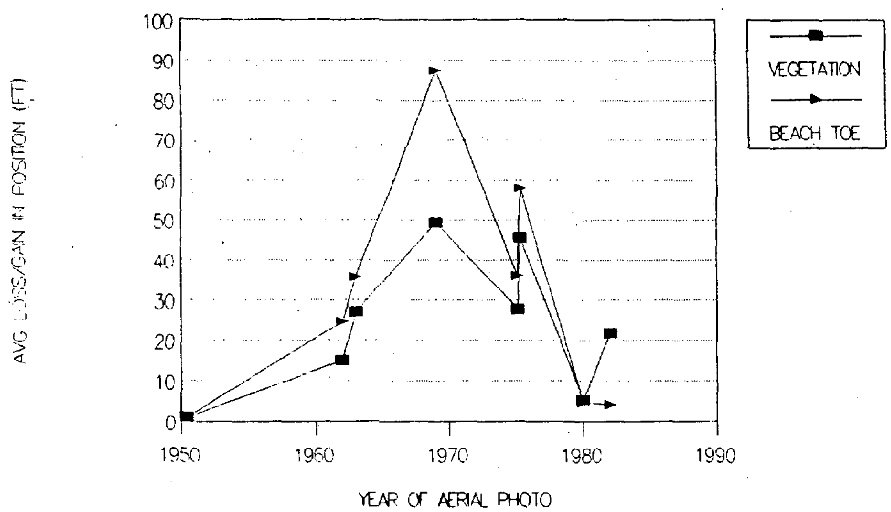

FIGURE 4-44 CUMULATIVE SHORELINE MOVEMENTS (AVG ACROSS BEACH SEGMENT) SOUTHERN SHORE, LANIKAI

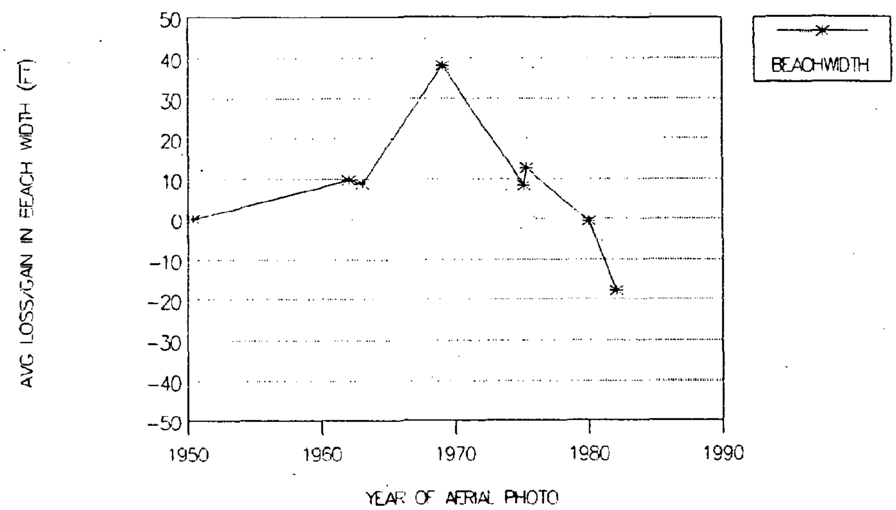

FIGURE 4-45 CUMULATIVE CHANGES IN BEACH WIDTH (AVG ACROSS BEACH SEGMENT)
SOUTHERN SHORE, LANIKAI

Transect lines at two locations along the Lanikai shoreline show the maximum horizontal shoreline changes. The cumulative shoreline movement at the two transect locations is displayed in Figure 4-46. Transect 1 is at the location of the open channel where maximum historical accretion and recent erosion has occurred. The maximum historical fluctuation occurred in the position of the beach toe line with a range near 200 feet. This shoreline reach has been artificially hardened with shore protection structures, and the waterline presently comes right up to the base of the seawalls and revetments. Transect 2 is at the location where maximum accretion has occurred in recent times. The maximum historical fluctuation occurred in the position of the vegetation line with a range near 75 feet. Presently, this area on the Lanikai coast has an often-used dry beach.

Figure 4-47 depicts the cumulative changes in beach width at the two transect locations. Note that at the Transect 2 location, the beach width from the most recent photo is about the same as the beach width in the earliest (1950) photo, although the horizontal movement of the shoreline has been seaward. This indicates that the parcels along this reach have gained vegetated fast lands while the dynamic beach width has remained relatively constant in the long-term. It is important to emphasize

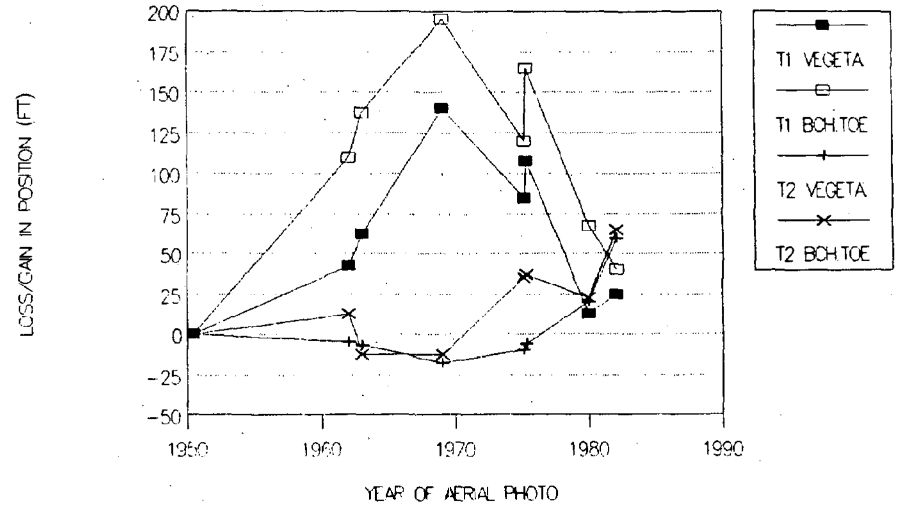

FIGURE 4-46 CUMULATIVE SHORELINE MOVEMENTS AT TRANSECTS 1 AND 2: LANIKAI

that the transect data represents changes occurring at single locations on the beach whereas average calculations quantify change along a continuous length of the beach. For long term monitoring of coastal processes, both techniques should be used to complement each other.

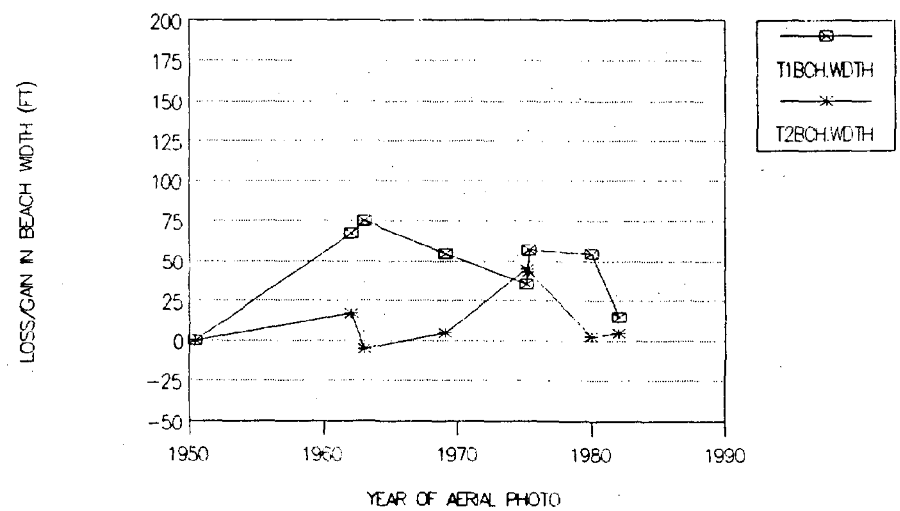

FIGURE 4-47 CUMULATIVE CHANGES IN BEACH WIDTH AT TRANSECTS 1 AND 2: LANIKAI

As the base map indicates, during recent years, erosion has occurred to the beach at both ends of Lanikai. South of Alala Point, this end of Lanikai has completely lost beachfront over approximately 1400 feet along the shore. North of Wailea Point, this end of Lanikai has lost beachfront over approximately 2000 feet along the shore. These are areas that have had as much as 50 and 100 feet of beach width at different times in the historic record. With such losses at both ends of the beach, it is only reasonable to assume that the beach sand has been transported offshore onto the reef flats. With the increase in reflectivity due to the seawalls and revetments in these areas, there is little chance for sediment to be re-deposited and for the beach to build back naturally in the near future. With some measure of shore protection presently existing along nearly 100% of the shoreline reach at the north and south ends of Lanikai, there will be no long term erosion of the vegetation line. However, without additional beach restoration and stabilization measures, the return of a dry beach in these areas may never occur. This is not to say that the shore protection structures have significantly aggravated the erosion problem. The southern Lanikai shore displayed similar historical erosion trends as the Kailua Beach Park shoreline (which was unprotected), and the Lanikai seawalls were constructed in response to the erosion cycle to protect existing residential improvements. Their influence now is to discourage sand buildup during a potential accretionary phase of the cycle.

Over the middle segment, occupying about one half of the Lanikai coast, there is now an ample beach width and a relative absence of shore protection structures. Erosional processes may be aggravated along this reach with the starving of sediment from the endpoints of the Lanikai coast. For this reason, a conservative estimate of long term erosion would be appropriate in the interpretation of the results from the historical data. At the Transect 2 location, the vegetation line was relatively stable from 1950 to the mid-1970's, varying ±20 feet. Since the 1970's. the shoreline has accreted about 60 feet relative to the 1950 photo. The 3000-foot long reach southward of Transect 2 has been relatively stable throughout the entire 30 year period, with a maximum range of fluctuation typically less than 50 feet (see Figure 4-43). For the southern end of Lanikai, the historical data indicates an average 50 foot range of fluctuation of the vegetation line for the entire 2800-foot long segment (although at the Transect 1 location, the recession has been over 100 feet). This suggests that, over the next thirty years, a maximum of 50 feet is an appropriate conservative estimate of erosional recession from the present position of the vegetation line for the dry sandy beach segment occupying the middle portion of the Lanikai shoreline. There is a probability that this reach will continue to remain relatively stable in the long-term.

FIGURE 4-48 LOSS OF BEACH ALONG HARDENED COASTLINE AT SOUTH END OF LANIKAI
(Houses at Wailea Point visible in background)

FIGURE 4-49 NARROW SANDY BEACH TOWARDS NORTH CENTRAL LANIKAI SHORE
(Note waterline at base of shore protection structures in background)

APPROPRIATE SHORE PROTECTION MEASURES

Appropriate erosion control measures for the Kailua section of the site area should begin with conserving all available sediment within this littoral cell. At the Kailua Beach Park, the Kaelepulu Stream mouth regularly becomes plugged with beach sand due to natural littoral processes. To prevent flooding of backshore areas, the mouth of the stream is artificially cleared of sediment by means of bulldozers. The material is often permanently removed from the beach area on the grounds that detritus material which mixes with the sand makes it unsuitable for placement back on the beach. Presently, no substantial effort is made to separate the clean beach sand overlying the "dirty" sediment during the removal process. This sizeable, permanent loss of precious beach sand from the Kailua littoral cell should be avoided through separation and washing techniques.

The additional measures of shore protection which would be appropriate at Kailua include beach nourishment and revetments. Adding sand to the eroded areas at the Beach Park could be a temporary measure to protect the beach but it would be difficult to project how long the supplied sediment would last given the great variability in the short term erosion patterns. Previous investigations have considered the economics of beach nourishment at Kailua, given the nearby offshore supply, but to date beach nourishment has not been attempted at Kailua. Buried revetments would be an appropriate structure to protect backshore improvements in this sandy beach area. However, if an erosion trend persists and begins to affect the nearby residential parcels north of the park, management of the shoreline must give consideration to the fact that the site area at Kailua is the head of the Kailua Bay littoral cell. If the head of the littoral cell is structurally protected, then sediment supply to the downstream parts of the littoral cell may be reduced, and the erosion problem may ultimately shift northward at Kailua. Since the number of present shore protection structures is at a minimum in the area, every chance should be given to allow the natural recurrence of an accretionary trend along the Kailua beach segment. Within the Kailua Beach Park shoreline reach, the open space park setting and natural beach area are primary considerations.

At Lanikai, much of the coastline has already been hardened with seawalls and revetments, especially at the two ends of the littoral cell near Alala and Wailea Points. As was previously mentioned, the beach has been lost in these areas and it may be difficult for sand to return naturally due to the increased reflectivity of the walls. If further protection is warranted in the adjacent residential areas towards the middle of the coast at Lanikai, revetments are the appropriate measure given the sandy base material. If the return of a continuous sandy beach at Lanikai is desired in the near future, a long term plan must be considered, including beach nourishment with structural measures to protect the beach fill, such as multiple groins and/or offshore breakwaters. The plan should be designed by coastal engineers incorporating appropriate measures for the entire Lanikai littoral cell. The shallow fringing reef at Lanikai should minimize the cost of offshore structures such as exposed or submerged breakwaters. With the complex coastal processes occurring at Lanikai, a project to design such structural beach stabilization measures may need to include modern techniques in physical and numerical modelling to verify the efficacy of the overall plan. The plan should also be designed with consideration of the water recreation activities in the area such as windsurfing, kayaking, swimming, etc.

EROSION MANAGEMENT RECOMMENDATIONS

There are two distinct littoral cells in the Kailua/Lanikai case study area: Lanikai Beach between Alala and Wailea Points, and Kailua Beach area from Alala Point north to the end of the case site area.

Lanikai Beach is already fairly established with shore protective structures along major portions of the extreme northern and southern shoreline reach. The following recommendations are suggested for the Lanikai shoreline:

- Based on the analysis of historical shoreline changes described herein, a 50-foot shoreline setback should be established for the central segment of the Lanikai Beach littoral cell. For the northern and southern reaches, the existing 40-foot setback should be retained.

- If shore protection is determined to be necessary, revetments should be the only shoreline structure permitted in the central Lanikai beach area. If existing seawalls are destroyed or are in need of major repair, revetments should be the only protective structure allowed to replace the previous seawall.

- The ultimate long-term goal should be beach nourishment combined with offshore structures and/or groin fields to restore and maintain the beach along the entire Lanikai shoreline. The Improvement District concept may be used to help reduce costs to the individual landowners.

- Property owners should not be permitted to claim accreted shoreline reaches. While the central Lanikai shore has historically been stable and short reaches have accreted seaward in recent times, there is no assurance that this trend will continue. The southern Lanikai shore is an example where encroachment onto accreted lands had occurred during the accretionary phase and loss of these lands during the erosion phase led to hardening of the shoreline.

- A thorough re-examination of the R-10 zoning designation should be conducted. Due to the long-term erosional changes along this shoreline, a large number of non-conforming lots (smaller than the minimum 10,000 square feet) have been created. Reconstruction of habitable structures in non-conforming lots should be carefully analyzed before perpetuating non-conforming lots.

The Kailua Beach portion of the case study area includes Kailua Beach Park which has seasonal erosion/accretion. There is a relatively stable beach area north of the park. Recommendations for this portion of the study area include the following:

- Based on the analysis of historical shoreline changes described herein, a 100-foot shoreline setback should be established for Kailua Beach Park and a 50-foot shoreline setback established for the remainder of Kailua beach within the study area.

- A special overlay zoning designation should be considered for the area between Alala Point and the north end of the Kailua case study area, and possibly extended to the north end of Kailua Bay. This new overlay zoning may be called *Beach District* or *Shore District* such as that included in the Kauai zoning ordinance. Specific rules and regulations should be developed to manage these areas and adequately protect them. As a further step, redesignation of a buffer strip fronting the residential zoned areas to Conservation District could be considered. Because of the existing Kailua Beach Park and existing beachfront along the entire bay shoreline that is easily accessible and intensely used by the public, extraordinary effort should be considered to preserve and maintain this significant beach resource.

- In the context of existing rules and regulations, parcels without existing shoreline protection structures should only be allowed to construct revetments if shore protection is determined to be necessary.

- Sediment cleared from Kaelepulu Stream mouth should be placed back onto the Kailua Beach Park beach area. Separation and washing techniques should be used as necessary to insure that the sand is suitable for beach replacement.

4.4 CASE STUDY SITE #3 - KUKUIULA-POIPU, KAUAI

GENERAL DESCRIPTION

This case study site is situated on the south shore of Kauai. The study reach extends from Ka Lae Kiki to the rocky shoreline cliffs of Makahuena Point, a distance of about 2-1/4 miles. Figure 4-50 shows the study reach. Exhibit C provides the base maps for this case study site at a scale of 1 inch = 200 feet. Figure 4-51 shows a reduced version of the base maps for reference.[66]

Much of the shoreline is rocky and irregular with pocket beaches nestled between or in the lee of outcrops of basalt. The two major beaches along this reach are situated in the Poipu area, fronting the Sheraton and Kiahuna Resorts, and fronting Poipu Beach Park. The beaches are composed primarily of calcareous sands of biologic origin. The backshore areas are generally low-lying except in the vicinity of Waikomo Stream mouth and at Makahuena Point, where shoreline cliffs rise steeply above the low lava basalt tidal platforms. The offshore bottom contours are relatively uniform, with slopes ranging from about 1V:20H to 1V:40H. Shoreward of the approximate 18-foot contour, the slope flattens to about 1V:50H, and the bottom is predominantly rocky substrate with sand pockets and channels. The very nearshore and shoreline region is highly irregular, with uniformly sloping bottoms in some areas and other areas having rugged rocky outcrops or shallow wave-cut tidal benches.

Lawai Road follows the coastline west of Waikomo Stream. Short stretches of the road directly front the shore and are protected with revetments after having been damaged by Hurricane Iwa and rebuilt. Hoonani Road follows the coast east of Waikomo Stream and leads directly into the Sheraton Kauai Resort, where it ends at a public right-of-way to the beach. East of the Stouffer Waiohai, Hoone Road continues along the coast past Poipu Beach Park and towards Makahuena Point.

[66] The reader is encouraged to use the full scale base maps in Exhibit C for better understanding of the information presented.

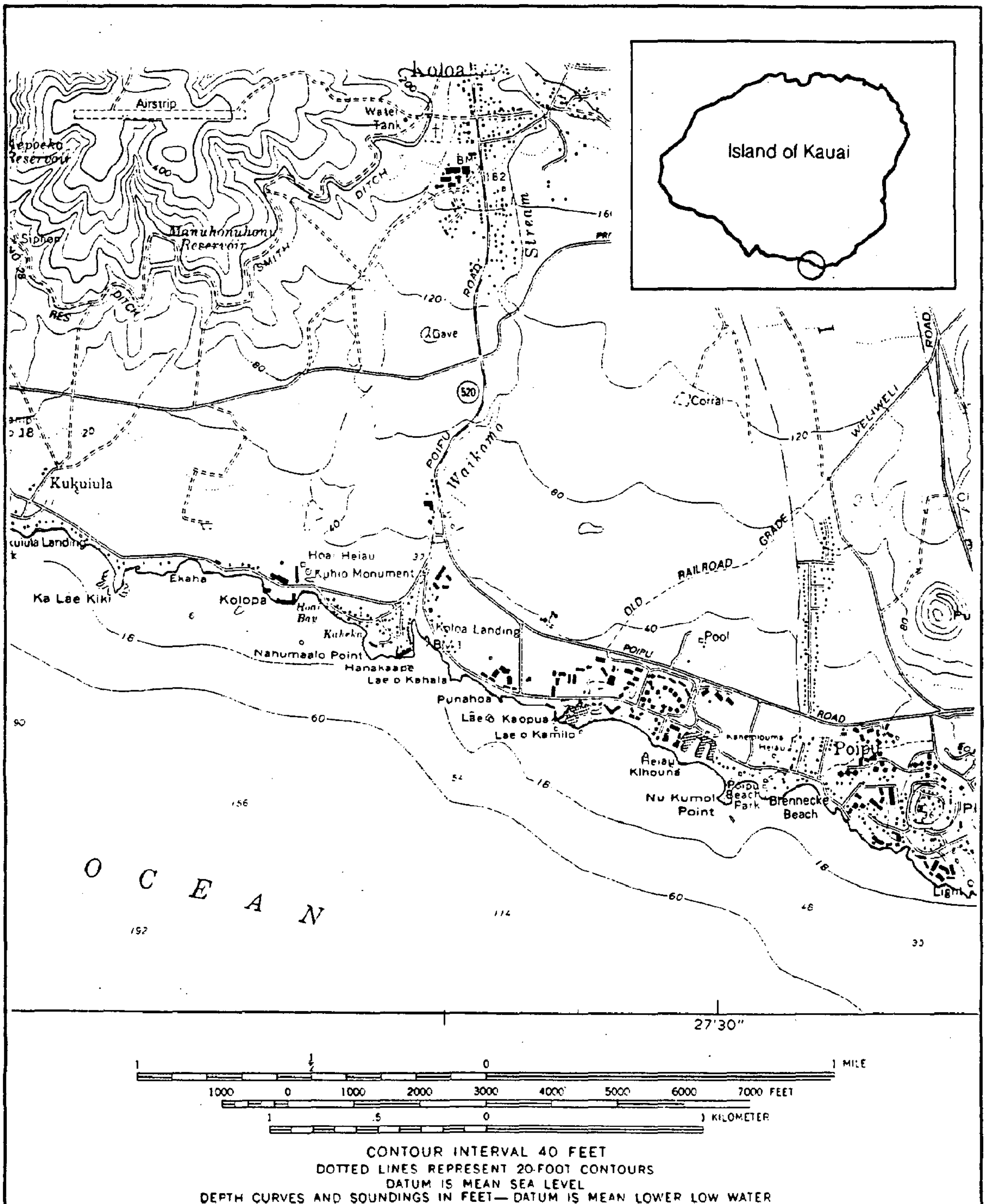

FIGURE 4-50 LOCATION MAP, CASE STUDY SITE #3 - KUKUIULA-POIPU, KAUAI

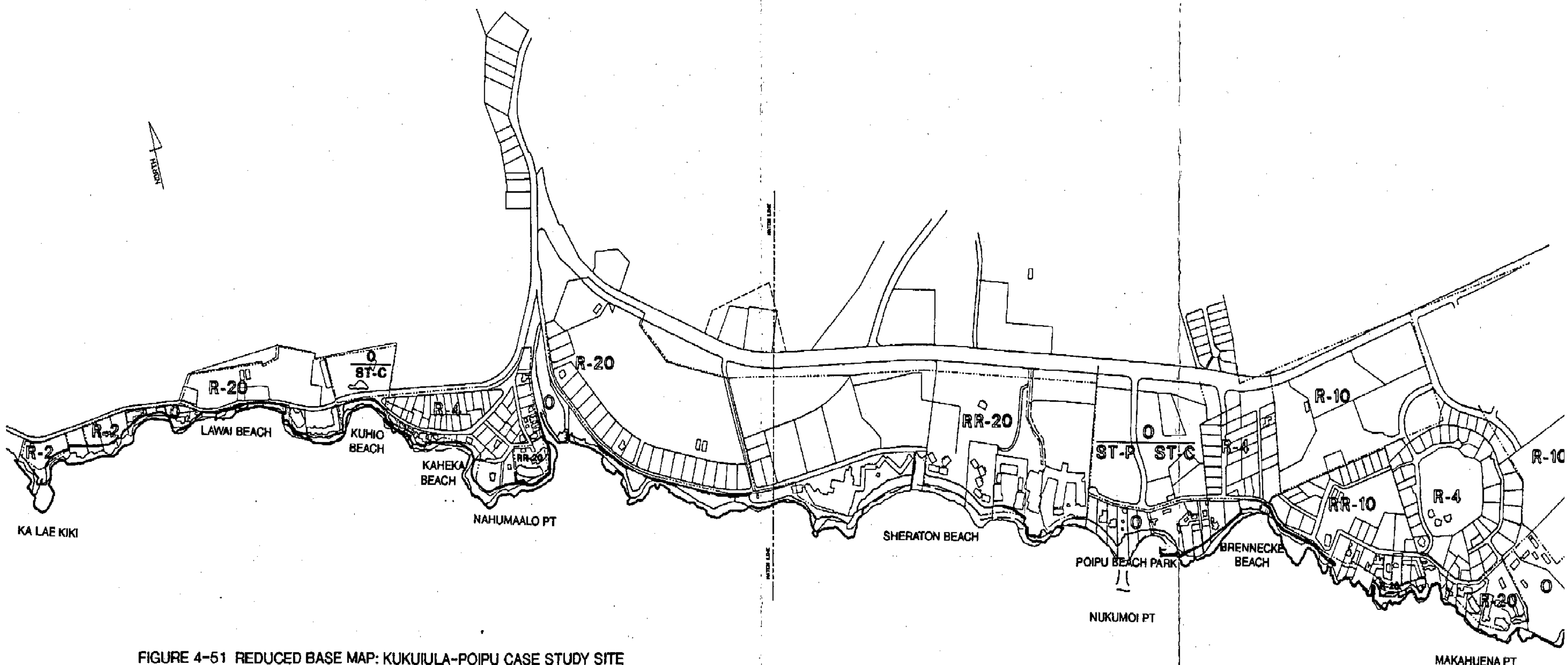

FIGURE 4-51 REDUCED BASE MAP: KUKUIULA-POIPU CASE STUDY SITE

LAND USE AND DEVELOPMENT

The Kukuiula-Poipu, Kauai case study area is located within the Koloa District[67] on the southern shore of Kauai. The Koloa District had a 1980 resident population of 8,734 and Poipu[68] had a 1980 resident population of 685.

The State Land Use designation for the entire case study area is Urban. The Land Use District map for the vicinity is shown in Figure 4-52. This designation extends to the shoreline and is under the County of Kauai jurisdiction.

The case study area is located within the Koloa-Poipu-Kalaheo Planning Area on the south shore of Kauai.[69] The communities of Kukuiula and Poipu have been primarily residential in the past. The County General Plan adopted in 1971 specifies that Kukuiula and especially Poipu should be developed as a principal visitor destination area. The area around Poipu, in particular, has been experiencing increased hotel and condominium resort development and has gradually changed to resort-residential in character.[70] The 1982 Kauai General Plan Update designates the area from Ka Lae Kiki to Nahumaalo Point near Koloa Landing as Urban Residential. The remainder of the case study area from Koloa Landing past Poipu Beach and Brennecke Beach is designated Resort. Figure 4-53 depicts the Kauai General Plan for the vicinity.

The shoreline along the entire case study area is zoned Open District of varying widths directly at the shoreline. Immediately mauka of this Open District are a variety of zoning districts. Figure 4-54 depicts the zoning districts for the vicinity. Beginning at the Ka Lae Kiki end of the case study area, there are two sections of Residential (R-2) District. Continuing towards Kolopa is Open District makai of Lawai Road until the Residential (R-20) designation for the Lawai Beach Resort at Kolopa. Immediately past Kolopa is an Open, Special Treatment District-Cultural: Historic (O/ST-C) District at Kuhio Beach. This encompasses the Prince Kuhio Park and Hoai Heiau mauka of Lawai Road. The Kaheka area, next to Kuhio Beach, is zoned Residential (R-4) except Whaler's Cove (TMK 2-6-07: 13) which is zoned Residential (R-20).

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[67] The Koloa District consists of a major portion of the southern Kauai shore mauka to the mountains.

[68] Poipu is the only coastal community within the case study site with population data.

[69] 1982 Kauai General Plan Update, prepared by Planners Collaborative with Richard A. Moore, Wilson Okamoto & Associates, VTN Pacific, William H. Liggett for the County of Kauai, June 1982.

[70] Koloa-Poipu Development Plan, prepared by the joint venture of EDAW inc. and Murodo & Associates, Inc. for the County of Kauai, 1977.

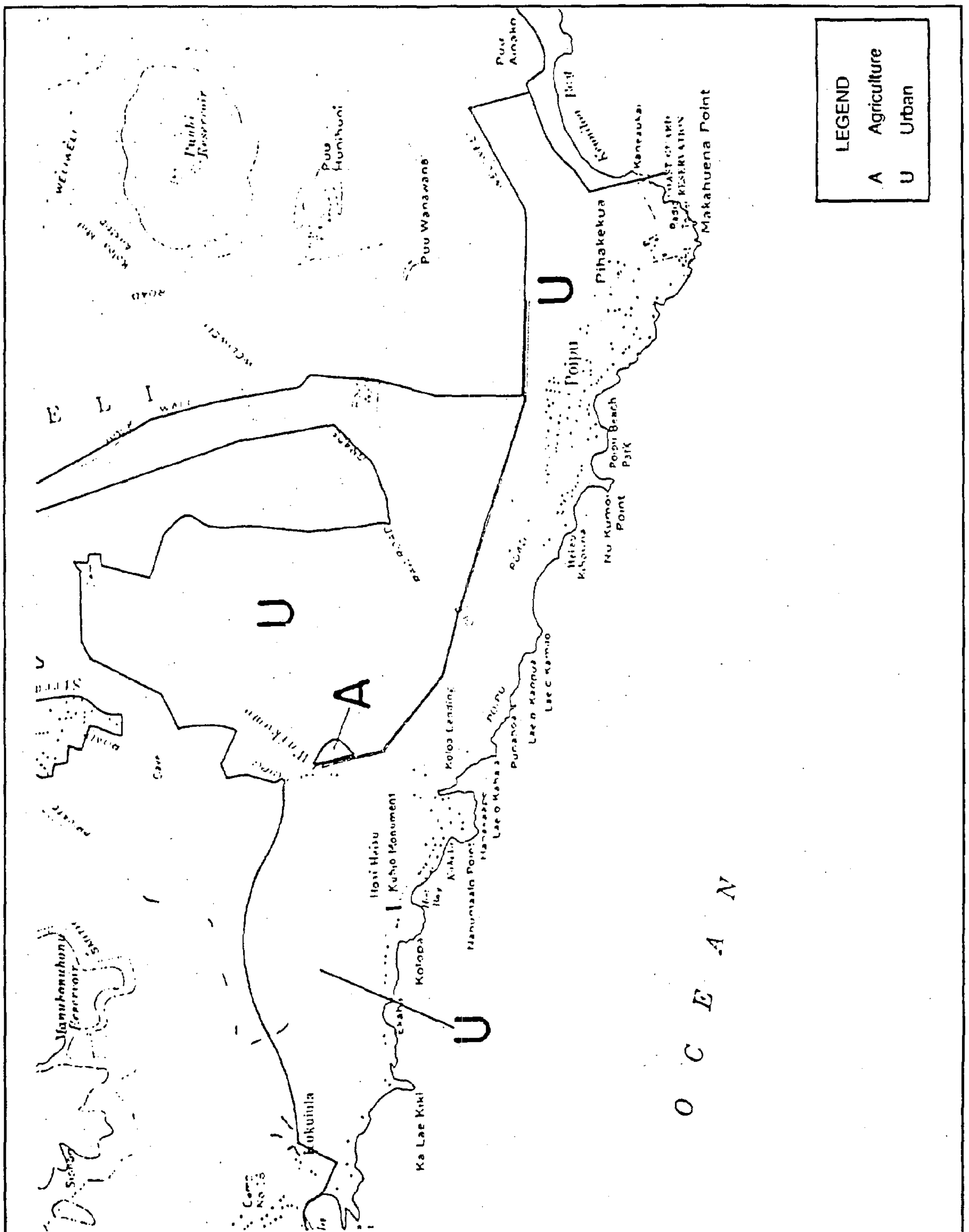

FIGURE 4-52 STATE LAND USE DISTRICT MAP FOR VICINITY

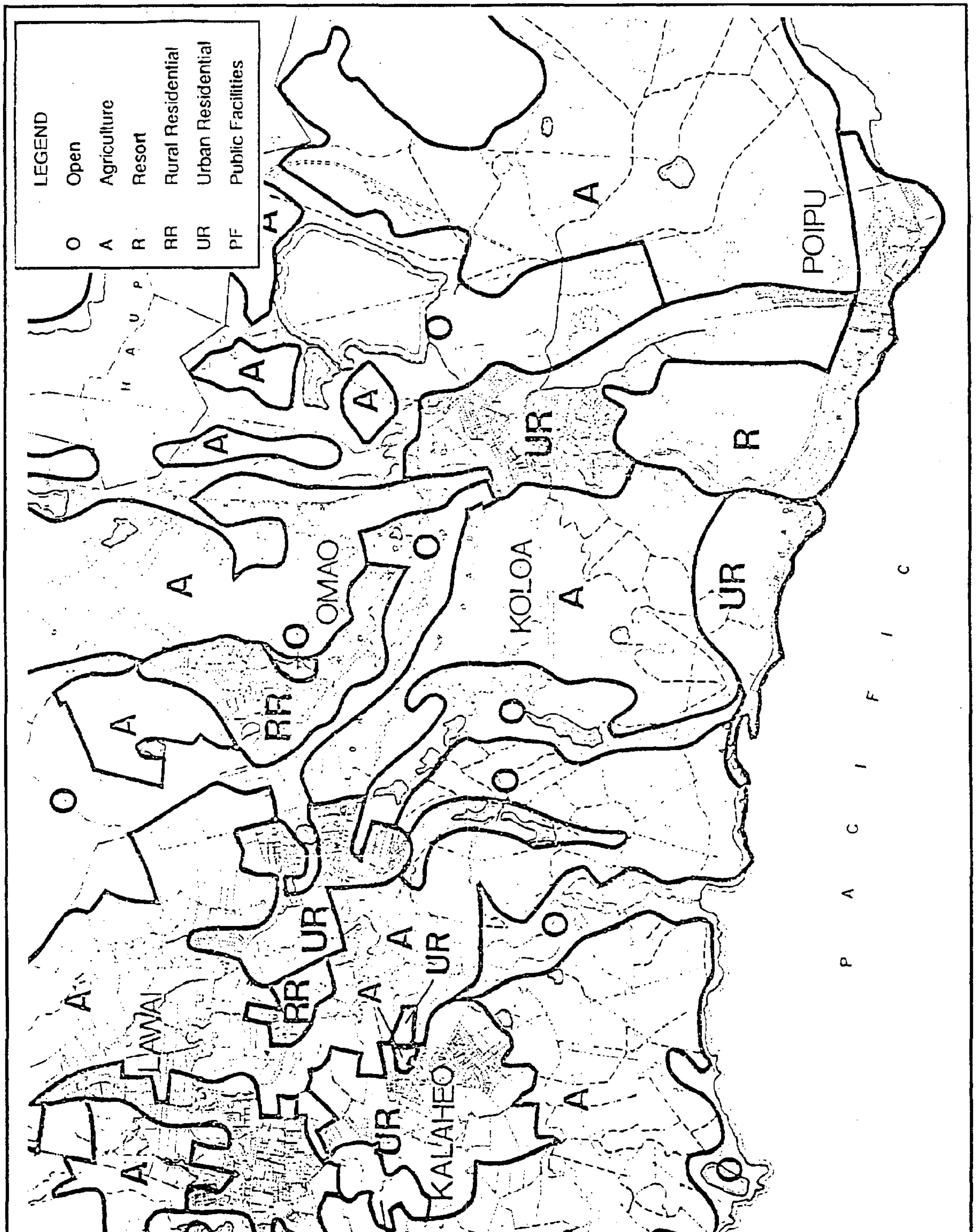

FIGURE 4-53 KAUAI GENERAL PLAN MAP FOR VICINITY

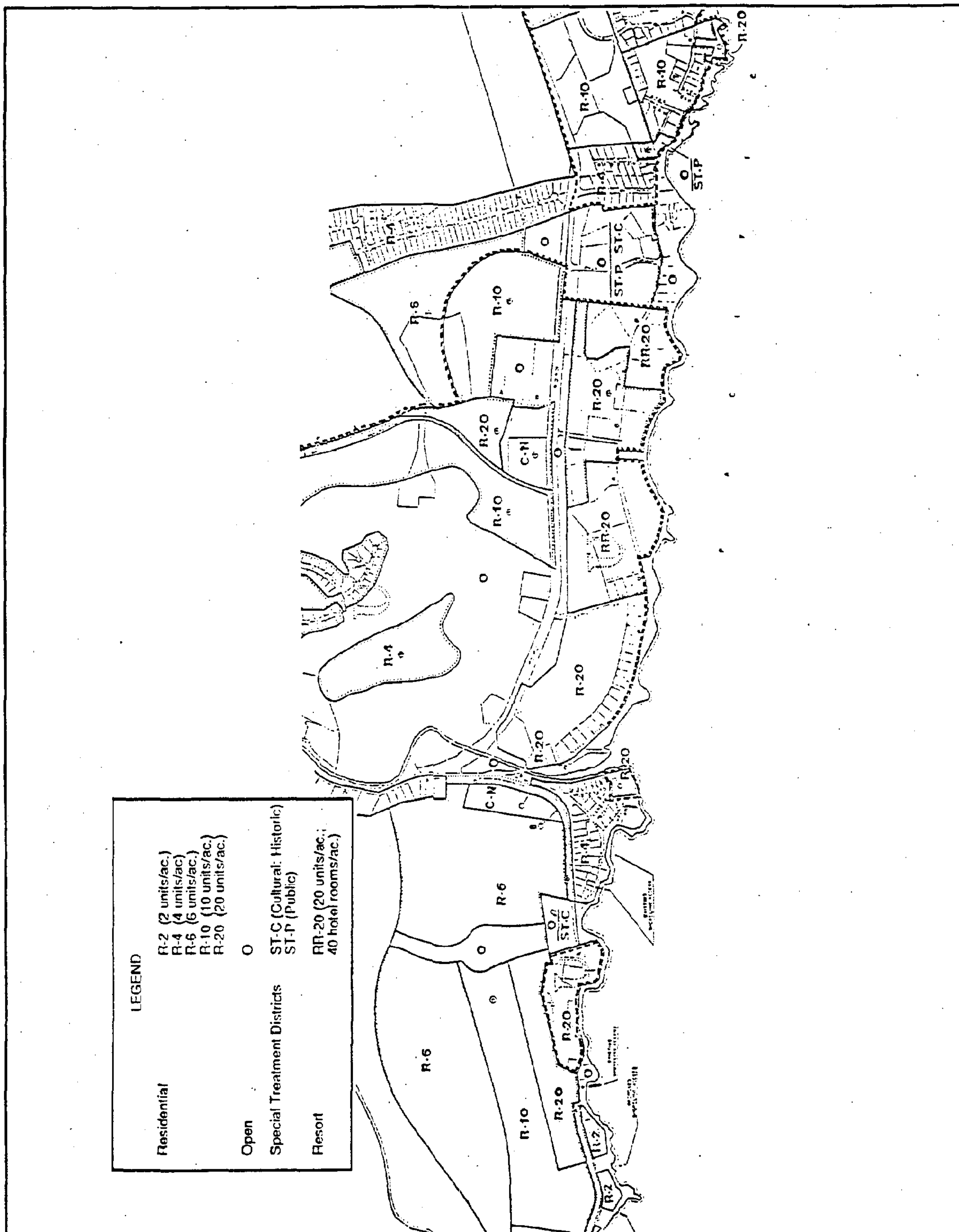

FIGURE 4-54 KAUAI ZONING DISTRICT MAP FOR VICINITY

The area beyond Waikomo Stream remains in Open District mauka to Poipu Beach Road until the Sheraton Kauai (TMK 2-8-16: 3) which is zoned Resort (RR-20). The adjacent parcel remains in Open District followed by Residential (R-20) District for two parcels of the Kiahuna properties. The parcels (Poipu Beach Hotel and Stouffer Waiohai) beyond Kiahuna properties are zoned Resort (RR-20) District. Open (O/ST-P, ST-C) District mauka to Poipu Beach Road begins at this point, continues beyond Poipu Beach Park and Brennecke Beach until the last parcel in the case study area, Poipu Shores, which is zoned Residential (R-20) District.

NEARSHORE WAVE CLIMATE

This coastline is somewhat sheltered from the predominant northeast tradewind-generated waves and winter North Pacific swell. These waves undergo considerable refraction effects prior to reaching shore, resulting in much reduced nearshore wave heights as compared to deepwater heights. However, the study reach is directly exposed to south swell during the summer months, as well as to infrequent Kona storm and hurricane waves from the southerly approach directions. Hurricane Iwa in November 1982 caused extensive damage to this coastal area.

A study was accomplished in January 1986 to determine the potential coastal flooding limits in the Poipu vicinity due to hurricane waves.[71] Coastal inundation limits were estimated for four scenario hurricanes; a model and worst case event from the east-southeast and south-southwest directions. The analysis was accomplished using numerical computer techniques and the models were verified using data from Hurricane Iwa. Wave refraction analysis was accomplished for the estimated most severe wave conditions for the scenario hurricanes and for Hurricane Iwa. The refraction diagrams are reproduced in Appendix J. The wave periods and deepwater approach directions that were modeled are:

14.7 sec from 237°T (Hurricane Iwa)
12.0 sec from 180°T (ESE Model)
13.7 sec from 180°T (ESE Worst Case)
12.7 sec from 185°T (SSW Model)
15.3 sec from 187°T (SSW Worst Case)

These wave approach directions are representative of south swell approach direction, although the wave periods are somewhat shorter than south swell periods. However, the refraction diagrams do provide a representation of the convergence and

[71] "Hurricane Vulnerability Study for Kauai, Poipu and Vicinity, Storm Wave Runup and Inundation", prepared for U.S. Army Engineer Division, Pacific Ocean, prepared by Sea Engineering, Inc. and Charles L. Bretschneider, January 1986.

divergence patterns in the nearshore region due to southerly wave approach. Generally, divergence occurs in the vicinity of the Waikomo Stream mouth and east of Brennecke Beach. In most cases, however, the incoming wave energy undergoes little refraction effects for the southerly approach directions, since the bathymetry contours are nearly parallel with the approaching wave fronts. Typical deepwater wave heights for south swell are 1-4 feet, with surf heights 6 to 8 feet not uncommon because of the long wave periods.

COASTAL PROCESSES

Small beaches exist in "pockets" along the coast, usually fronted by shallow rocky reef or rocky tidal platforms. Figures 4-55 through 4-58 show these contained pocket beaches, which are expected to be relatively stable under typical wave conditions. Seasonal fluctuations within these pocket beaches could be expected for some of the beaches that are susceptible to west-northwesterly winter swell waves which can refract towards shore. Storm wave activity could also cause loss or accretion due to onshore-offshore transport. Subsequent longshore transport of sediment deposited in nearshore regions could result in transference of sand from one pocket beach to another. This situation is postulated to have occurred subsequent to Hurricane Iwa, where some beach areas lost sand while others gained sand.

The major beaches from the Sheraton (Figure 4-59) eastward to Poipu Beach Park (Figure 4-60) are a series of crescent-shaped beaches that are stabilized by headlands, offshore rocky outcrops, and man-made structures. Nukumoi Point is really a natural tombolo[72], where the beach has accreted to the point where it is connected with the offshore rocky outcrop, which functions as a natural breakwater. A smaller offshore rock outcrop serves a similar purpose between the Kiahuna Plantation Resort and Poipu Beach Hotel, although the beach has not accreted seaward as much as at Nukumoi Point. Headlands fronting the Sheraton Resort, Stouffer Waiohai Resort, and the east end of Poipu Beach Park serve as boundaries of the littoral cells. A man-made breakwater helps to further stabilize the beach fronting Poipu Beach Park by augmenting the rocky headland at the eastern boundary of this littoral cell.

[72] Tombolo is a bar or spit that connects or "ties" an offshore feature (breakwater, island, rock outcrop) to the mainland shore. Spits form in the lee of a shoal or offshore feature by waves that are refracted and/or diffracted around the offshore feature. It may eventually be grown into a tombolo linking the feature to the mainland.

FIGURE 4-55 BEACH FRONTING LAWAI BEACH RESORT

FIGURE 4-56 BEACH FRONTING PRINCE KUHIO PARK

FIGURE 4-57 BEACH ALONG BEACH ROAD, WEST OF NAHUMAALO POINT

FIGURE 4-58 BRENNECKE BEACH, EAST OF POIPU BEACH PARK

FIGURE 4-59 BEACH FROM SHERATON RESORT TO POIPU BEACH HOTEL

FIGURE 4-60 BEACH AT EAST END OF POIPU BEACH PARK

The rocky shoreline areas are exposed to swell and storm wave activity, which keeps the rocky tidal platforms and headlands scoured of sediment. Seawalls line much of the rocky shorefront, protecting the backshore from wave runup and scouring. In most cases, the seawalls are situated sufficiently landward above the wash of waves to permit public access along the waters edge. Many of the seawalls were re-built subsequent to being damaged or destroyed by Hurricane Iwa. Along some reaches, rubble piles appear to be remnants of revetments or loose rocks placed to reduce wave runup but without the organized construction of a revetment.

LONG-TERM SHORELINE CHANGES

Historical aerial photos were used to determine the long-term fluctuations of the vegetation line and beach toe line (or waterline), using the technique described in Section 1.4 of this report. The dates of the historical aerial photos used in this analysis are:

March 1960 (earliest available photo)
December 1962
March 1972
October 1976
June 1981 (subsequent to January 1980 Kona storm)
July 1987 (subsequent to Hurricane Iwa in November 1982)
March 1988

Much of the shoreline within this case study reach consists of rocky basalt terraces and headlands. While loss of backshore vegetated fast lands may have occurred due to wave runup, overtopping, and scouring from extreme storm events, the rocky shoreline interface between land and water is stable. Thus, from an erosion management viewpoint, these rocky shorelines are not of significant concern in comparison to the dynamic sandy beach areas. The following analysis focused on the beaches within the study reach to determine the long-term changes in position and beach width. These beaches include:

"Lawai Beach" (fronting Lawai Beach Resort)
"Kuhio Beach" (fronting Prince Kuhio Park)
"Kaheka Beach" (along Beach Road, west of Nahumaalo Point)
"Sheraton Beach" (from Sheraton Resorts to Poipu Beach Hotel)
"Poipu Beach Park" (from Stouffer Waiohai Hotel to breakwater at east end of Poipu Beach Park)
"Brennecke Beach" (small pocket beach east of Poipu Beach Park)

FIGURE 4-61 ROCKY SHORELINE EAST OF KA LAE KIKI POINT
(Typical of rocky basalt terraced shoreline with seawalls protecting oceanfront lots)

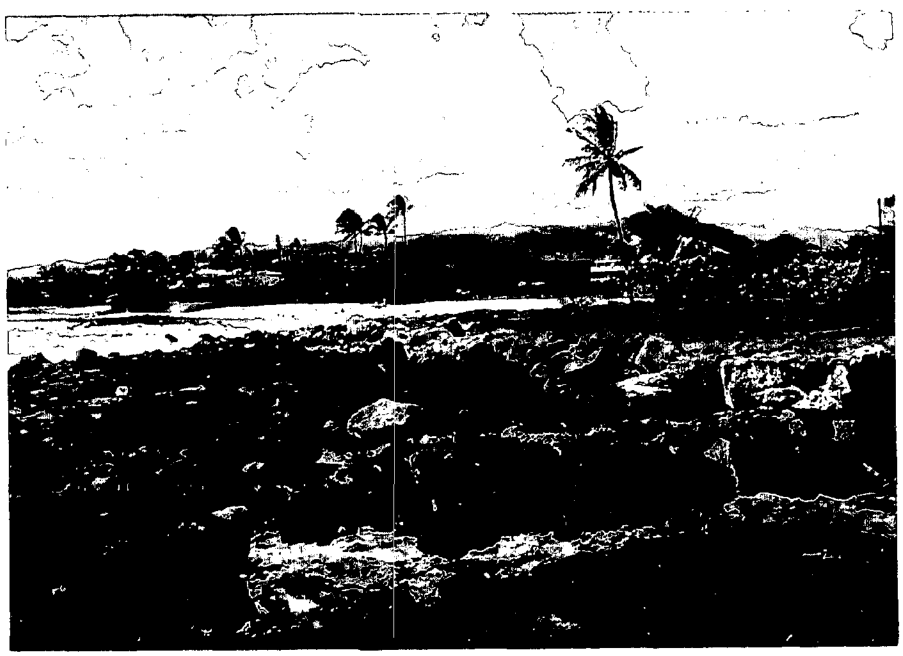

FIGURE 4-62 ROCKY SHORELINE AT NAHUMAALO POINT, EAST OF "KAHEKA" BEACH
(Note rocks placed at edge of vegetation line to reduce wave runup)

Figures 4-63 through 4-68 graphically depict the average erosion (-) or accretion (+) of the vegetation line and beach toe line across the entire beach (sq.ft./ft), relative to the earliest photo. By establishing the earliest photo as the zero baseline, these cumulative plots of shoreline loss or gain are indicative of the horizontal position of the shoreline over time. For the pocket beaches situated adjacent to the road, the landward limit of the beach is fixed by shore protection structures, and only the beach toe line is analyzed. For the two major beaches, both the vegetation line and waterline are analyzed. Overlays of the historic shorelines from the aerial photos are contained in Appendix K for each of the beaches.

All four of the pocket beaches show cyclical loss and gain of the beach. Average horizontal fluctuations of the beach toe are typically less than ±40 feet. For three of the four pocket beaches, the present location of the beach toe line (March 1988 photo) is about the same as the earliest photo (March 1960) within ±10 feet. Kaheka Beach shows a significant net accretion of the beach of +30 feet subsequent to the June 1981 photo, which is anomalous from the other pocket beaches.

The two major beach systems also show a cyclical loss and gain of both the beach toe line and vegetation line. However, the cycles are not as highly fluctuating as the pocket beaches, and the horizontal movements are slightly greater. Sheraton Beach has been continuously receding since early 1970, with a net recession of about 50 feet for the beach toe line from March 1972 to March 1988. Poipu Beach Park beach has been more stable, with the average beach toe location in the 1988 photo within 10 feet of the location in the 1960 photo. Maximum fluctuation of the beach toe line has been greater than 40 feet between the most accreted and most eroded positions. Poipu Beach Park beach is expected to be more stable in the long-term than the Sheraton Beach because of the tombolo.

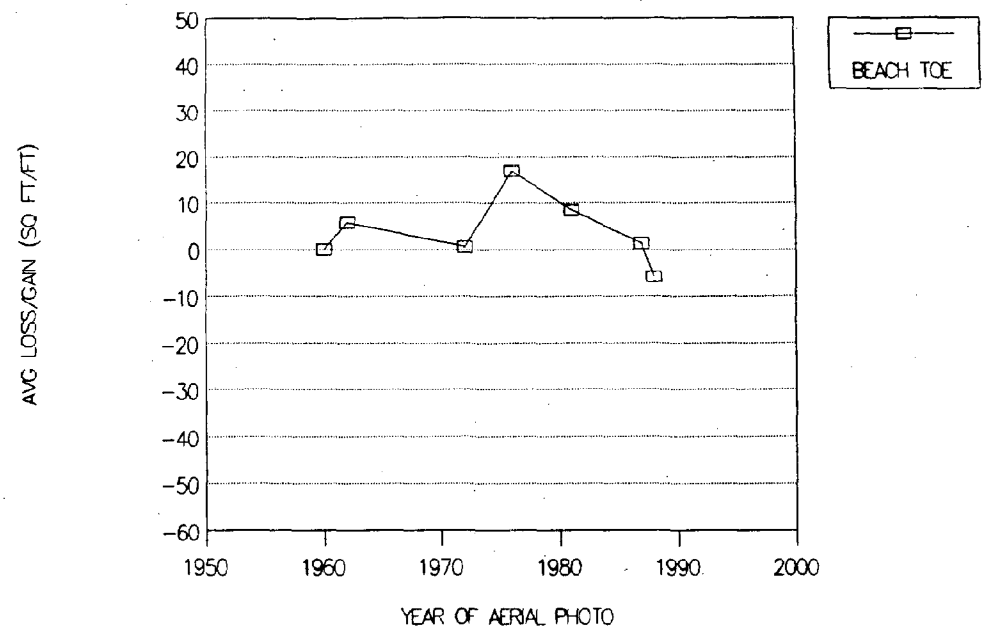

FIGURE 4-63 LAWAI BEACH CUMULATIVE SHORELINE MOVEMENTS (AVG ACROSS ENTIRE BEACH LENGTH)

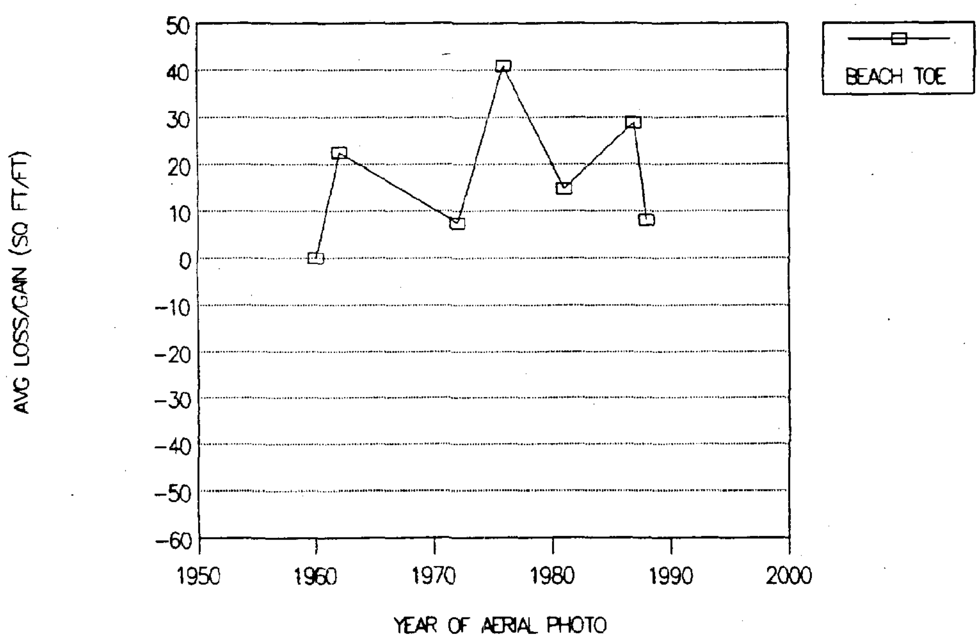

FIGURE 4-64 KUHIO BEACH CUMULATIVE SHORELINE MOVEMENTS (AVG ACROSS ENTIRE BEACH)

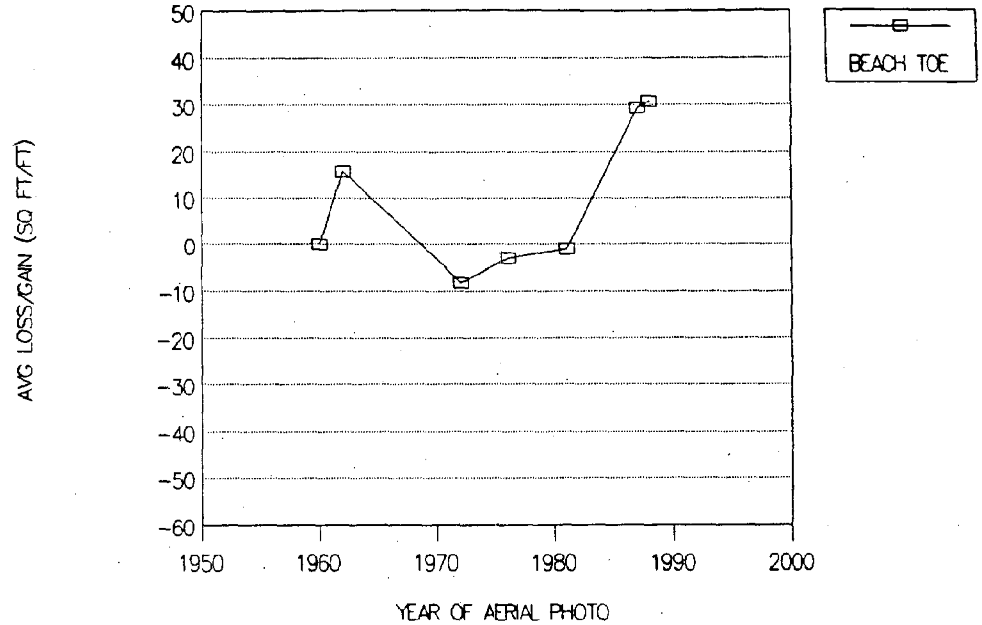

FIGURE 4-65 KAHEKA BEACH CUMULATIVE SHORELINE MOVEMENTS (AVG ACROSS ENTIRE BEACH)

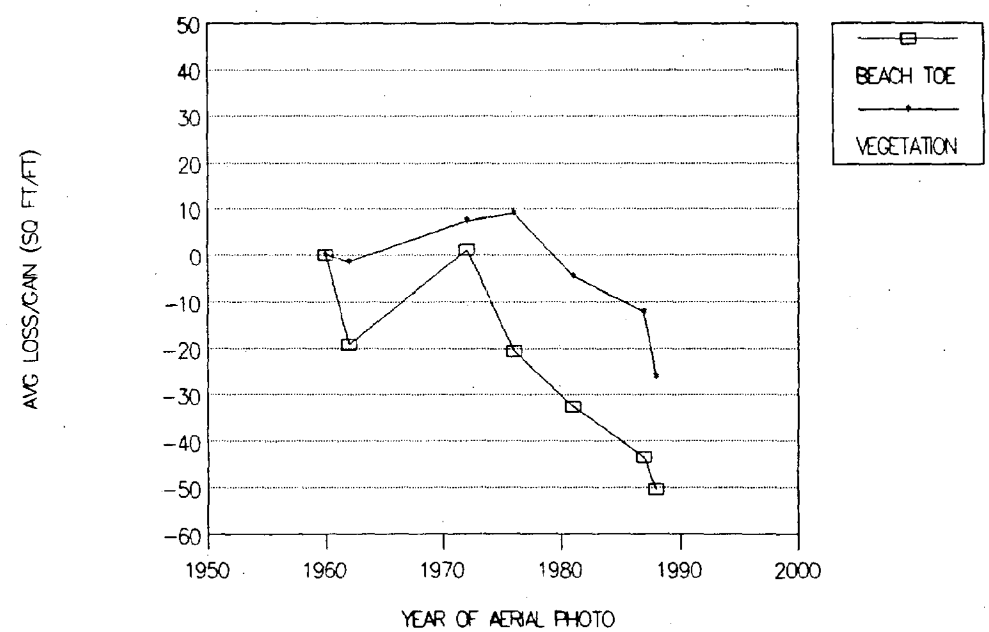

FIGURE 4-66 SHERATON BEACH CUMULATIVE SHORELINE MOVEMENTS (AVG ACROSS ENTIRE BEACH)

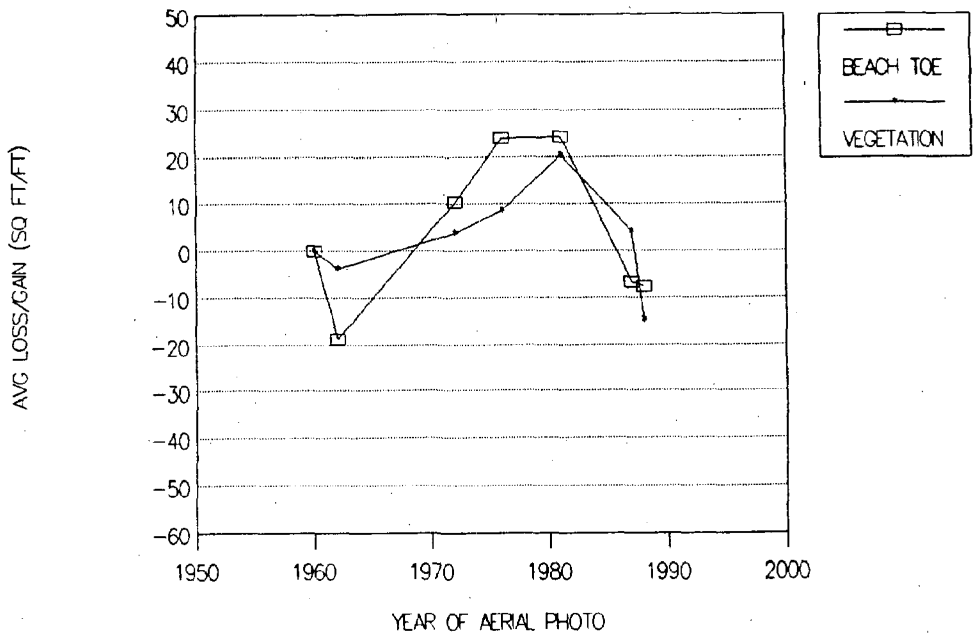

FIGURE 4-67 POIPU BEACH CUMULATIVE SHORELINE MOVEMENTS (AVG ACROSS ENTIRE BEACH)

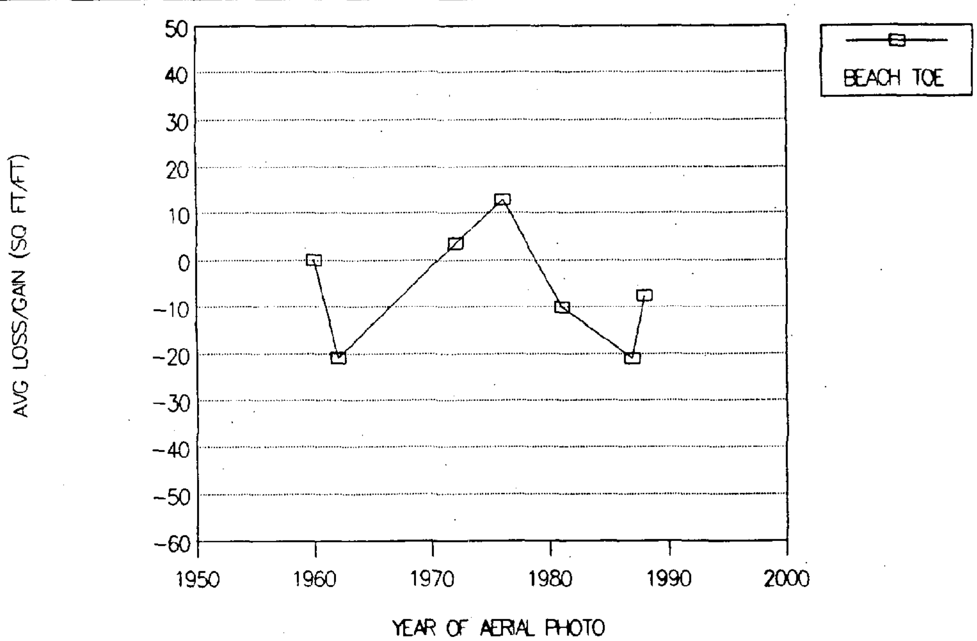

FIGURE 4-68 BRENNECKE BEACH CUMULATIVE SHORELINE MOVEMENTS (AVG ACROSS ENTIRE BEACH)

Figure 4-69 depicts the change in the beach area (sq.ft.) relative to the earliest photo, for all beaches. The beach area is a measure of the total quantity of sediment within the beach littoral cell between the vegetation line and the beach toe line (or waterline). This area divided by the length of the beach would provide a value representing the average beach width per unit length of beach. Because the beaches are not uniformly configured, such as the tombolo formation at Poipu Beach Park beach, the total area of the beach systems are examined herein to determine the quantity of sediment gained or lost within the beach systems over the long term. When there is substantial loss of sediment from the beach over the long-term, then this would indicate that there is a net deficit of sand within the beach littoral cell and a resulting narrowing of the beach width.

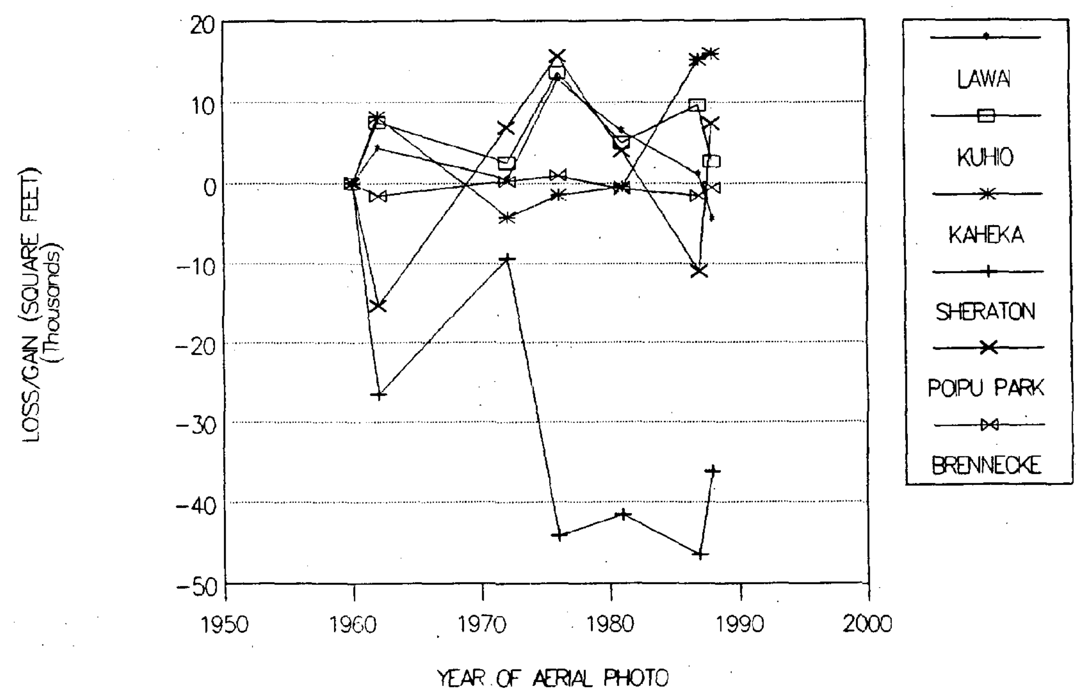

FIGURE 4-69 CUMULATIVE CHANGES IN BEACH WIDTH (ACROSS ENTIRE BEACH)

Lawai and Kuhio Beaches show quite similar gains and losses of sediment. Between 1976 and 1988, Lawai Beach lost about 17,000 square feet of beach area and Kuhio Beach lost about 11,000 square feet. On the other hand, Kaheka Beach gained about 17,000 square feet of beach area during the same time period. This implies that these three pocket beaches are part of the same overall littoral cell, although the pocket beaches are physically discontinuous. Net offshore transport from both Lawai and

Kuhio beaches may have ended up at Kaheka beach due to net longshore transport eastward over the shallow nearshore "reef" areas. Severe Kona storms in January 1980 in addition to Hurricane Iwa in November 1982 may have caused this net eastward transport of sediment from the Lawai and Kuhio beaches to Kaheka beach. The prominent headland at Nahumaalo Point serves as the east boundary of this littoral cell, while Ka Lae Kiki Point may serve as the west boundary of the cell.

Sheraton and Poipu Beach Park Beaches show somewhat similar trends in loss and gain of beach area, except for the period between 1972 and 1987. Between the March 1972 and October 1976 photos, the Sheraton Beach lost over 30,000 square feet of beach area. The Poipu Beach Park beach gained some area during this same time period, but only about 9,000 square feet. This implies that these two major beaches are separate littoral cells. Between the October 1976 and July 1987 photos, Poipu Beach Park beach lost over 26,000 square feet of beach area, while the Sheraton beach remained relatively stable. This could be due to artificial restoration efforts for Sheraton Beach subsequent to the January 1980 Kona storm and Hurricane Iwa in November 1982. More than likely, however, the reason for this apparent "stability" of the Sheraton beach is the fact that the vegetation line has been receding at about the same rate as the beach toe line during this time period, resulting in a relatively constant beach area. While the losses and gains within these two beach systems seem not to be highly correlated, the proximity of the two beach systems to each other would logically indicate that these beaches are sub-cells within a larger littoral cell. Sand storage in offshore sand channels may be the reason for the lack of correlation between the two beaches.

Based on the analysis of historical photos, the following long-term trends are estimated for the two major beaches:

Sheraton Beach: Because Sheraton Beach has been continuously receding since the early 1970's, an average rate of erosion can be used to estimate the future long-term erosion trend:

Avg rate of erosion of vegetation line from October 1976 to March 1988
= 35 feet/11.5 years = 3 feet/year
Avg rate of erosion of beach toe line from March 1972 to March 1988
= 50 feet/16 years = 3 feet/year
Net rate of sediment loss from beach area between March 1960-1988
= 37,000 square feet/28 years = 1300 square feet/year
= 1 foot/year (avg for entire 1480 linear feet of beach)
USE: <u>3 feet/year average long-term rate</u>

Poipu Beach Park beach: Because Poipu Beach Park beach has shown a cyclic accretion/erosion trend from the early 1960's to the present, the maximum shoreline fluctuation should be used to estimate the future long-term trend:

Max cycle of vegetation line accretion/erosion
= +20 feet to -15 feet = 35 feet
Max cycle of beach toe line accretion/erosion
= -19 feet to +24 feet = 43 feet
Max cycle of sediment gain/loss from beach area
= -15,000 to +15,000 square feet = 30,000 square feet
= 30 feet (avg for entire 1000 linear feet of beach)
USE: Max 40 feet for 30-year period

APPROPRIATE SHORE PROTECTION MEASURES

Seawalls and revetments are appropriate for most of the shoreline reach except for the two major beach systems. The hard basalt platforms provide a good foundation for the structures, and the seawalls can be built in the dry at elevations above the high water line.

Within the major beach systems, buried revetments are appropriate and have been constructed subsequent to Hurricane Iwa to restore portions of the shoreline and to serve as a last line of defense during future extreme storm wave events and erosion cycles. Naupaka hedges planted at the crest of the revetment hides the shore protection structure from view. For most of the Sheraton Beach, no shore protection structures have been built, although naupaka hedges have been planted at the backshore edge of the beach to minimize storm wave runup and scouring of backshore areas. The hedges help to stabilize the shoreline, but are only considered a temporary measure to prevent erosion loss. Continued net long-term loss of sediment from the Sheraton Beach system may require beach nourishment to maintain the beach area if the vegetation line is hardened with buried revetments. Offshore submerged reefs or low profile offshore breakwaters would serve to stabilize the Sheraton Beach, similar to how Nukumoi Point serves to stabilize the Poipu Beach Park beach. The offshore structures would be more costly than the shoreline buried revetments, but have the advantage of stabilizing the beach area as well as minimizing recession of the vegetation line.

Groins are not functionally suitable for the beach areas since they may aggravate the offshore transport of sediments from the beach during high surf conditions.

EROSION MANAGEMENT RECOMMENDATIONS

The Kauai case study area is very different physically than those presented for Oahu. Within the study area there are 4 pocket beaches and 2 major beaches with rocky shoreline connecting the beaches. The overall recommendation for this case study area is the implementation of the Shore District as specified in the Kauai zoning ordinance. This district was established to protect shoreline areas but the implementation of rules and regulations is needed and areas designated.

Recommendations for this study area include the following:

- For the rocky shoreline areas, the present 40-foot setback is adequate and should be retained.
- A 180-foot shoreline setback should be established for the Sheraton Beach area (3 feet/year average erosion rate x 30 years x 2). Based on the analysis of historical shoreline changes described herein, an estimate of shoreline recession over the next 30 years is 90 feet. Because of the high density zoned use, the time horizon for the shoreline setback is recommended to be twice that for low density use, or 60 years. (This is equivalent to using twice the average erosion rate for a 30-year time horizon.) Offshore structures are recommended to stabilize the beach. More direct shore protection, if necessary, should be limited to buried revetments.
- The Poipu Beach Park area should have an established 80-foot shoreline setback (2 x maximum erosion/accretion cycle) and the Open District zoning should be maintained. Based on the analysis of historical shoreline changes described herein, an estimate of the maximum range of shoreline recession over a thirty year period is 40 feet. Because of the need to preserve the open space natural setting of the park, the shoreline setback is recommended to be twice the maximum erosion limit. The Shore District should be assigned to this area.

5.0 RECOMMENDATIONS TO IMPROVE EROSION MANAGEMENT IN HAWAII

This chapter contains general recommendations for improving the management of shoreline erosion in Hawaii. Over the years, the regulatory environment in Hawaii has become increasingly complicated. Planning and development in shoreline areas has become time-consuming, expensive, and subject to review by numerous agencies, elective bodies, commissions, and boards. As a result, even modest additions to the regulatory regime are likely to be viewed with some skepticism. The management approach taken begins with the recognition that the shoreline is a very precious resource in Hawaii. Both natural actions, such as erosion, and human actions, such as the construction of revetments or seawalls, can affect the value of this resource. The premise of this study is that through improved planning and coordination, management of erosion can be made more efficient and equitable.

Chapter 3 contains a description of the regulatory regime for erosion control and management in Hawaii and has pointed out some of the shortcomings of the system with respect to erosion management. In this section some recommendations for building upon the existing system and improving its inner-workings so as to improve erosion management are presented. Regulatory controls are presented as a tool which can be used in conjunction with structural remedies (seawalls, revetments, groins, etc.) which were discussed in Chapter 2. The recommendations for changing the management system are based on the following general principles:

- erosion management should be based on careful study, analysis, and consideration of alternatives and impacts of policy changes on the physical environment;
- new regulations should be designed as part of the existing regulatory system;
- regulations should be easy to administer and enforceable; and
- erosion management should promote greater coordination between various government agencies and property owners.

In order to make a significant improvement in the system for managing erosion management in Hawaii, some very hard decisions need to be made regarding the level and nature of involvement of not just the various federal, state, and local agencies, but also private property owners and the public-at-large. There are, however, numerous constraints affecting the viability of any proposal to change the existing system. These are discussed in the following section.

5.1 CONSTRAINTS AFFECTING THE IMPROVEMENT OF EROSION MANAGEMENT IN HAWAII

One of the basic problems that exists in terms of regulating or changing shoreline development in Hawaii is that already much of the coastline has been developed or plans to develop coastal areas are well underway. The presence of existing structures, older structures under renovation, and new structures under construction greatly complicates efforts to alter the regulatory system.

Because the shoreline is an extremely precious resource in Hawaii, there is tremendous pressure to develop beachfront areas and competition between those who would use it for residential, resort, and open space purposes. Efforts to extend the existing forty (or twenty) foot limit may meet resistance because doing so may result in the reduction of an already scarce resource in high demand.

While it may be one thing to impose development restrictions on raw, undeveloped land, to promulgate new rules and regulations for built-up areas may create conflicts between citizens and their government. There may be legal challenges resulting from actions which could be interpreted as government "taking property without just compensation." This concern is especially relevant when either re-drawing setback lines, establishing new districts, or redesignating lands for conservation purposes. Certainly more study of the legal aspects of various proposed measures is justifiable.

Another aspect of erosion management in Hawaii is that while the number of government units is relatively small compared to many other states, there are nonetheless numerous federal, state, and local agencies which have jurisdiction over shoreline management areas. At times, the many different permits, levels of approval, and types of authorizations are confusing to the public. Without the full cooperation of all governmental units, the adoption of structural and non-structural remedies will not be easily accomplished. There is reason to believe that the coordination between various permitting and review agencies with jurisdiction over shoreline areas in Hawaii needs to be improved.

A major constraint to the formulation and implementation of sound erosion management policies results from the very nature of erosion itself. As an act of nature, erosion may be very difficult to predict and subject to numerous uncontrollable factors.

A related problem is the shortage of coastal engineers and other specialists knowledgeable about coastal processes and erosion within the regulatory agencies themselves. While consultants can assist government by performing various studies and tasks on a project by project basis, the technical capacity of government itself to undertake erosion studies and design appropriate plans and policies needs to be increased. This problem of recruitment and retention of trained specialists in government is not unique to the coastal management area.

Another constraint affecting erosion management is the public's general apathy towards the problem itself. Only when erosion threatens to destroy valuable property is it perceived as a problem. Even then, affected property owners may become particularly concerned over their lands and property, but the general public is generally unaware or uninterested, at least until the expenditure of public funds is proposed. Hence, erosion is the type of problem which is easy to neglect and difficult to plan for.

There is also the problem with erosion that many individual property owners may be more inclined to adopt structural remedies such as the construction of revetments or seawalls rather than non-structural remedies which would curtail or limit the use of their properties. When one property owner constructs an illegal seawall, those abutting property owners may be inclined to follow suit, either to minimize the damage resulting from the neighboring seawall or because there may be a prevailing attitude that regulations are not enforced. Especially in those areas where numerous illegal structures have already been built it may be difficult to change attitudes and practices.

Illegal seawalls create special problems from a regulatory and management perspective. Considerable effort must be expended in order to identify and inventory existing shore protection and to research the permit history to determine whether or not a given structure is "illegal." County, State, and Federal records need to be searched because it may be difficult to presently ascertain the jurisdictional responsibilities at the time the structure was built. Once a structure is determined to have been built without the required permit(s), then enforcement of the existing regulatory requirements are necessary. Reviewing after-the-fact permit applications presents numerous problems, especially if there is no overall erosion management plan for the area. For example, if erosion has progressed to the stage where removal of the illegal shore protection structure will result in imminent erosion damage to a residential dwelling, then several different questions could arise. Should, for example, the homeowner be forced to remove the illegal structure and relocate the dwelling? Should government share the costs for relocation, and more importantly, can government afford such a subsidy program for relocation? Alternatively, should government undertake or subsidize the cost of constructing more suitable beach nourishment and beach stabilization measures to restore the beach area such that the illegal structures can be removed without homeowners facing imminent loss of their homes to erosion damage?

The point to emphasize is that if overall erosion management plans had been adopted for specific areas, then many of these policy issues would have already been addressed and clear direction regarding the disposition of existing illegal structures would have been established. After-the-fact permit applications would be reviewed within the context of the priorities and goals established by overall erosion management plans. While it may be necessary to adopt some sort of after-the-fact permit review process for illegal structures, this process will likely function more effectively once erosion management plans have been developed.

Finally, there are obvious information gaps about the methodologies for the measurement and prediction of erosion and the extent of erosion in Hawaii. While this report has suggested appropriate techniques and methods for collecting and analyzing data, certainly more effort should go into the creation of a usable and reliable database which can be periodically updated. The lack of readily available and usable information is one of the most significant constraints to improved coastal erosion management in the state.

5.2 GENERAL RECOMMENDATIONS TO IMPROVE EROSION MANAGEMENT IN HAWAII

In previous sections, this study has discussed the nature of the erosion problem and alternative responses--both structural and non-structural. The review of other states (Florida and North Carolina) which have more advanced erosion management systems, as well as efforts currently underway in Hawaii suggest that there is room for improvement.

As indicated in the previous section, some of the constraints affecting the management of erosion in Hawaii result from the nature of the problem itself. On the other hand, some of the problems relate to the organizations, agencies, and to the system for managing erosion in the state.

One of the most basic problems stems from the fact that in Hawaii, there is no overall system for coastal erosion management per se. While several different agencies and levels of government have jurisdiction over shoreline areas under Chapter 205A Coastal Zone Management, there is no formal agency nor authority explicitly charged with the responsibility of erosion management. Several other states, such as Florida, have recognized the importance of beach and coastal resources and have developed more extensive beach and erosion management systems. In Hawaii, an ad hoc, de facto system for handling erosion exists. The system is dependent upon the interpretation of rules and procedures spread throughout building codes, land use ordinances, administrative rules and regulations, and state law.

One of the hardest decisions which needs to be made involves the allocation of responsibilities between the state and the county governments. An immediate problem that arises is that the four counties in Hawaii are different, making it difficult to treat them all equally. Not only are there differences in terms of the extent and nature of the erosion problems, but there are also substantial differences between each county in terms of resources, commitment to shoreline management, and capacity to plan for and manage its erosion problems. Another point to remember is that technically all counties in the state are subordinate to the state government. Legally speaking, local governments are creations of the state and hence all powers and authorities are ultimately derived from state law. Although some specific recommendations are directed towards individual state and local government agencies, it may be useful to encourage a more holistic view of the state-local government sector. This report recommends that the State works together with the Counties in establishing overall guidelines and procedures for managing erosion. It also recommends increasing the staff resources in the Counties to monitor and enforce regulations related to coastal erosion.

Recommendations for improving the erosion management system in Hawaii include the following:

(1) The State CZM office should play a preliminary role in the development of a statewide approach for identifying critical erosion-prone areas throughout the state and should continue to seek funds from the Federal government to enhance study, planning, and design of appropriate shoreline erosion countermeasures in Hawaii. The CZM office should provide general direction, technical assistance, overall coordination between government agencies, and support of local planning and management efforts.

(2) The State CZM Office should take the lead role in coordination with each county, in the development of an on-going system for monitoring beach erosion that includes routine data collection and analysis including aerial photography, computer mapping, and erosion rate projections.

There is need for more advanced study of coastal processes in the state. Advanced study includes, for example, the development of appropriate and cost-effective methodologies for measuring and monitoring beach erosion in the state. This study has pointed out some of the short-comings of transect analysis and has suggested an alternative, case-study based approach which provides more detailed and reliable data on which to base erosion control and management polices. Data that are needed to effectively design erosion control programs include determination of littoral cells, rates and patterns of erosion and accretion within these cells, sand budgets, determination of long-term shoreline changes, wave climates, and other factors relevant to understanding the erosion processes.

Greater effort should be placed into the identification of littoral cells and using these as geographically bounded areas for appropriate management plans. Evidence from the case studies as well as other studies of erosion problems in Hawaii suggest that it may be most productive to design policies and countermeasures for erosion according to littoral cells rather than beaches and long shorelines.

(3) The Counties should take the lead role in terms of monitoring and enforcing erosion management regulations. If the state is to establish a serious erosion management program, then agreed upon policies need to be backed with additional financial and human resources, particularly at the local level, in order to establish a credible program for monitoring beach erosion and enforcing

erosion control regulations. The State should consider new ways of channeling more funds towards local government agencies to assist in the improvement of their monitoring and enforcement capabilities.

(4) Based on a program of data collection and analysis, littoral cells should be classified into stable and unstable areas, and appropriate shoreline setbacks should be determined considering erosion processes and designated land uses. Stable areas are shorelines which are non-eroding (rocky) or historically have displayed little tendency for erosion. Unstable areas are shorelines which historically have displayed progressive, cyclical, or fluctuating erosion tendencies. Priorities utilizing both environmental criteria (e.g., rates of erosion, severity of erosion, etc.) and economic criteria (e.g., extent of development, cost of land, existence of site improvements, etc.) could be developed to further guide public policies.

(5) Long-term erosion management plans (EMPs) should be developed for critical, unstable, erosion-prone areas which involve a combination of non-structural and structural remedies.

(A) Non-structural remedies include:
- possible redesignation as conservation district;
- alteration of the 40 foot (in some cases 20 foot) shoreline setback;
- creation of overlay districts; and
- improvement of permitting requirements for erosion control structures.

(B) Structural remedies include:
- revetments;
- bulkheads/seawalls;
- buried shoreline structures;
- offshore breakwaters;
- offshore reefs;
- groins; and
- beach fill and other replenishment techniques.

Site-specific management plans should be developed for critical, unstable, erosion-prone areas rather than general, all-purpose plans which do not distinguish between different shoreline areas. One of the more extreme non-structural remedies involves removing lands which are in urban, rural, or agricultural districts and reclassifying them into conservation districts on the basis that erosion in these areas is so severe that they belong in conservation.

It may be necessary in some instances to consider the establishment of new conservation district subzones, called "Shoreline Erosion Subzones" which prohibit any use whatsoever.

A less extreme approach involves the alteration of the 40 foot shoreline setback, as was recommended in several of the case study sites. While county governments have the authority to increase shoreline setbacks, more detailed study of approaches to setting shoreline setbacks on the basis of erosion rates is needed. Another possibility involves the creation of either special overlay districts for erosion prone areas or, perhaps, extending flood districts to include high erosion districts. Perhaps standards similar to FEMA's 100 year flood definition could be applied. These non-structural approaches should be utilized with structural remedies. At present, location specific erosion rate data are unavailable or limited, making it difficult to recommend one approach over another.

(6) Erosion management plans for littoral cells should include policies and programs for alternative management and financing of physical structures which could include the creation of improvement districts, impact fees, and other cost-recovery techniques for financing improvements which benefit private property owners. Often erosion problems occur in built-up areas. Individual property owners may act in isolation having to bear the full costs of erosion control. Management plans should include strategies for financing and sharing the costs of improvements among all beneficiaries.

(7) More concerted effort should go towards streamlining the permit process and clarifying erosion related policy objectives in federal, state, and local permits. To improve interagency coordination between various levels of government with jurisdiction over erosion control, a reminder clause or check box should be included in each agency's application form, so that not only the applicants but also the processing staff can be reminded that other agencies must be notified. At the same time, an ad hoc staff-level committee should be convened on a regular schedule by either the County or State to review applications for shore protection and use of beach lands. The committee should discuss current applications, share information, and attempt to arrive at a consensus approach when both State and County jurisdictions are affected. These meetings would elicit any basic policy differences which could then be resolved at Director/Chairman/Board level. Membership could include County Planning agencies, DLNR, CZM, OCEA, OSP, COE, and other agencies such as DAGS' Land Survey Division, and the County Parks and Recreation Department.

(8) Government agencies charged with regulatory and management responsibilities should develop in-house expertise and knowledge regarding coastal processes and coastal engineering principles. The establishment and maintenance of a coastal erosion database requires expertise to determine the applicability of existing information, the data gaps, and the most cost-efficient data collection and analysis approach based on available funding. Analysis of the data can be contracted to outside experts. However, for the agencies to fully understand, interpret, and accomplish appropriate judgmental review of the results and recommendations of the analysis requires coastal engineering expertise. A credible regulatory and management program also requires a sound scientific and engineering basis. For example, Florida's regulatory responsibilities are conducted by the Bureau of Coastal Engineering and Regulation. Coastal engineering staff review permit applications and make recommendations with supporting evidence of either approval or denial. In-house expertise and knowledge can be developed by increased staffing with individuals having the requisite experience and by training of existing personnel. Training can include seminars and workshops conducted by academic or private professionals, or possibly by other governmental agencies having in-house expertise. The University of Hawaii not only has a graduate level program in ocean engineering but also offers an introductory undergraduate level course in coastal engineering, which would require a moderate commitment of time and effort but could provide a good background for technical staff. The newly-formed School of Ocean and Earth Science and Technology at the UH can be a good resource for information and training.

5.3 PROPOSED SYSTEM TO IMPROVE EROSION MANAGEMENT IN HAWAII

The proposed management system is intended to provide a basis for building a more comprehensive and rational system for planning and implementing erosion countermeasures. As mentioned earlier, the regulatory regime in Hawaii is already crowded without the addition of erosion management policies. Yet the problems of erosion have become serious enough to warrant government action, both to protect citizens from potential loss and to encourage more orderly, sensible, and controlled development along the shoreline.

Figure 5-1, "Proposed System for Improving Erosion Management" contains a number of suggested actions to be taken in order to strengthen the planning for, and management of, erosion problems in Hawaii. There are three proposed phases: study, planning, and implementation. It is recommended that the State CZM office initiate the study phase, but that the planning and implementation phases be carried out by the Counties, with strong input and support from relevant state and federal agencies.

<u>1st PHASE: STUDY</u>

During the study phase, the following major objectives should be accomplished:

- o Identification of an appropriate methodology and data collection strategy to be put in place for the long-term study, monitoring, and prediction of coastal erosion in Hawaii;
- o Classification of all coastal areas in the state into either stable areas where no immediate action is needed, or, unstable areas prone to erosion, where critical action is needed;
- o For those unstable, critical, erosion prone-prone areas, the boundaries of the littoral cells should be delineated so that the development of effective, site-specific erosion management plans can be initiated;
- o Relevant agencies, elective bodies, and the general public should be notified and presented with study results for review and commentary.

<u>2nd PHASE: PLANNING</u>

It is recommended that erosion management plans (EMPs) be developed for specific littoral cells rather than adopting general plans which do not take into consideration

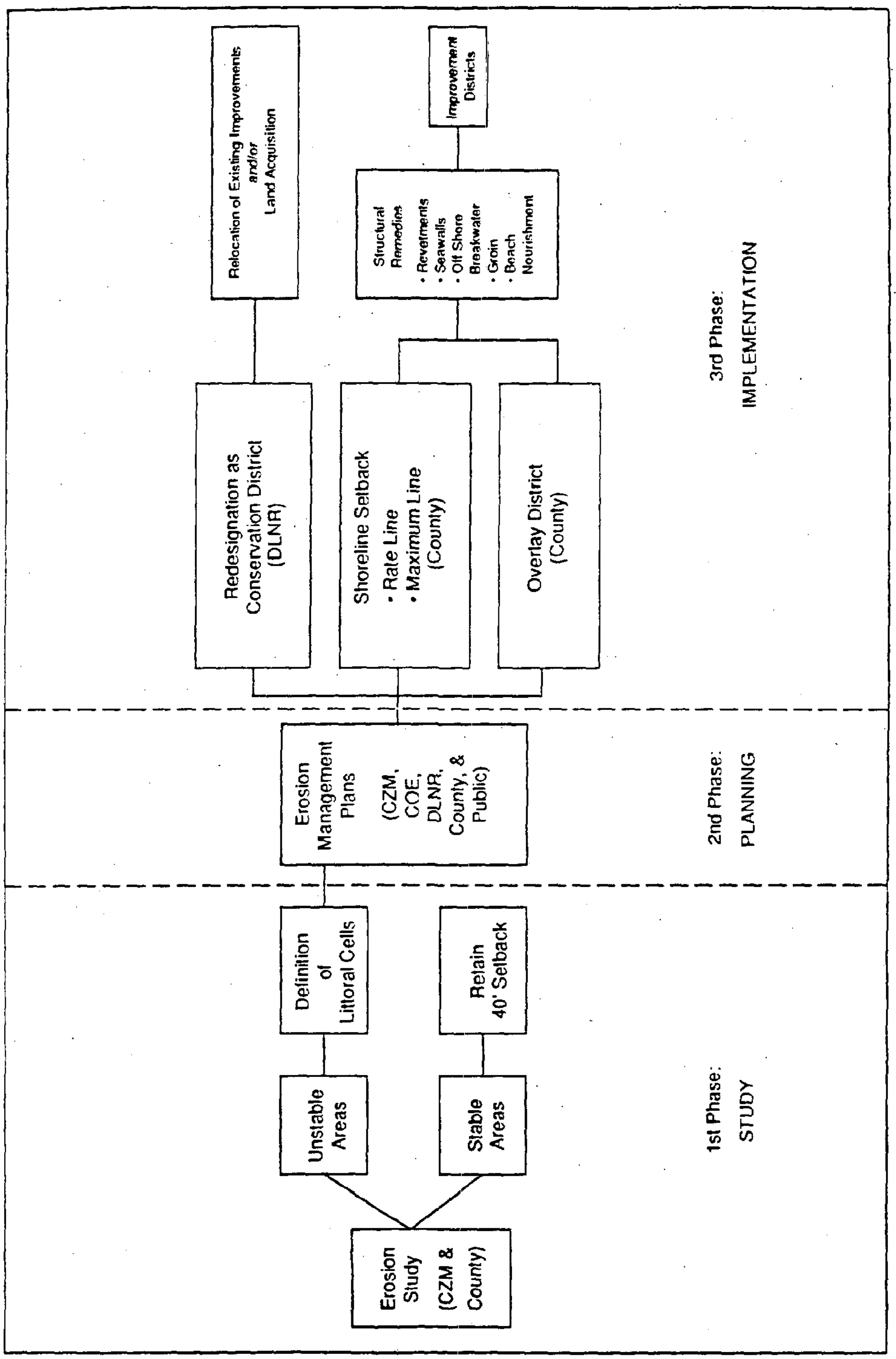

FIGURE 5-1 PROPOSED SYSTEM FOR IMPROVING EROSION MANAGEMENT IN HAWAII

specific geologic and physical conditions. As demonstrated in the three case study sites, the geological processes and nature of coastal erosion problems can vary greatly not only across the state, but also along a single coastline. It is also recommended that depending on the location of the erosion problem and the nature of the remedy, different federal, state, and local government authorities as well as private property owners may be involved in varying degrees. The purpose of the planning phase is to define the appropriate roles for government and the private sector and ensure maximum coordination between the various parties concerned with coastal erosion.

It is expected that EMPs may differ substantially between one area and the next. The selection of the most appropriate shoreline stabilization or protection measure for a given site is a function of geologic features, wave climates, erosion processes, land use, and existing development, as well as the economic benefits and costs associated with the various erosion countermeasures. This report has provided some basic guidelines to decision-making (Chapter 2) and has suggested an approach for evaluating and determining the most appropriate erosion control remedies (case studies in Chapter 4).

It is recommended that the EMPs contain the following elements:

(1) Detailed maps showing boundaries of littoral cells, shoreline erosion, property lines, shoreline setbacks, overlay districts land use designations, structures and shoreline protection/stabilization measures;

(2) Descriptions of agency jurisdictional boundaries and responsibilities;

(3) Detailed information regarding rates of erosion, areas subject to erosion damage, historical erosion data, and predicted levels of erosion;

(4) Predicted erosion limits and redefinition of setbacks based on 30-year time horizon for residential property and a 60 year time horizon for resort and commercial properties;

(5) Alternatives involving some combination of structural (revetments, seawalls, groins, etc.) and non-structural (setbacks, overlay districts, performance standards, and other recommendations);

(6) Definition of priorities and policies with respect to competing uses and desires;

(7) Evaluation of the various benefits and costs associated with each alternative and

recommended actions based on maximizing benefits and minimizing costs within the context of the priorities and policies;

(8) Allocation of responsibilities (administrative, financial, etc.) between federal, state, and local agencies , as well as private property owners for the implementation of the recommended actions; and

(9) Very strong public involvement in not just the review of plans, but also the selection of alternatives and design concepts.

3rd PHASE: IMPLEMENTATION

The implementation phase is the most critical because it is where the recommended actions in the EMPs will be carried out. Without the actual implementation of policies, the planning and study costs cannot be fully justified. It is also important to note, that while a number of the more likely alternatives are discussed in this report, it is expected that other alternatives may arise in the course of further study and planning. Implementation, therefore, could involve one or more of the following:

- o redesignation of areas as conservation district;
- o designation of a new shoreline setback;
- o creation of an erosion control district;
- o structural remedies; and
- o creation of an improvement district.

o Redesignation of lands as Conservation Lands

Putting land into conservation districts serves a number of purposes. First, it reduces development pressures, since only limited types of development are allowed. Second, putting erosion prone areas into conservation areas is a rational action, given the function of conservation districts which includes the provision of parklands, wilderness, and beach areas. While redesignation of urban lands into conservation lands may appear to some as an extreme action, the reality is that once severe erosion occurs, the area seaward of the new shoreline becomes conservation land, under state jurisdiction.

In reality, re-designation of lands into Conservation Districts may not be enough to restrict development even for erosion hazard areas, since there are allowable uses on conservation lands. There may need to be an altogether new subzone created, called "Shoreline Erosion Subzone" in which even more stringent restrictions regarding development apply. At the same time, relocation of existing improvements and/or land acquisition by government may be necessary.

- <u>New Shoreline Setback</u>
  For many areas in the state, the forty foot shoreline setback (20 feet in some cases) may be adequate. For areas with rocky shorelines or where erosion rates are extremely slow, then the existing shoreline setbacks and shoreline setback variance procedures may be adequate. In areas of rapid erosion, the shoreline setback of forty feet may be inadequate. Two approaches for the determination of a new shoreline setback in high erosion areas are proposed: (1) rate line; and (2) maximum line. The rate line is a setback proposed for those areas of high erosion, where erosion has been progressive and relatively consistent. From the long-term history of erosion, average annual erosion rates can be estimated and used in conjunction with the time horizons to establish new setbacks. In areas where erosion fluctuates, it is proposed that a maximum setback line be drawn, similar to how the Federal Emergency Management Agency flood boundaries are delineated. This maximum line would be estimated from the historical, long-term maximum erosion-accretion cycle. It is also recommended that separate shoreline setback variance procedures be developed for those areas where new shoreline setbacks are established.

- <u>Erosion Control Districts</u>
  For large areas where erosion is a persistent problem affecting numerous property owners, the creation of a special overlay district, called an erosion control district may be appropriate. In these areas, specific standards regarding the construction of shoreline erosion control and stabilization structures in erosion prone areas may need special building and design requirements separate from other areas.

- <u>Structural Remedies</u>
  This report has described a variety of applicable structural remedies. It is recommended that structural remedies be implemented only after completion of an erosion management plan. Detailed analysis of erosion processes as well as the effects of any structural countermeasure should be completed by professional coastal engineers before implementation. It is further recommended that all new shoreline protection structures and renovations of existing structures be built with accompanying plans and diagrams. Moreover, all completed work should be inspected to ensure that proper construction practices were followed and the structure does not create any unintended or undesirable effects.

At present, when erosion occurs, most property owners are inclined to automatically consider structural remedies before any other alternative. By encouraging owners and others affected by erosion to become involved early on in a planning process, it is hoped that a broader range of alternatives can be considered. As pointed out earlier, property owners acting in isolation (e.g. building their own seawalls) may end up imposing unintended costs on to their neighbors. Moreover, there may be some economies of scale and other efficiencies which result from joint problem solving and collective action. In addition, many of the other important issues, such as public access, beach preservation, and shoreline management can also be addressed in the context of this planning process.

- Improvement Districts
  One possible alternative called for by the Erosion Management Plans could be the creation of improvement districts. This concept is useful in those areas where the scale of desired improvement is great and an equitable, efficient mechanism for allocating costs of building erosion control structures among different property owners is desired. While the creation of an improvement district may require a great deal of consensus among diverse elective and appointive bodies, it remains as one of the only financing tools available to communities in need of large, expensive improvements such as off-shore control structures or beach nourishment and replenishment projects. The advantage of this approach is that those property owners who benefit most by a particular improvement could be assessed a charge proportional to the benefit they receive. Certainly more investigation into the apportionment of costs for given improvements needs to be carried out, but given resource constraints and competition for limited public resources, improvement districts may be the only feasible means of financing certain large-scale improvements.

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EXHIBIT A

SHORELINE BASE MAP

FOR CASE STUDY SITE #1 - MAKAHA, OAHU

EXHIBIT B

SHORELINE BASE MAP

FOR CASE STUDY SITE #2 - KAILUA-LANIKAI, OAHU

EXHIBIT C

SHORELINE BASE MAP

FOR CASE STUDY SITE #3 - KUKUIULA-POIPU, KAUAI