KAUAI

HAWAII REGIONAL SEDIMENT MANAGEMENT KEKAHA AND POIPU REGIONS FINAL REPORT

GEOMORPHOLOGY, COASTAL PROCESSES, SHORELINE CHANGE & POTENTIAL RSM PROJECTS

Prepared for

US Army Corps of Engineers

U.S. Army Corps of Engineers
Honolulu District,
and
State of Hawaii
Department of Land and Natural Resources
Office of Conservation and Coastal Lands

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EXECUTIVE SUMMARY

Regional Sediment Management (RSM) is a systems-based approach with the goal of better managing sediment across multiple projects, both Federal and non-Federal, through improved interagency cooperation, science, and engineering practices.

This RSM Plan for the Kekaha and Poipu regions of Kauai has been produced as a part of the Hawaii Regional Sediment Management Study. The document compiles available information for the study region, including studies produced directly in support of the Hawaii RSM Plan. This information is to be used in the future as a basis for identifying potential RSM projects which could reduce Federal project costs in the region while improving environmental outcomes and increasing the public benefit. The potential benefits associated with the implementation of RSM efforts in these regions are many fold.

Quantification of sediment resources and pathways in the regions will provide engineering design guidance necessary to restore vital beach resources and conduct Federal maintenance dredging in the most cost effective way. Investigation of RSM opportunities in these regions will further our understanding of the dynamics of the complex coastal processes at work and promote the development of long-term systems based strategies for sediment management.

This document includes the following information for each of the Kauai RSM regions: a) objectives of the overall RSM program; b) descriptions of the existing Federal projects; c) geomorphologic processes such as beach sediment production; d) coastal processes including wave climate and sea level rise; e) coastal ecosystems; f) characterization of the region's shorelines including shoreline erosion maps, identification of shoreline structures, chronologies of historical events affecting the shorelines, beach profiles, and beach volume change rates (final regional sediment budgets for the Kekaha and Poipu RSM regions have yet to be developed); g) identification of potential sand sources for beach nourishment; h) identification of potential future RSM projects; and i) a bibliography summarizing each of the references sources used in this document.

This plan makes the following conclusions regarding potential RSM projects in the Kekaha and Poipu RSM regions of Kauai.

Kekaha Region

- In the Kekaha region, the long lengths of sandy beaches result in high volumetric rates within each littoral cell, (in comparison to the rates calculated for the Oahu and Maui RSM studies). The beaches in this region are both erosional and accretional. Seasonal fluctuations are generally as significant as the long-term change rates.
- Kikiaola Harbor Sand Bypassing is a potential RSM project. The Kikiaola Harbor breakwaters and an offshore sand sink appear to prevent longshore sand transport from Waimea Beach to the downcoast beaches, based on accretion upcoast of the harbor and erosion downcoast of it. The potential project would be to remove sand from Waimea Beach and place it on the

downcoast Kikiaola Beach. It is recommended that the State of Hawaii implement the sand bypass plan for Kikiaola Harbor as cited in the fully executed project cooperation agreement.

- Another potential RSM project is rerouting of the Kikiaola Harbor Gulch. The gulch discharges directly into Kikiaola Harbor. Rerouting of the gulch to downcoast of the harbor would minimize the amount of maintenance dredging of the harbor and should be considered for future RSM studies.
- The sand sources search resulted in the identification of 189.4 acres (766,461 m^2) of stable reef-top sand stored off the coast of the Kekaha region. The majority of this sand is located in two large sand fields off of Kekaha Beach Park.
- There are presently three existing Federal projects in the Kekaha region.

Poipu Region

- In the Poipu region, the historic erosion rates are relatively small. Thus, only a small amount of beach nourishment would be needed to create stable beaches.
- Poipu Beach Park Restoration is a potential RSM project. The County of Kauai desires restoration of the popular Poipu Beach Park. The potential project is to place 6,000 cubic yards of sand. The recent erosion rate is 800 cubic yards per year so the proposed beach fill quantity would be expected to remain in the reach for six to eight years.
- The sand sources search resulted in the identification of 72.2 acres (292,104 m^2) of stable reef-top sand stored off the coast of Poipu, Kauai. The majority of this sand is located in a large sand field off of Brennecke Beach.
- There are presently no existing Federal projects in the Poipu region.

The preliminary sediment budget analysis presented in this report is based on limited available data. The scarcity of historical shoreline data points could be masking the historical physical processes within each region, i.e. rate changes or trend reversals could be occurring during certain periods of time when shoreline data points are not available and thus any changes are not apparent in the historic beach volume graphs.

The Honolulu District RSM web site has been updated to include the Kauai regions. Historical aerial photography, digitized shorelines, ground photography, coastal structure inventory, regional sediment budget, reports and other Kauai RSM products are available to the public on the web site. An Internet Map Server provides real-time mapping capabilities to enhance the utility of the information compiled for the regions.

A workshop was conducted in January 2011 concerning the needs, findings and RSM opportunities within the Kekaha and Poipu regions. The workshop provided an overview of the tasks accomplished in the Kauai regions and included detailed discussions on the findings presented in the Kauai RSM Plan.

It is recommended that the following work be completed in association with future Kauai RSM studies.

- Coastal Processes Modeling: Continue water circulation and wave transformation numerical modeling to refine the Kauai regional sediment budgets. As an example, the analysis could indicate a reversal in transport direction in the Kekaha region, associated with Kona waves.
- Perform field visits and jet probing of reef-top sand sources.
- Perform grain size characterization of potential beach nourishment sites (potential RSM projects) and analyze their compatibility with potential sand source sites.
- Develop further data on the sediment yield (inputs) to the Kauai littoral cells from the streams and rivers to provide a better understanding of the overall sediment budgets. Define sediment source(s) and loads into Kikiaola Harbor.
- Develop a further understanding of seasonal fluctuations of the beaches within each region. This could include development of new shoreline profiles.
- Confirm/refine the 0.40 cubic yards per square foot beach volume conversion factor for applicability to Kauai RSM region beaches.
- Update the preliminary Kauai regional sediment budget and RSM plan based upon the findings of the above.
- Develop a state-wide approach to utilization of sand sources, including the consideration of inter-island sand exchanges given the proximity of the islands and the high demand for sand.
- Re-establish the State Programmatic General Permit for small (<10,000 cy) beach nourishment projects and/or develop a new State (or regional) permit(s)/program for opportunistic sand use for beach nourishment projects.
- Potential RSM Projects: Develop details for potential RSM projects identified to improve sediment management strategies in the region. Activities to reduce project costs and increase beneficial use of sediments on a regional scale at Poipu Beach Park and Kikiaola Beach should be investigated and coordinated with various stakeholders.

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I. Introduction

The Regional Sediment Management (RSM) Program is authorized under Section 516 of the Water Resources Development Act of 1996. The program provides a systems approach to sediment management in order to recognize and more effectively utilize sediment as a resource in an environmentally effective and economical manner.

The Hawaii RSM Study is part of this larger program. The Federal sponsor of the Hawaii RSM is the Honolulu District of the U.S. Army Corps of Engineers (USACE-POH). The non-Federal sponsor is the State of Hawaii, Department of Natural Resources (DLNR), Office of Conservation and Coastal Lands.

This document is a preliminary RSM Plan for two regions on the island of Kauai: Kekaha Region and Poipu Region. This RSM Plan is a living document and will be updated as the planning and implementation process continues.

II. Regional Sediment Management Program

Regional Sediment Management refers to the effective use of littoral, estuarine, and riverine sediment resources in an environmentally effective and economical manner. RSM strives to maintain or enhance the natural exchange of sediment within the boundaries of the physical system (Rosati et al 2001). RSM changes the focus of engineering activities from the local or project-specific scale to a broader scale that is defined by the natural sediment processes. A prime motivator for implementation of RSM principles and practices is the potential for reducing construction, maintenance and operation costs for Federally-authorized navigation and storm damage reduction projects.

The larger spatial and longer temporal perspectives of RSM, as well as the broad range of disciplines with a stake in RSM projects, require partnerships with, and co-leadership of RSM initiatives by, the stakeholders.

Goals of the National RSM Program are:

- To improve regional sediment management practices within the U.S. Army Corps of Engineers (USACE);
- To highlight and document unique elements of RSM and provide guidance for future implementation of specific RSM actions as appropriate;
- To foster state and local partnerships for RSM, resulting in a unified vision, cost-sharing, and co-leadership of RSM actions;
- To improve regional project efficiencies by engaging cross-mission objectives of the USACE (civil works projects will be managed with the deliberate intent to achieve cross-mission benefits, e.g., navigation, flood risk management, and ecosystem restoration);
- To improve decision support technology for RSM (conceptual, analytical, and numerical models are adapted and enhanced to support implementation of RSM).

III. Hawaii Regional Sediment Management Study

A. Overview

The Honolulu District has already completed the first stage of the Southeast Oahu Regional Sediment Management (SEO/RSM) study for the Diamond Head to Pearl Harbor (D2P) and Mokapu Point to Makapu'u Point (M2M) regions on Oahu. The D2P study was completed in 2009 (Moffatt & Nichol 2009) and the M2M study was completed in 2006 (Oceanit Laboratories 2006).

Products developed as part of the SEO/RSM effort included: 1) documentation of long-term trends in wave climate, 2) development of a regional sediment budget, 3) identification of suitable sand sources, 4) development of sediment transport models, 5) implementation of a web-enabled public GIS portal and 6) preparation of a RSM plan for the region. Many of the products of the study and GIS data for the study regions can be accessed online through the Honolulu District website at <http://www.poh.usace.army.mil>.

Additional studies in the SEO/RSM effort for 2010 include:

- Waikiki Remote Camera Imagery Analysis
- Shoreline Modeling with Longshore Advection and Diffusion

The Hawaii RSM investigations were initiated in 2010 for the following regions:

- Kekaha Region on Kauai;
- Poipu Region on Kauai;
- Kahului Region on Maui;
- Kihei Region on Maui.

This document addresses the two RSM regions on Kauai. Figure 1 shows the locations of these two regions.

B. Kekaha Region

The Kekaha region is located along the southwest shoreline of the island of Kauai, between Kokole Point to the west and the Waimea River to the east. It includes the towns of Waimea and Kekaha. See Figure 2 for a more detailed view of this region.

The Kekaha Regional Sediment Management study is intended to quantify the transport of sediment through the Waimea River and along the Pacific shoreline from the river mouth extending several miles to the west. Effective management of sediment in the Kekaha region could potentially reduce the operation and maintenance costs of the Federal projects in the region, including:

- Kikiaola Light Draft Harbor Navigation Project;
- Waimea River Flood Control Project;
- Kekaha Beach Shore Protection Project.

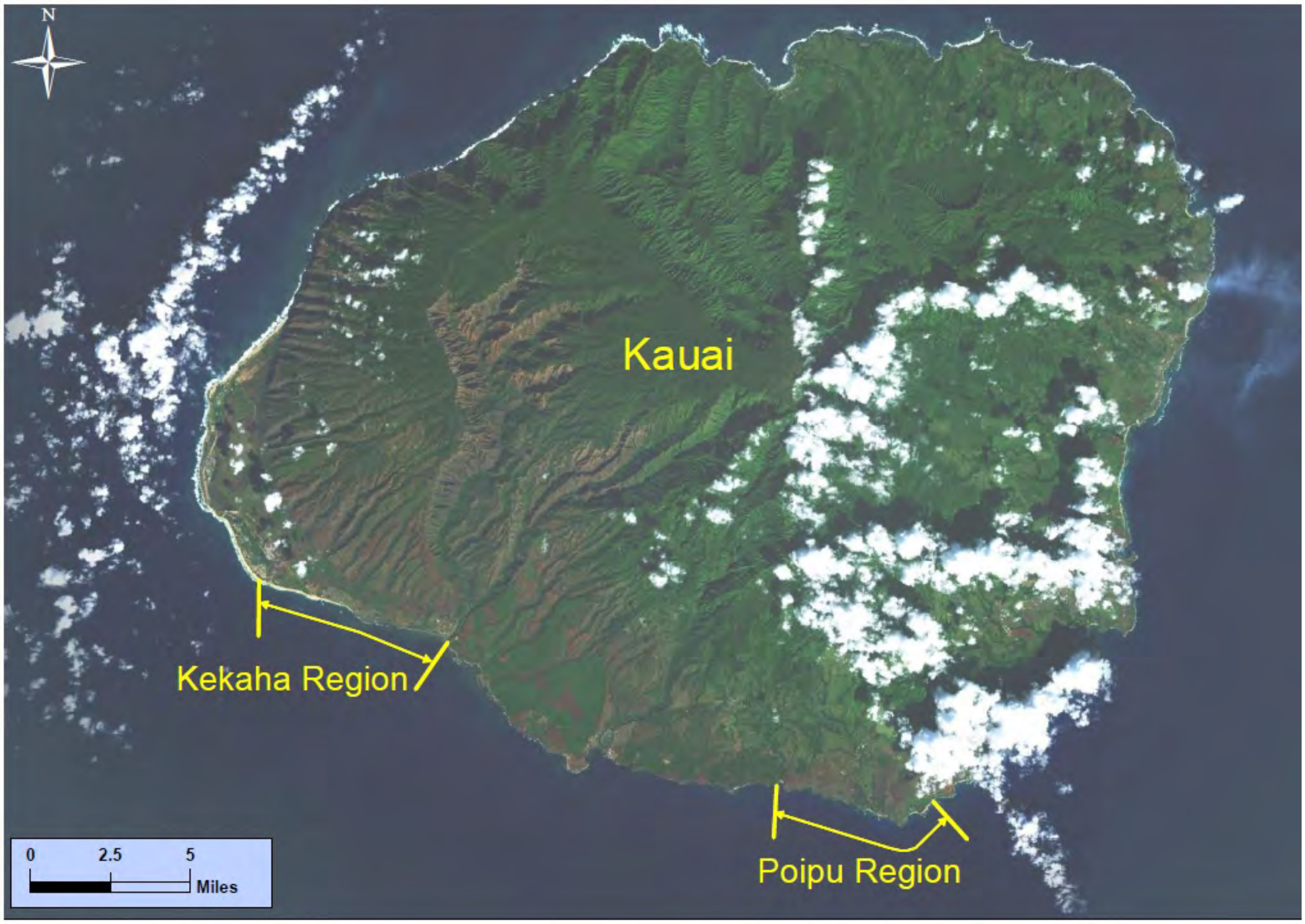


Figure 1. Hawaii RSM Regions of Kauai

A. Poipu Region

This region is located along the south shoreline of the island of Kauai, from Lawa'i Bay on the west end, around the southeastern tip of the island, to Makawehi on the east end. The town of Poipu is towards the eastern end of this region. The region has numerous rocky headlands and pocket beaches. See Figure 3 for a more detailed view of this region. There are no federal projects in the region.

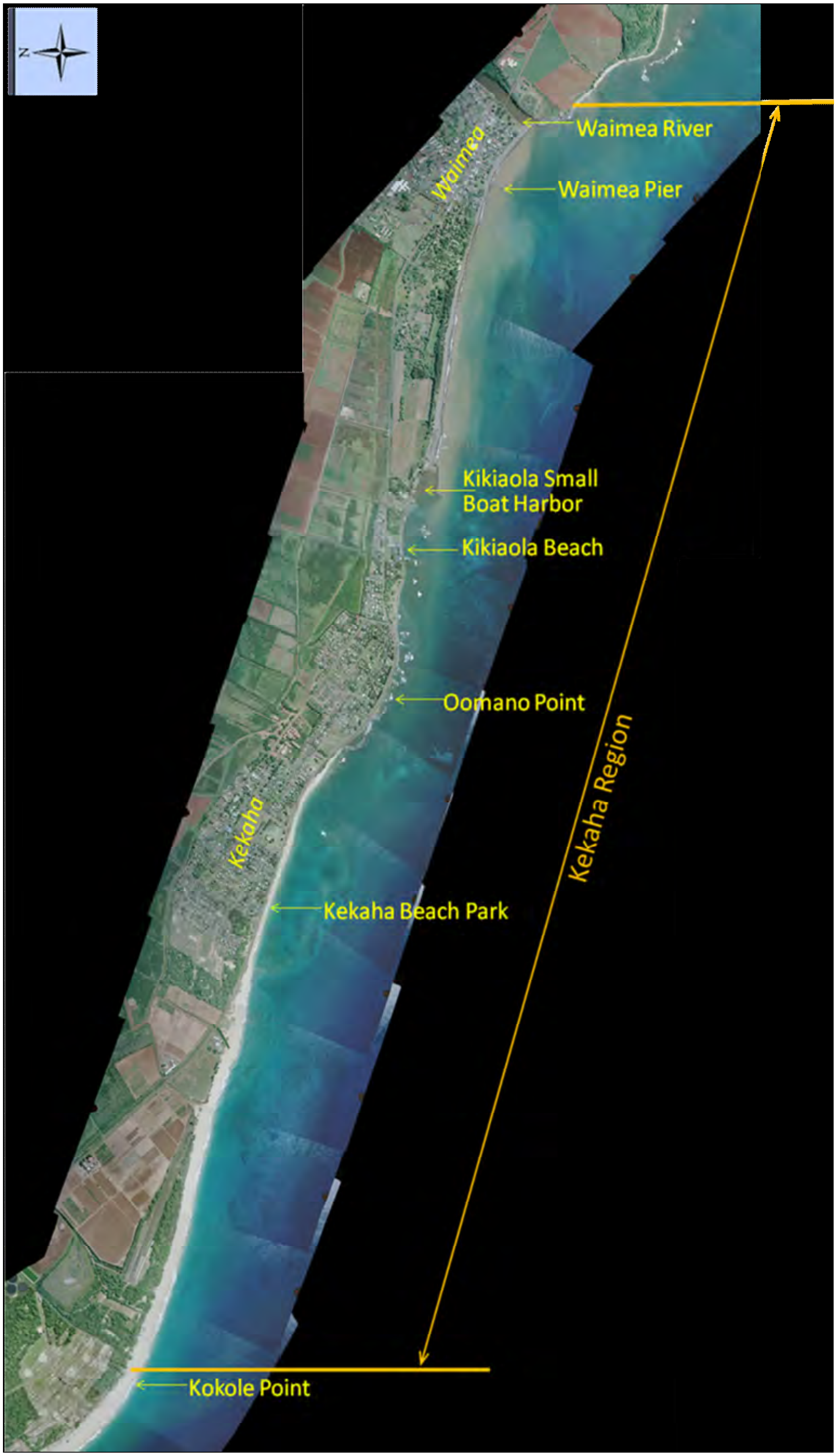


Figure 2. Kekaha Region

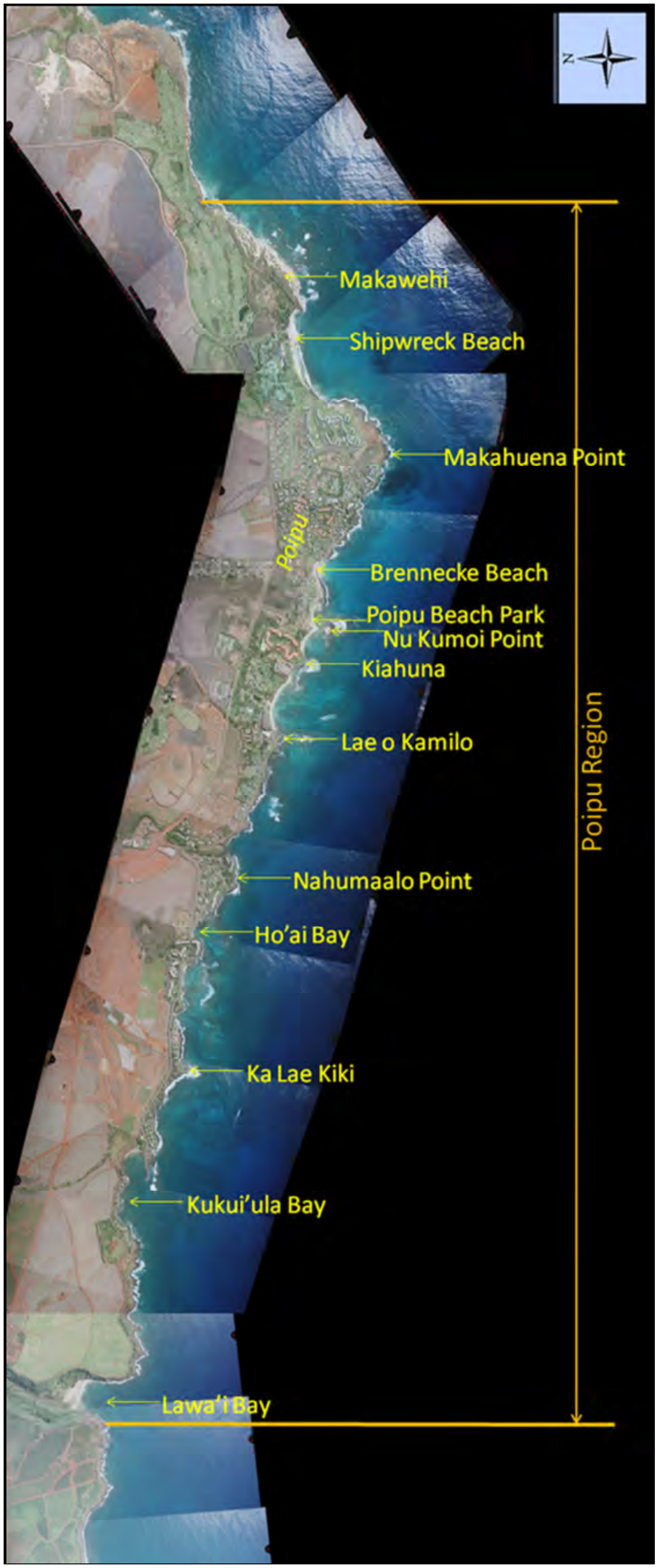


Figure 3. Poipu Region

II. Federal Projects in the Kauai RSM Regions

A. Overview

There are several Federally-authorized projects on the island of Kauai, three of which are within the Kekaha region. (There are no Federal projects in the Poipu Region). The project locations are shown in Figure 4. The other Federal projects in Kauai are on the east coast of Kauai (Nawiliwili Deep Draft Harbor, Nawiliwili Small Boat Harbor, and Kapaa Beach projects), north coast of Kauai (Hanalei River project), and between the two RSM regions on the south coast (Hanapepe River and Port Allen Harbor projects).

This section presents only the projects within the Kauai RSM region, as they relate to the sediment analysis, but Federal projects in other areas could also be relevant to the overall program. Given the relative proximity of the Hawaiian Islands to each other and the remoteness of the chain as a whole, inter-Island RSM projects should also be considered, particularly if a large supply of accessible beach quality sand can be found at or near an existing Federal project.

B. Federal Navigation Projects

Kikiaola Light Draft Harbor: This harbor is located between the towns of Kekaha and Waimea and is used by recreational and commercial boaters. The harbor was initially constructed in 1959.

The Kikiaola Light Draft Harbor (Figure 5) project was to construct navigational improvements to eliminate dangerous breaking wave conditions within the entrance channel and allow for the safe passage of vessels entering the basin. Improvements consisted of: a) dredging a 725-foot long entrance channel varying in width from 105 to 205 feet to a depth of eleven feet, b) dredging 320-foot long access channel varying in width from 70 to 105 feet to a depth of seven feet, c) removing 150 feet of the existing outer east stub breakwater, d) raising the crest elevation and flattening the seaward slope of approximately 764 feet of the existing east breakwater, e) removing and reconstructing the 71-foot long inner east breakwater, and f) modifying 245 feet of the existing west breakwater. Construction of the Kikiaola Light Draft Harbor modifications was completed in August 2009.

The project is being cost shared between the U.S. Army Corps of Engineers and DLNR. DLNR has been unable to commit to additional funding to fulfill their obligation to construct items of local cooperation such as the sand bypass system and west breakwater root repair. These features are currently in the design phase and integral to the overall function of the modified harbor project.

Separate from the Federal project, the State DLNR funded an inner harbor dredging project. DLNR awarded a construction contract in June 2009. This project provided maintenance dredging of portions of the inner harbor.

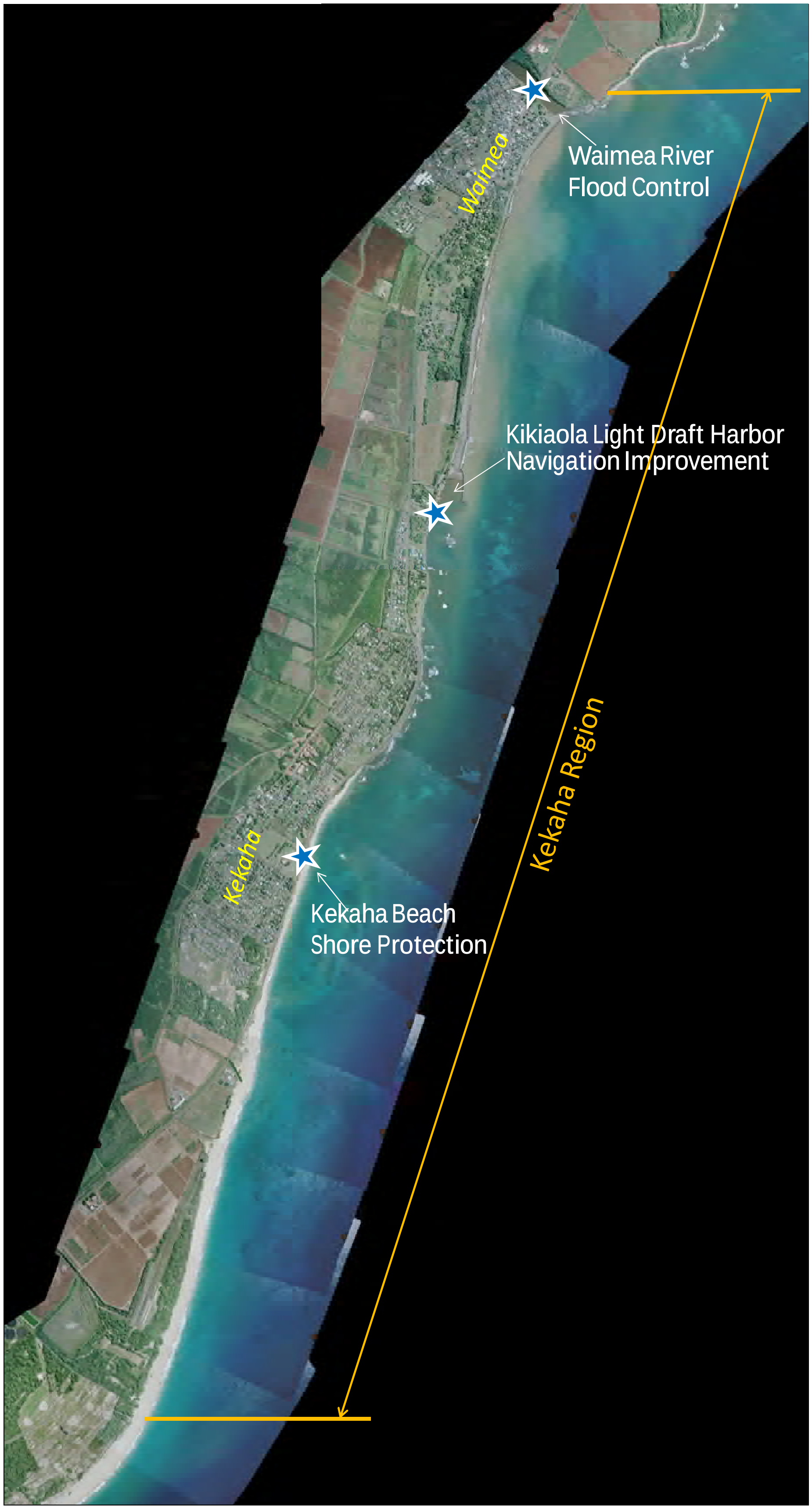


Figure 4. Federal Projects in the Kekaha Region

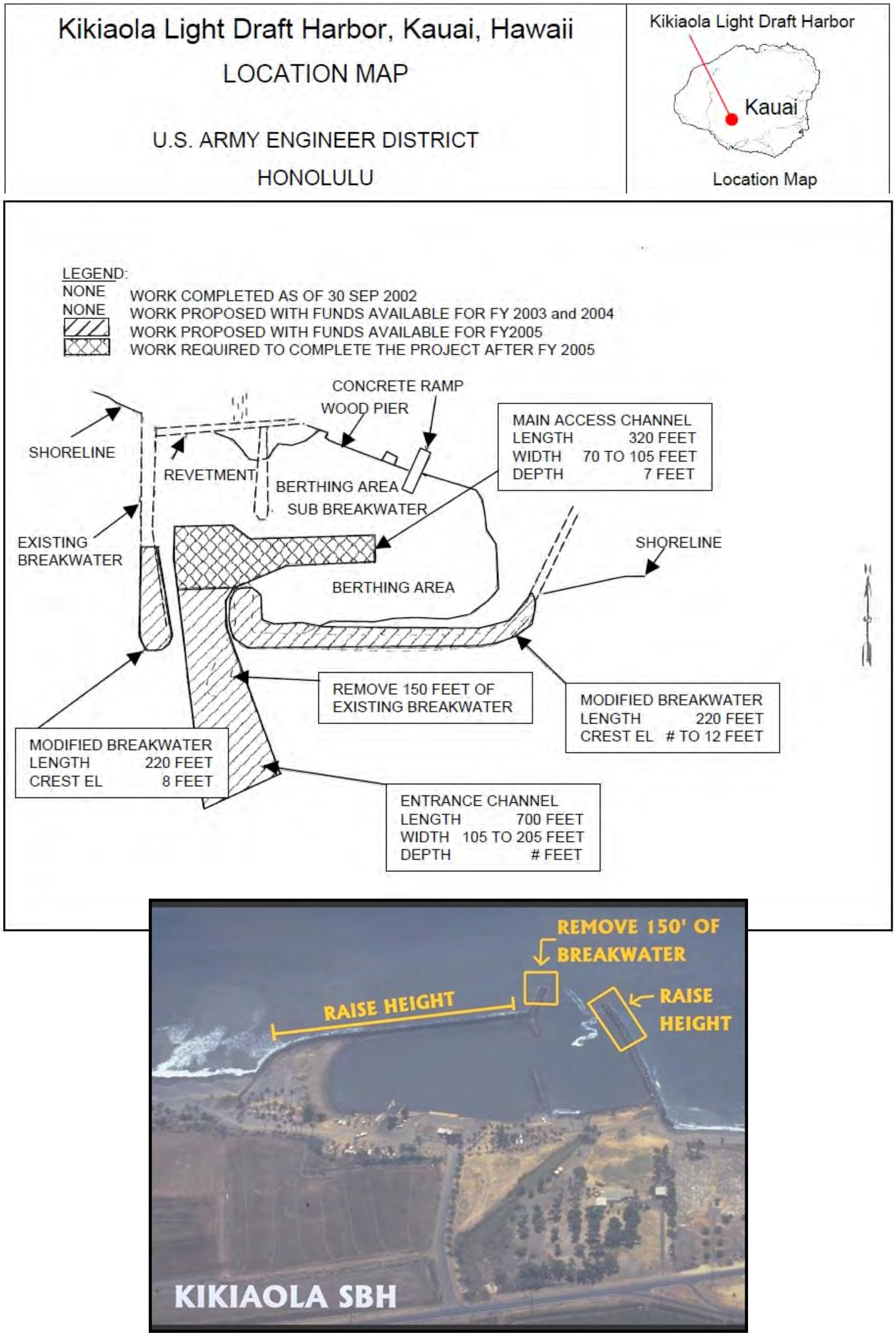


Figure 5. Kikiaola Light Draft Harbor Project Map

C. Shore Protection Projects

Kekaha Beach Project: Kekaha Beach is located on the southwest coast of the island of Kauai near the town of Kekaha. The shore protection project consists of a 6,250-foot long rubble mound revetment with a crest elevation of 12 feet Mean Lower Low Water (MLLW) (Figure 6). (There is an additional 4,600-foot long contiguous revetment which extends around Oomano Point). The project was constructed of two layers of armor stones 1.5- to 2.5-ton, underlayer of 300- to 500-pound stones placed on a bedding of spalls to 50-pound stone. The previous existing dumped-rock revetment was removed and reused for armor and underlayer stone in the new revetment. The project was completed in May 1980. Repair of Hurricane Iwa damages to the revetment in November 1982 were completed in October 1983.

The project is in the operations and maintenance phase. The project was last inspected in September, 24 2009, and the Project Condition Code at that time was “Minimally Acceptable”. The non-Federal sponsor is the State of Hawaii, Department of Transportation, Highways Division.

D. Federal Flood Control Projects

Waimea River: The Waimea River mouth is on the southwest coast of Kauai, at the eastern edge of the Kekaha RSM region.

The existing project, completed in 1984, consisted of: a) cement-rubble-masonry floodwalls totaling 3,320 linear feet, b) levee totaling 1,030 linear feet toward the mouth of the river, c) rock protection along 4,600 feet of the toe of the levee, d) road rising of a 500-foot section at the upstream end of the project, and e) new floodgates (Figures 7 and 8). The project was authorized in May 1983 under Section 205 of the Flood Control Act of 1948, as amended. The non-Federal sponsor is the County of Kauai, Department of Public Works (DPW), which operates and maintains the project.

Since the completion of the Federal project in 1984, Kauai DPW began monitoring the rate of sediment deposition at the project. Sediment surveys indicate that, during a 10-year period between 1979 and 1989, sediments were being deposited at the project site (downstream end of the river) at a rate of 5,000 cubic yards per year. The Kauai DPW has continued their efforts to remove this sediment deposition over the years, as their funding permits.

A site investigation of Waimea and Hanapepe was conducted on 7 January 2005. This investigation was requested by the County of Kauai DPW due to flooding that occurred on 1 January 2005. The flooding in Waimea resulted from the river being high thus closing the outfall gates, preventing storm water from draining into the river and ponding in the town. A study to determine if a pumping station is feasible to reduce interior drainage ponding will be conducted in the Flood Plain Management Services (FPMS) program.

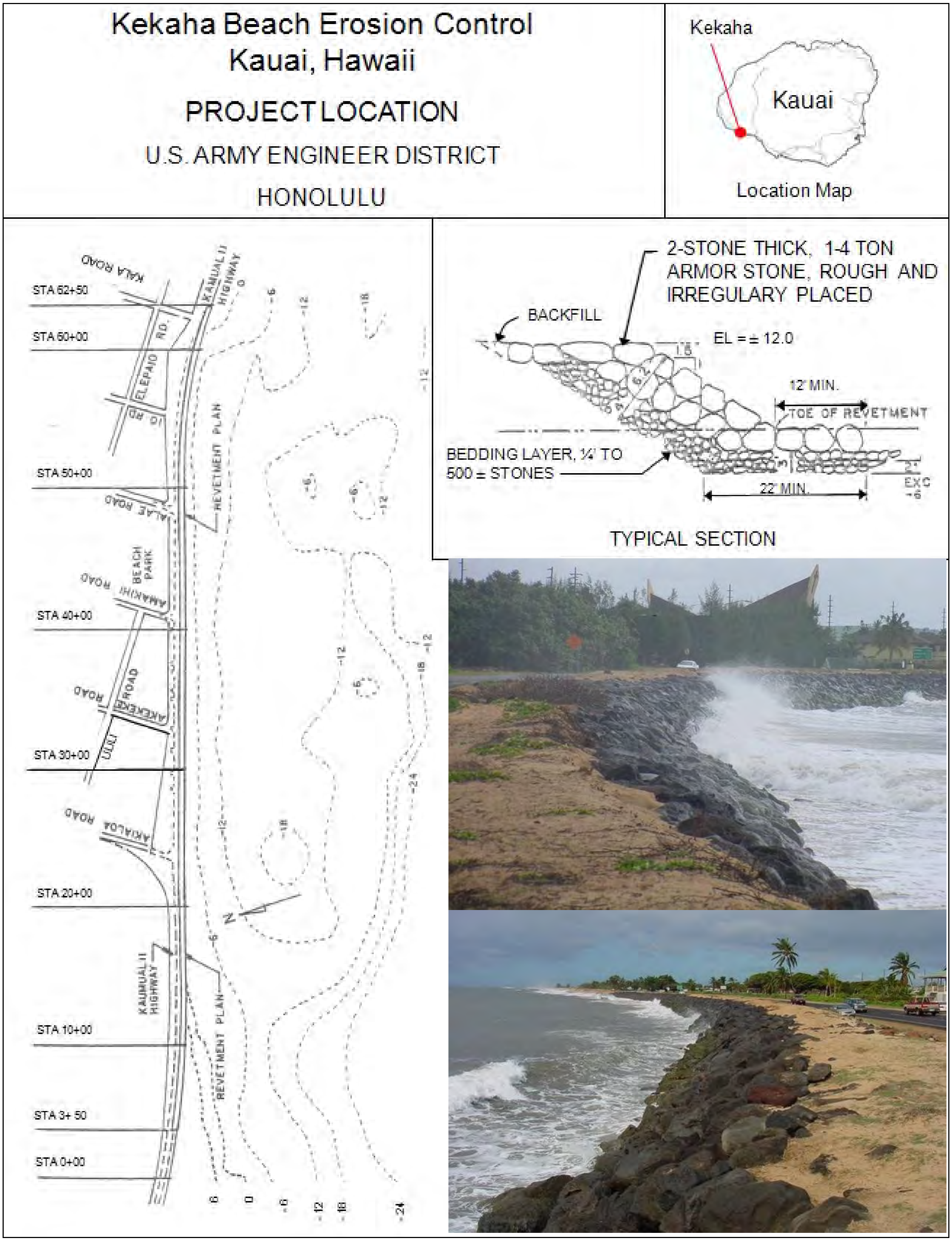


Figure 6. Kekaha Beach Project Map and Photos

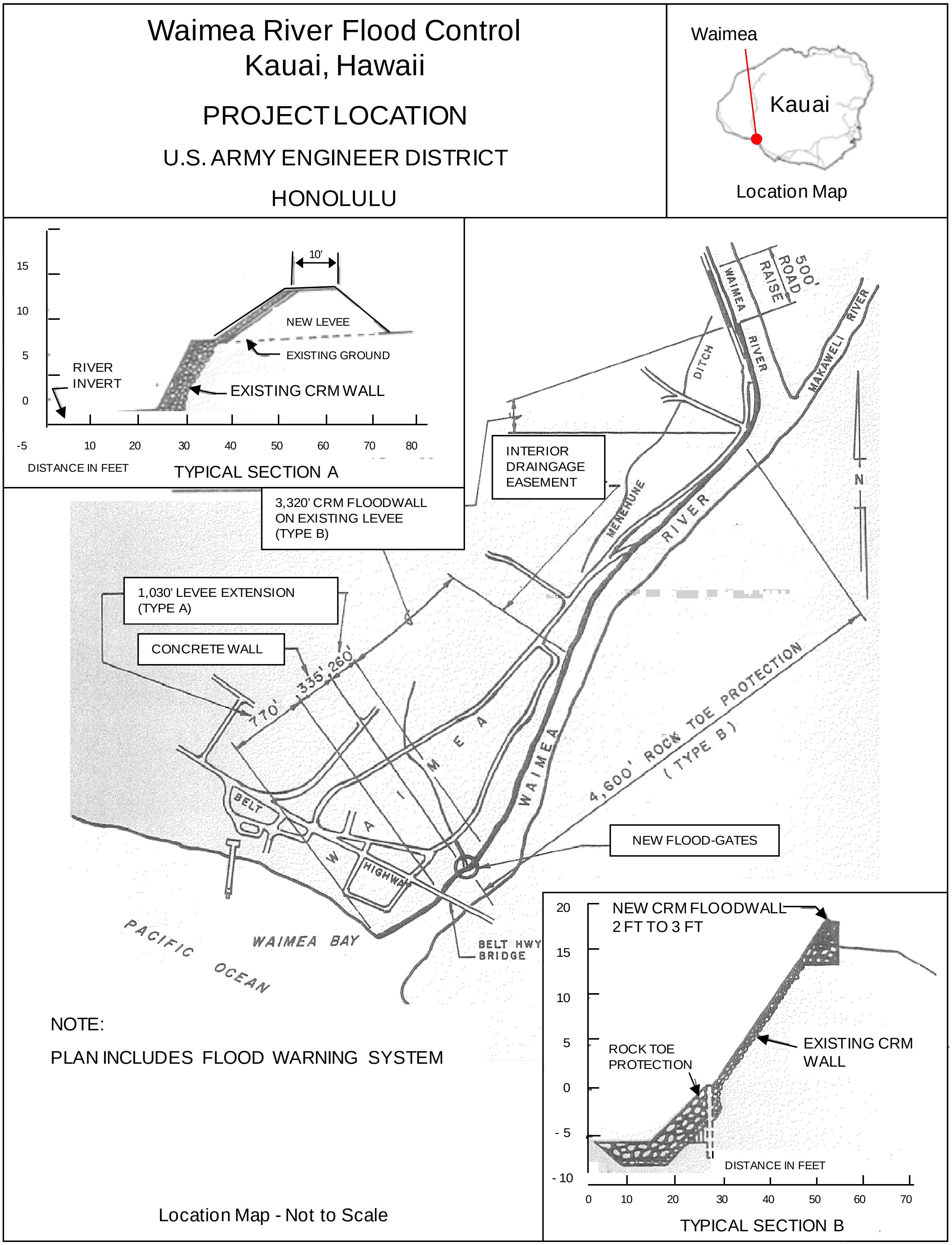


Figure 7. Waimea River Flood Control Project Map

Additionally, USACE-Honolulu District is conducting technical studies on a reimbursable basis to the DPW to determine whether existing levees meet the FEMA's criteria for levee certification. Preliminary hydrology and hydraulic study results indicate that the existing levee does not meet the height requirement to contain the 100-year flood event. In order to attain the FEMA levee certification and pass the 100-year event, a new start is being sought under the Section 216 of the Flood Control Act of 1970, Review of Completed Projects, for fiscal year 2011.

The Waimea River Flood Control project was last inspected in April 2009. The facility is considered to be in acceptable condition without any detrimental conditions, which would affect its flood control function.

Figure 8. Waimea River Flood Control Project Photos

III. Objectives

A. Overview

This section describes the objectives for the Hawaii RSM study. In summary, the objectives are:

- identify erosion hotspots and erosion watchspots in the study regions;
- provide and follow guidelines for the planning of shore protection measures;
- investigate the feasibility of beach nourishment, sand bypassing, and sand backpassing in the study regions;
- identify any dune systems in the study regions that may be suitable for protection;
- provide recommendations as to how the coral ecosystems in the study regions can be better protected during construction projects;

- promote understanding of coastal processes and the appropriate response in terms of project layout and design among property owners and developers;
- support increased coordination and collaboration between agencies regarding issues in the RSM regions;
- encourage coordination between the County, State, and Federal agencies in reviewing permit applications and associated environmental reviews of proposed major structures along the shoreline;
- identify any existing major structures that may be problematic with regard to sediment management and whose removal or modification could reasonably be considered;
- identify any new major structures that could have a beneficial effect on shoreline processes and coastal erosion, in a regional context; and
- inform the public of ongoing studies and plans in the regions and obtain public input on any plans, particularly pilot beach nourishment projects that may arise as part of the study.

Some of these objectives are addressed in this specific report and some are addressed by the overall RSM program. Each of these objectives is described further below.

B. Identification of Erosion Hotspots and Erosion Watchspots

Erosion hotspots are areas where coastal erosion has threatened shoreline development or infrastructure. They are existing management challenges. In many cases, the shoreline has been armored to protect property and development, and there has been a noticeable environmental impact and/or a decrease in recreational use. Erosion hotspots can be restored, but restoration will require substantial economic resources (University of Hawaiʻi and County of Maui 1997).

Lost beaches are a subset of erosion hotspots. Lost beaches lack a recreational beach, and lateral shoreline access is very difficult, if not impossible.

Erosion watchspots are areas where the coastal environment will soon be threatened if shoreline erosion trends continue. A potential conflict between the desire to protect property and the desire to maintain the beach resource exists at erosion watchspots.

A study objective is to identify erosion hotspots and erosion watchspots in the study region. The beach volume change rates (Section X and Appendices F and G) and the shoreline erosion hazard maps prepared by the University of Hawaiʻi (Section IX.B and Appendices D and E) identify erosional areas. On Kauai, there are several areas where infrastructure is threatened by shoreline erosion, e.g. the highway along Kekaha Beach and Oomano Point. Many of the erosional areas are already protected by seawalls / revetments.

C. Guidelines for Shore Protection Measures

Shore protection measures can include such measures as groins, breakwaters, revetments, and seawalls – often in combination with beach nourishment. If properly engineered with a full analysis of environmental effects, shore protection measures can be extremely effective. However, improperly planned and engineered structures can exacerbate erosion, particularly in adjacent areas; and can cause other environmental impacts, such as smothering of reef organisms by placed sand.

A study objective is to provide and follow guidelines for the planning of shore protection measures that are appropriate, in regulatory, environmental, and engineering terms, for the study region. The potential RSM projects identified in this study will follow the appropriate guidelines and engineering standards.

D. Beach Nourishment, Sand Bypassing and Sand Backpassing

Beach nourishment can provide protection for upland infrastructure, as well as providing additional beach suitable for recreational activities and habitat. Potential drawbacks of beach nourishment include the potential for impacts on surf breaks; increased turbidity and reef coverage, with the potential to damage reef ecosystems; and increased shoaling in navigation channels that may lead to additional dredging. In addition, if appropriate sand sources cannot be identified close to the nourishment area, then beach nourishment can be extremely costly. Sand bypassing can provide sand to beaches that are sand starved due to the natural or man induced interruption of littoral transport. Sand backpassing can be implemented at beaches where there is an imbalance of sand in the downdrift and updrift directions.

Many coastal states have established Beach Management Districts (BMDs) to deal with coastal erosion (Hwang and Fletcher 1992). A BMD is a special designation for a group of neighboring coastal properties that provides a mechanism for implementing erosion mitigation projects at multi-property scales. Variations of the district concept that have been used for capital improvement projects in different states include the improvement district, the overlay district, and the special taxing district. The advantage of a district is that it provides economies of scale, and allows a group of adjacent landowners to address shoreline issues as a unit rather than as individual property holders.

An objective is to investigate the feasibility of beach nourishment, sand bypassing and sand backpassing in the study region. In support of this objective, an assessment of suitable sand sources for beach nourishment has been prepared by the University of Hawaii. The results of this assessment are described in Section XI. Beach nourishment and sand bypassing projects that could be potential RSM projects are described in Section XIII. Beach nourishment, sand bypassing and sand backpassing along eroding beaches within the Kauai RSM regions will continue to be investigated as part of the ongoing RSM efforts.

E. Dune Preservation and Restoration

In an unmodified system, sand dunes act as a reservoir of sand. Typically, in response to sea level rise and/or erosional wave activity, a beach will shift landwards. If the backshore is a sand-rich dune system, then the shift does not affect the general beach characteristics – the beach profile does not change significantly other than through its location. If, however, the backshore is a lava outcrop, a clay barrier, or a modified shoreline such as a seawall or revetment, the beach will experience a sediment deficit and may disappear.

Sand dunes in the Hawaiian Islands have been degraded in a number of ways. They have been used as sources for construction materials or beach nourishment (sand mining); they have been overbuilt; and they have been lowered to improve sea views. All of these activities have decreased the ability of sand dunes to act as reservoirs and nourish beaches through natural processes. They also degrade the ecological value of dune systems.

A study objective is to identify any dune systems in the study region that may be suitable for protection, either through engineering and/or bioengineering methods (dune stabilization) or through regulatory means. Any/all dunes on Kauai should be protected given the importance of dune systems. Future RSM projects will protect dunes and future RSM studies may address this objective in more detail.

F. Coral Reef Ecosystems, Water Quality, and Upland Activities

Clean water is necessary for healthy reefs and consequently healthy beaches. This objective includes keeping the reef healthy by controlling water quality and upland activities that could pollute nearshore waters. These upland activities include construction, agricultural and urban runoff, sewage production, and industrial pollution. Water-based recreational activities such as boating, fishing, snorkeling, and SCUBA diving can also affect reef ecosystems. An objective is to provide recommendations as to how the coral ecosystems in the study region can be better protected, including reef protection provisions during construction in nearby areas. Future RSM projects will include provisions to protect the coral reefs, such as measures for turbidity control, accidental spills, accidental ship groundings, and proper placement of dredge equipment pipelines, spuds, and anchor systems.

G. Shoreline Setbacks and Coastal Erosion Hazard Data

As mandated under the State Coastal Zone Management Act, the County of Kauai has delineated the boundaries of the coastal Special Management Area (SMA) on Kauai and has adopted regulations to manage development within the SMA. The Kauai General Plan Ordinance states: “When development is proposed along a sandy beach, hazards of long-term coastal erosion should be assessed and used to determine appropriate setbacks.” The University of Hawai‘i has developed a set of draft erosion hazard maps for Kauai which are tools for this assessment. These are available at <http://www.soest.hawaii.edu/coasts/kauaicounty/KCounty.html> and are provided as Appendices D and E herein for the two Kauai RSM regions. While not a specific study objective, the Hawaii RSM study could provide useful input to this ongoing program.

H. Proactive Development of Coastal Lands

Development of coastal lands, especially adjacent to beaches, requires advanced planning by property owners and regulatory agencies. Activities at one coastal location can have significant effects elsewhere in a littoral cell, so that coordination of coastal development by property owners and suitable regulation and enforcement by regulatory agencies are both crucial (Hwang and Fletcher 1992).

Proactive management occurs in the planning stages of new developments or redevelopments along the shoreline, well before project layout is finalized. This type of planning is beneficial to coastal landowners and developers who are not always aware of shoreline processes, coastal hazards, and the potential impacts of development on the beach and other nearshore areas (University of Hawaiʻi and County of Maui 1997).

A study objective is to promote understanding of coastal processes and the appropriate response in terms of project layout and design among property owners and developers. This objective is met through the production of this document and associated workshops. Objectives in terms of regulatory agencies and coordination and enforcement of regulation in the coastal zone are covered below.

I. Inter-Agency Coordination

County, State, and Federal agencies regulate activities including beach nourishment, dredging, and other work in the coastal area. Generally, the State DLNR regulates work such as beach nourishment seaward of the certified shoreline, while the County of Kauai regulates landward work – which may include staging, sandbagging, etc., in support of beach nourishment. The certified shoreline is defined as: ‘‘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”.

The USACE regulates this work through Section 10 of the River and Harbor Act (work in navigable waters) and Section 404, Clean Water Act (fill in water).

Additional State and Federal agencies that typically regulate work in and near the water are: the State Department of Health; the State Historic Preservation Office; the Office of Hawaiian Affairs; the U.S. Fish and Wildlife Service; and the NOAA National Marine Fisheries Service.

Given the overlapping regulatory authorities associated with the implementation of RSM projects, inter-agency coordination is critical to the efficient permitting and conduct of beach nourishment projects. In 2005, the USACE and the DNLR jointly issued a State Programmatic General Permit (SPGP) for beach nourishment in the State of Hawaiʻi. Among other objectives, the SPGP provides a streamlined application process for Small-Scale Beach Nourishment (SSBN) and restoration projects (up to 10,000 cubic yards) by consolidating four permit processing functions solely within the DLNR:

- Department of the Army, State Programmatic General Permit (SPGP);
- State of Hawai‘i Department of Health Section 401 Water Quality Certification;
- Hawai‘i Coastal Zone Management Federal Consistency Review;
- DLNR Conservation District Use Permit.

A goal of the USACE and the State of Hawaii is to extend this coordination and streamlining process. A specific objective of this RSM Plan is to support increased coordination and collaboration regarding issues in the Kauai RSM regions. This objective is met through the production of this document, associated workshops, and the USACE RSM website. Currently, the State of Hawaii Department of Health (DOH) Section 401 Water Quality Certification component of the SSBN application process has lapsed and it is unclear if it will be renewed. The lack of this programmatic permit will hinder future beach nourishment efforts.

J. Structures and Activities within the Shoreline Area

Much of the shoreline within the Kekaha study region has been modified with the construction of structures such as seawalls, revetments, groins and breakwaters. In contrast, very few areas of the Poipu region have been modified. The specific structures are discussed in Section IX.A. Additional details about these structures and graphics showing the locations of the structures are provided in Appendices F and G.

For major structures, (those that are anticipated to affect shoreline processes), three study objectives can be defined.

- The first is related to issues of inter-agency coordination, as discussed in Section V.I. By highlighting the regional nature of sediment management, the RSM Program in Kauai may encourage coordination between the County of Kauai, the State, and Federal agencies in reviewing permit applications and associated environmental reviews of proposed major structures along the shoreline.
- The second study objective is to identify any existing major structures that may be problematic with regard to sediment management, and whose removal or modification could reasonably be considered.
- The third study objective is to identify any new major structures that could have a beneficial effect on shoreline processes and coastal erosion, in a regional context.

These objectives are achieved by this study which identifies the major structures that influence the shoreline of each region and by the potential future RSM projects which will consider advantageous shoreline structure changes.

K. Public Awareness and Education

Kekaha Beach and Poipu Beach have been identified as “eroding beaches” in the public’s eye and potential RSM studies may be of interest in the region. The objectives of the present study, in relation to public awareness, are to inform the public of ongoing studies and plans in the region and obtain public input on any plans, particularly pilot beach nourishment projects that may arise as part of the study. This objective is partially met just via the publication of this document. This objective could also be met through a combination of public workshops, community college courses, and a Kauai RSM website. This process will be continued through the ongoing development of this Hawaii RSM Plan.

IV. Geomorphology

A. Hawaiian Islands

Each Hawaiian Island was formed by at least one shield volcano that built up basaltic lava in intermittent layers from a hot spot on the constantly-shifting Pacific Plate. The general chronological succession along the island chain has been from the northwest to the southeast. Kauai is at the northwest end of the chain, thus making it one of the older islands.

As the volcanoes forming the Hawaiian Islands grow, their weight causes the underlying surface to bend, causing subsidence and uplift and leading to local variations in relative sea-level rise. This subsidence is most evident on the Big Island, where the local relative sea-level rise is ~4 mm/year. Towards the west, away from the volcanic hot spot, the plate under the islands reverses and flexes, causing uplift.

There are currently two models for Kauai's morphology, a single shield model and a two-shield model. (Fierstein, Fletcher, 2002). More than 1.5 million years after the primary shield-building stage had ceased on Kauai, rejuvenated volcanism, (the Koloa Volcanic Series), began resurfacing two thirds of the eastern side of the island. Locations on the north, east and southern coasts of Kauai contain lavas of the Koloa Series.

B. Reefs

Coral reefs are found along much of the Hawaiian Island shorelines. Fringing reefs are the most common type in these waters. These reefs are formed on the fringing slopes of the shield volcanoes, after the volcanic activity has ceased, but before the land subsides (the atoll stage of island evolution); they are found on the shallow shelves of the islands.

Reefs are wave-resistant structures formed by shallow-water organisms in warm water environments. Commonly, fringing reefs along relatively sheltered coasts have land-derived (detrital) grains mixed with the predominantly calcareous sands covering them and their adjacent beaches. On the exposed coasts of Hawai‘i, the powerful wave energy is the main factor controlling the growth of the reef structure. The larger waves during El Niño years can clear nearly half of the coral growth on the northern Oahu shelf. Kona storm waves and hurricane-induced waves can also be detrimental to reefs.

Kauai is surrounded on all sides by patches of nearshore fringing reef, with a reef flat sometimes as wide as 1 km. The reefs are under the influence of high wave energy due to the island's geographic position. (USGS website)

The reef structure plays a role in the sediment budget by dissipating the incoming wave energy, refracting wave fronts to near shore-normal, stabilizing the toe of the beach, and providing a source of sand. The reef can also act as a sink for sand and it can limit the potential for sand to move back to the beach after a major storm.

C. Study Regions

The two study regions are located along the southern side of Kauai. The Kekaha study region spans approximately six miles on the southwest coast of Kauai between the mouth of the Waimea River and Kokole Point to the west (as shown in the previous Figure 2). The Poipu study region is approximately five and a half miles along Kauai's southeastern coastline. The Poipu region extends from Lawa'i Bay in the west, wraps around the rocky southeastern tip of the island, and includes Shipwreck Beach to the east (as shown in the previous Figure 3).

The **Kekaha Region** shoreline is relatively straight and faces south southwest (approximately 180-200 degrees). Most of the region lies within the broad Mänä plain which extends along the west coast and is skirted by one of the longest stretches of sandy beach in the state (Fierstein, Fletcher, 2002). The Waimea River discharges at the Kekaha region's eastern boundary and provides sediment to the downcoast Waimea beach area. Nearly all of the streams that drain the mountains of Waimea have been channelized and redirected toward Waimea town by the Waimea and Kekaha irrigation ditches (USGS, 2010). The Kekaha Region includes Kikiaola Light Draft Harbor, and a lengthy stretch of shoreline protected by rock revetment.

The **Poipu Region** coastline is primarily rocky with offshore reefs and numerous headlands and pocket beaches. The Poipu region is part of the Hunihuni coastal plain, which extends into the ocean as a mass of rejuvinated basalt. The Lawa'i Stream discharges at the region's west end. The Poipu shoreline bore the brunt of devastation related to Hurricane Iniki in 1992. Although the Poipu region has been developed, there is only one small "pocket" harbor and relatively few man-made shore protective devices along this region's coastline.

More details about the shoreline features of each region are provided in Section IX.A and in Appendices F and G.

D. Sediments

Hawaiian beach sand is composed of two general types of grains mixed together in proportions that vary from one locality to another. Light-colored calcareous grains of biochemical origin (the fragments of skeletal parts of certain marine invertebrate animals and algae) contrast with dark-colored silicate grains of terrigenous (land-based) origin. Modern sand production on Hawaiian reefs is believed to be relatively low compared to that of 2,000 to 4,000 years ago, when sea level was higher, the wave energy may have been lower, and the reef systems produced larger volumes of sand.

The sand in the Kauai regions is both calcareous and terrigenous. Whereas the predominant sand on Oahu and Maui is calcareous, much of the sand in the Kauai study region is terrigenous. In the Kekaha region, a major source is detrital sediment from the Waimea River; sediment originating from the river's watershed is discharged from the river mouth during periods of significant flow. As stated previously, the Waimea River's sediment yield is estimated to be 5,000 cubic yards per year. Previously, the sediment yield of the Kikiaola Harbor Gulch was estimated to be 1,600 cubic yards per year (USACE 1998); it is likely that this sediment remains within Kikiaola Harbor which is dredged periodically. Within the Poipu region, there are numerous streams and gulches which discharge into the shoreline, the most significant being the Lawa'i Stream. However, the sediment yield rates for these streams and gulches are not known.

Figure 9 highlights the contrast in sand found on the beaches of the Kekaha region; the beaches at the eastern end of the region, nearest the Waimea River mouth, are dark brown, whereas the sand along Kekaha Beach towards the western end are a much lighter calcareous sand.

Sand can be lost to the beach system through the following mechanisms:

- Cementation: Beachrock is formed by cementation of calcareous beach sand in the intertidal zone (Moberly 1963). Beachrock can consist of sand or gravel cemented by calcium carbonate, which in turn is formed from (and impounds) calcareous sediments. Bottles, fence-posts, and similar items can also be cemented into beachrock, demonstrating the ongoing nature of this formation. Relatively little beachrock is found in the Kekaha region, therefore, this formation is not believed to be a significant component in coastal erosion in the Kekaha region.
- Abrasion and dissolution: Calcareous sand can be lost through abrasion (it is much less resistant to abrasion than terrigenous sediment, Moberly and Chamberlain 1964) and dissolution. It is an open question whether ongoing acidification of the oceans, as they impound anthropogenic carbon dioxide, will increase dissolution of calcareous sand to a significant component.
- Offshore transport: Sand can be lost irretrievably offshore. Once sand is transported into deep water (below approximately -30 feet MLLW, and certainly once it is past the drop-off at the end of the first reef crest), there is no natural mechanism for returning it to the beach system. The sand also drops into channels and depressions on the reef.   However, these areas, offshore of the reef edges, may be suitable as sand borrow sites.
- Upland transport: Over the Holocene period, sand has been stored in coastal dunes, sand plains, and other upland areas. In principal, this sand is available to the beach system as the shoreline retreats. In practice, armoring of the shoreline impounds this sand.
- Sand Mining: Sand mining is an obvious mechanism for beach erosion. In the early 1900s, large quantities of sand were removed from Waikiki Beach and on the north shore of Maui. Large-scale sand mining is now prohibited: the few exceptions include clearing sand from stream mouths.

Figure 9. Two Different Types of Sand within the Kekaha Region: Terrigenous – Top Photo; Calcareous – Bottom Photo

These loss mechanisms all contribute to a relatively low volume of sand available to the beach system. On many Hawaiian beaches, including those in the Kauai study regions, the available sand ends beyond the toe of the beach in a water depth of only 4 to 6 feet where the bottom becomes reef. In contrast, on mainland beaches the sand deposits often extend a considerable distance (hundreds to thousands of yards) offshore.

V. Coastal Ecosystem

Marine life in the Hawaiian Islands is diverse and complex and includes marine birds, corals, sponges, alga and seaweeds, nematodes, fish, crustaceans, sea turtles, and marine mammals such as seals, dolphins and whales.

The fringing coral reefs offshore of the islands not only provide shoreline protection, but also provide food and habitat for many threatened and endangered species in the waters around Kauai. Listed species that may occur in or near the study region include: the Hawaiian monk seal, humpback whale, green sea turtle, spinner dolphin, white tern, and others. Macroalgae covers over fifty percent of the benthic habitat in the reef system.

The United States Coral Reef Task Force has determined six priority threats to coral reefs: over fishing, lack of public awareness, recreational overuse, climate change, coral disease, and land-based pollution. Sedimentation and turbidity from runoff and dredging activities can smother adult and juvenile corals (Rogers 1990) and often contains nutrients which results in excessive algal growth on the coral. Sedimentation can also inhibit coral recruitment (Tomascik and Sander 1985) and reduce coral biodiversity (Edinger et al 1998).

The Hawaiian Islands Humpback Whale National Marine Sanctuary includes areas around the islands of Maui, Lanai, and Molokai, and parts of Oahu, Kauai (north shore) and Hawaii. The sanctuary extends seaward from the shoreline to the 100-fathom isobath (NMS 2009 and NOAA 2010c)   The Kauai RSM regions do not lie within the sanctuary's boundaries.

The Waimea Bay/ Waimea Pier area is designated as a Fishery Management Area (DLNR 2010b). There are no Marine Life Conservation Districts on Kauai (DLNR 2010a).

VI. Coastal Processes

A. Water Levels

Hawai'i shorelines are microtidal, with ranges much smaller than those observed over the west coast of the continental United States. The nearest tide station to the Kauai RSM regions is at Nawiliwili Harbor on the east coast of Kauai. The water level datums, measured by NOAA at this station and reported on their web site, are given in Table 1 (NOAA 2010a).

Table 1: Tidal Datums at Nawiliwili Harbor (1983-2001 Epoch)

Datum	Water Level (feet, MLLW)
Highest Observed Water Level (9/11/1992)	4.98
Mean Higher High Water (MHHW)	1.83
Mean High Water (MHW)	1.42
Mean Sea Level (MSL)	0.82
Mean Tide Level (MTL)	0.81
Mean Low Water (MLW)	0.20
Mean Lower Low Water (MLLW)	0.00
Lowest Observed Water Level (5/24/1967)	-1.09

There are significant non-astronomical components to the water levels at the Hawaiian Islands. Extreme tide levels can occur due to large scale oceanic eddies that propagate through the islands. These eddies produce tide levels as much as 0.5 to 1 foot higher than normal for periods of up to several weeks.

During severe storm events, an additional increase in water level can result from storm surge due to reduced atmospheric pressure and wave setup due to the action of breaking waves on the reef. During hurricane conditions, an additional water level rise can occur due to wind stress.

Although the tidal elevation changes are small – with a diurnal range less than 2 feet – tides and tidal currents may be important in the study region, particularly during storm conditions, because nearshore wave heights in areas affected by the fringing reefs are limited by the water depth. In the previous D2P study, the circulation modeling indicated that the tidal currents are not significant relative to littoral transport.

B. Sea Level Rise

Based on measurements at Nawiliwili Harbor, the mean sea level in the study region has increased at an average rate of 1.53 ± 0.59 mm per year (6.1± 2.3 inches per century) between 1955 and 2006 (NOAA 2010b). This rate is less than the eustatic (global average) rate of sea level rise over the 20th century.

The rate of change of sea level is not constant. The mid-Holocene highstand, which peaked between 4,000 and 6,000 years before present, affected sea level across the tropical Pacific Ocean and left its mark on the island and reef morphology (Dickinson 2001). The recent rate of global sea level rise appears to be accelerating in response to anthropomorphic climate change (Intergovernmental Panel on Climate Change 2007).

For long-term planning it is important to consider a range of potential sea level rise scenarios. USACE Engineering Circular (EC) 1165-2-211, dated July 2009, provides "guidance for incorporating the direct and indirect physical effects of projected future sea-level change in managing, planning, engineering, designing, constructing, operating, and maintaining USACE projects". This circular states that planning studies and engineering designs should consider alternatives that are developed and assessed for a range of possible future rates of sea-level change, specifically "low," "intermediate," and "high" rates, for both "with" and "without" project conditions. The low would be the historic rate of sea-level change, which is approximately 6.1 inches per century (3 inches over the next 50 years) for Kauai. The "intermediate" and "high" rates are based on global/eustatic sea level rise projections and the local rate of vertical land movement. Based on a USACE EC spreadsheet calculator, the intermediate and high sea level rise rates for Kauai would be 1.2 feet and 1.9 feet, respectively, over the next 50 years. Plans and designs should be evaluated for sensitivity and risks associated with each of these rates, and in the context of potential timing and costs.

C. Wave Climate

The wave and wind climate in the Hawaiian Islands is seasonally variable (Moberly and Chamberlain 1964). The predominant winds in the vicinity of the Hawaiian Islands are the northeast trade winds, which are present approximately 75% of the year (M&N 2000). Summer typically extends from April to November and includes the period of strong northeast trade winds (June to September) and the transitional periods just preceding and following. During this period, the winds range from northerly through easterly, and occasionally southerly. Wind speeds may range up to 35 or 45 mph.

Winter can be defined by a weakening of these northeast trade winds and the appearance of southerly Kona winds. The year to year variation in the Kona conditions is very large: in some winters no Kona conditions appear, while in other years there may be four or five storms. Generally, during the winter months of December to March, winds from the southwestern quadrant are present 10 to 15 percent of the time.

Waves that approach the Hawaiian Islands are a combination of locally-generated and long-distance swell waves. Four wave types are normally identified:

- **Northeast Trade Waves**: These waves usually dominate the local wave spectrum during the summer (April to November). They result from the strong trade winds blowing out of the northeast quadrant over long fetches of open ocean. The waves typically have periods ranging from 5 to 8 seconds and heights up to 12 feet. They are present 90 percent or more of the time during the summer, and more than 50 percent of the time in the winter.

- **Southern Swell**: The summer season in the Hawaiian Islands is the winter season in the southern hemisphere, and strong winds blowing over long fetches produce very large waves in the region adjacent to Australia and in the Southern Indian Ocean. These waves arrive at the Hawaiian Islands as low amplitude, long-period waves from the southern quadrant. Typically, southern swell can be identified along the Hawaiian coasts because of its low height (typically 1 to 4 feet) and long period (14 to 22 seconds). In a typical year, southern swells arrive at the Hawaiian Islands about 50 percent of the time, usually during the months of April through October.
- **Kona Storm Wave**: Kona storm waves are generated by the interim winds associated with local fronts or Hawaiian lows of extra-tropical origin (see below). These waves are neither frequent nor consistent, as they are associated with erratic westerly winds and the weakening of the northeast trades. However, since these waves may develop to a large size and may approach the Hawaiian Islands from the south, they are extremely important in relation to beach dynamics and nearshore water circulation along the south and west shores. Kona storm waves may approach the Hawaiian Islands from any direction between the southeast and the west, but the larger waves are usually from the southwest. Commonly, the periods range from 8 to 10 seconds, and heights from 10 to 15 feet. In a typical year, Kona storm waves may arrive at the Hawaiian Islands about 10 percent of the time, usually during the winter months.
- **North Pacific Swell**: Waves produced by storms in the Aleutian area and by mid-latitude lows may arrive in the Hawaiian area throughout the year, but they are the largest and most numerous during the period from October to May. They may approach from the northwest, north, or northeast, and typically have periods of about 10 to 15 seconds and heights from 8 to 14 feet. Some of the largest waves reaching the Hawaiian Islands are of this type.

One way of visualizing the offshore waves approaching the Hawaiian Islands is through the swell wave rose shown in Figure 10. The Kekaha and Poipu regions, on the leeward shore of Kauai, are exposed to Kona storm waves, southern hemisphere swell and to some extent North Pacific Swell. Kona waves can approach the regions either from the south or west   Southern hemisphere swell approaches the regions from the south.   North Pacific swell reaches the western end of the Kekaha region. With the exception of the Shipwreck Beach area of the Poipu region, the study regions are sheltered from the predominant northeast tradewind-generated waves.

Other wave types occur much less frequently. Hurricane waves can approach from the southeast through southwest directions. Tsunamis can approach from any direction and can create significant scour on reef fronts. The 1960 Chile tsunami included a wave crest of more than 4 feet above sea level and a trough of approximately 6 feet below (Houston 1978) – low enough to uncover much of the reef surface in the study region.

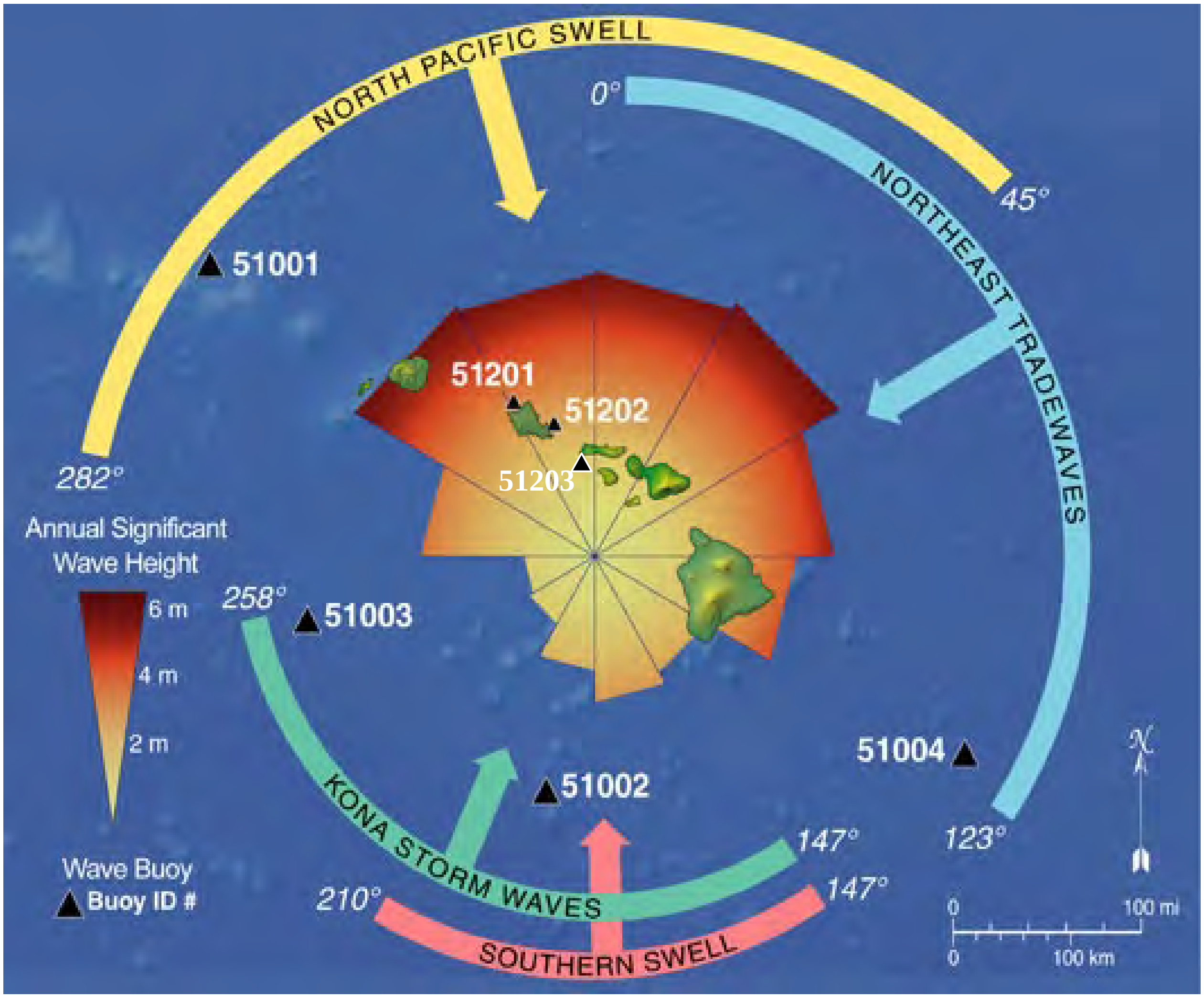


Figure 10. Dominant Wave Directions, Swell Wave Rose, and Monitoring Buoy Locations (Vitousek and Fletcher 2008)

D. Numerical Modeling of Wave Transformation

The nearshore wave climate in the study region has been investigated by the USACE Honolulu District using the STWAVE model. STWAVE simulates depth-induced wave refraction and shoaling, current-induced refraction and shoaling, depth- and steepness-induced wave breaking, diffraction, and wave growth because of wind input. The incoming wave conditions used for the model studies were based on the closest Wave Information Studies (WIS) stations to the study regions.

A summary of the WIS data and results of the modeling are discussed below for each of the two Kauai regions. The complete reports for each region are provided in Appendices B and C.

Additionally, USACE performed an analysis as to whether or not Kona waves are captured in the WIS data. NOAA National Data Buoy Center (NDBC) wave data from five specific Kona events were compared to the USACE WIS data. Some, but not all, of the Kona events resulted in elevated wave energy. The analysis concludes that WIS generally captures these events, but overestimates the wave heights in some cases and underestimates the wave heights in some cases (peak error up to 1 meter).

Kekaha Region

Kekaha is on the southwest shore of the Kauai with exposure to waves arriving from approximately 170 to 300 deg. The closest Wave Information Studies (WIS) save point is Station 120 located at 21.5 deg North and 160 deg West in a depth of 3,438 m (11,280 ft). Station 120 is shown in Figure 11 with a yellow circle. A wave rose for Station 120 for 1981-2004 is given in Figure 12. The wave rose shows distribution of wave height with wave direction. The largest wave heights come from storms out of the northwest.

Three representative years were chosen for further study and nearshore wave transformation. The three years are: a low wave condition year (1984), a medium wave condition year (1992), and a high wave condition year (1994).

Since the WIS save points are in deep water and away from Kauai, the wave heights include energy from both waves moving toward and away from the island. To eliminate energy moving away from Kekaha, the WIS spectra for these three years were truncated to include only energy from 167.5 to 342.5 deg (255 deg +/-87.5 deg). Then, the truncated spectra were used to recalculate wave height, peak wave period, and mean wave direction.

These wave parameters from the truncated spectra were then analyzed using the Coastal Engineering Design and Analysis System (CEDAS) to quantify the distributions of wave height period and direction.

A summary of the percent and number of occurrence plots are shown in Figure 13 for 1984, Figure 14 for 1992, and Figure 15 for 1994. The individual plots are provided in Appendix B. The directions on these plots are relative to the normal of the local wave grid (0 deg in the relative system is a wave from 255 deg clockwise from north, +45 deg is 210 deg, and -45 deg is 300 deg). The plots are useful for assessing wave height, period, and direction combinations to be run for the nearshore wave transformation analysis.

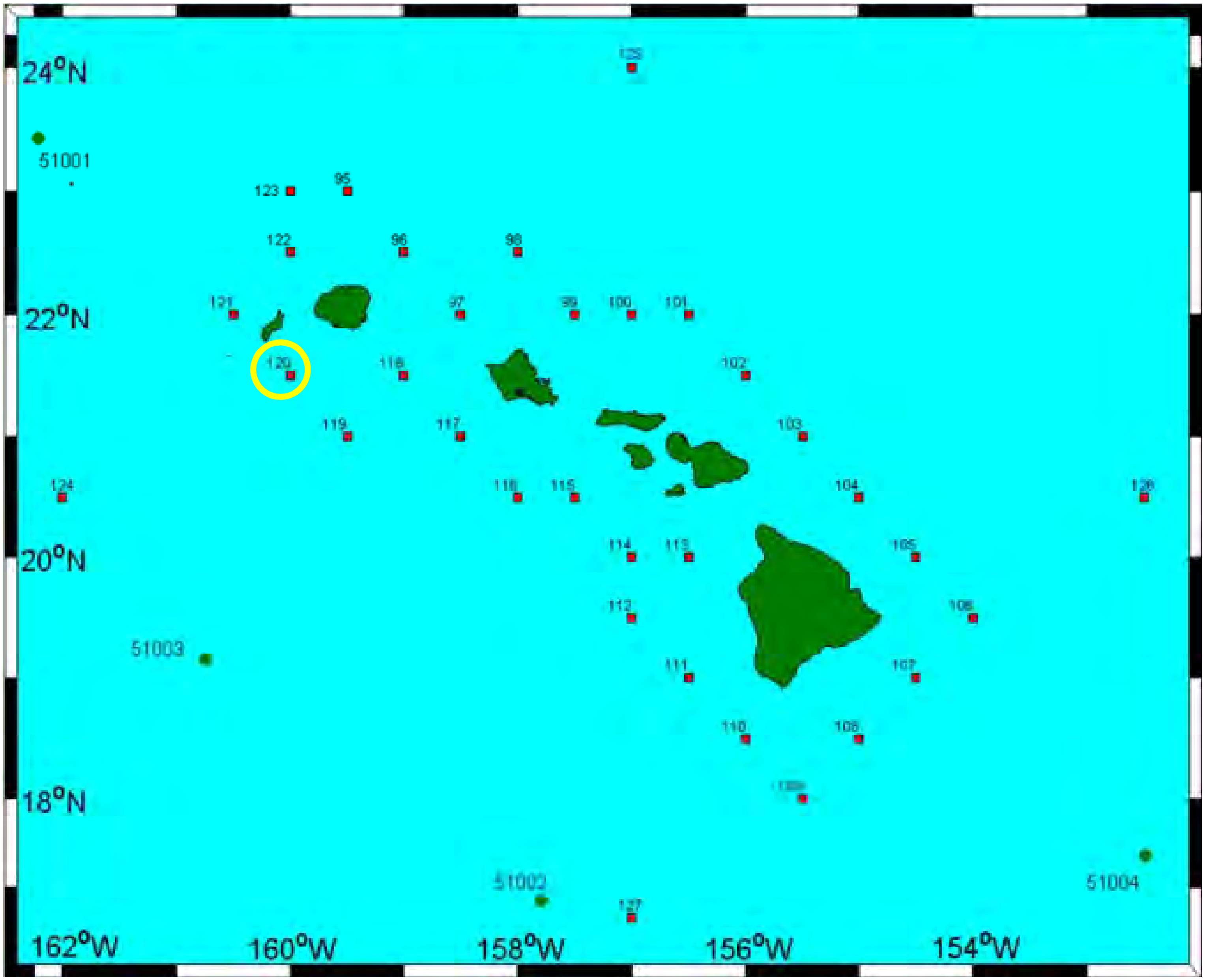


Figure 11. WIS Station Location – Kekaha Region

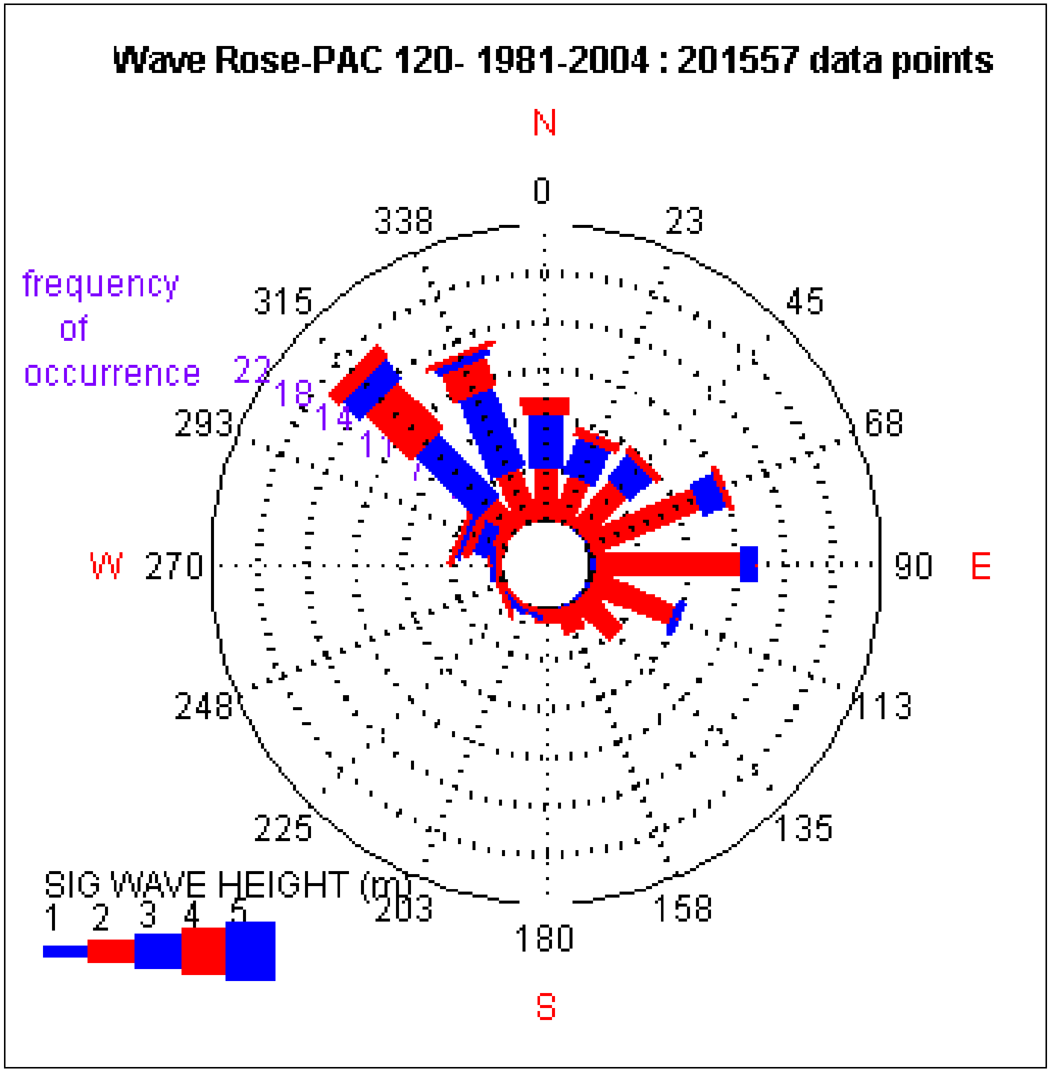


Figure 12. Wave Rose for 1981-2004 for WIS Station 120

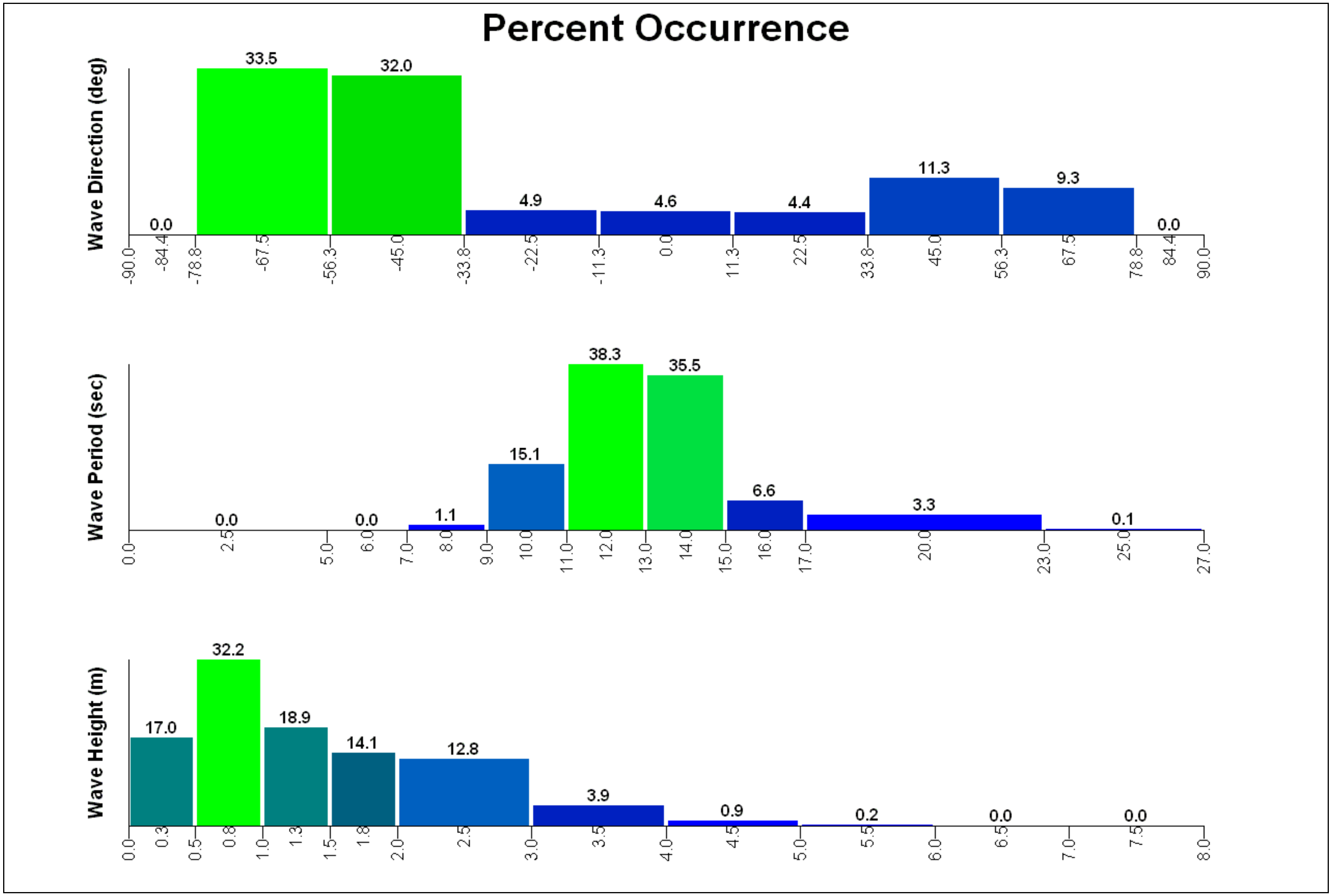


Figure 13. 1984 Percent Occurrences for Wave Height, Peak Period, and Mean Direction for WIS Station 120

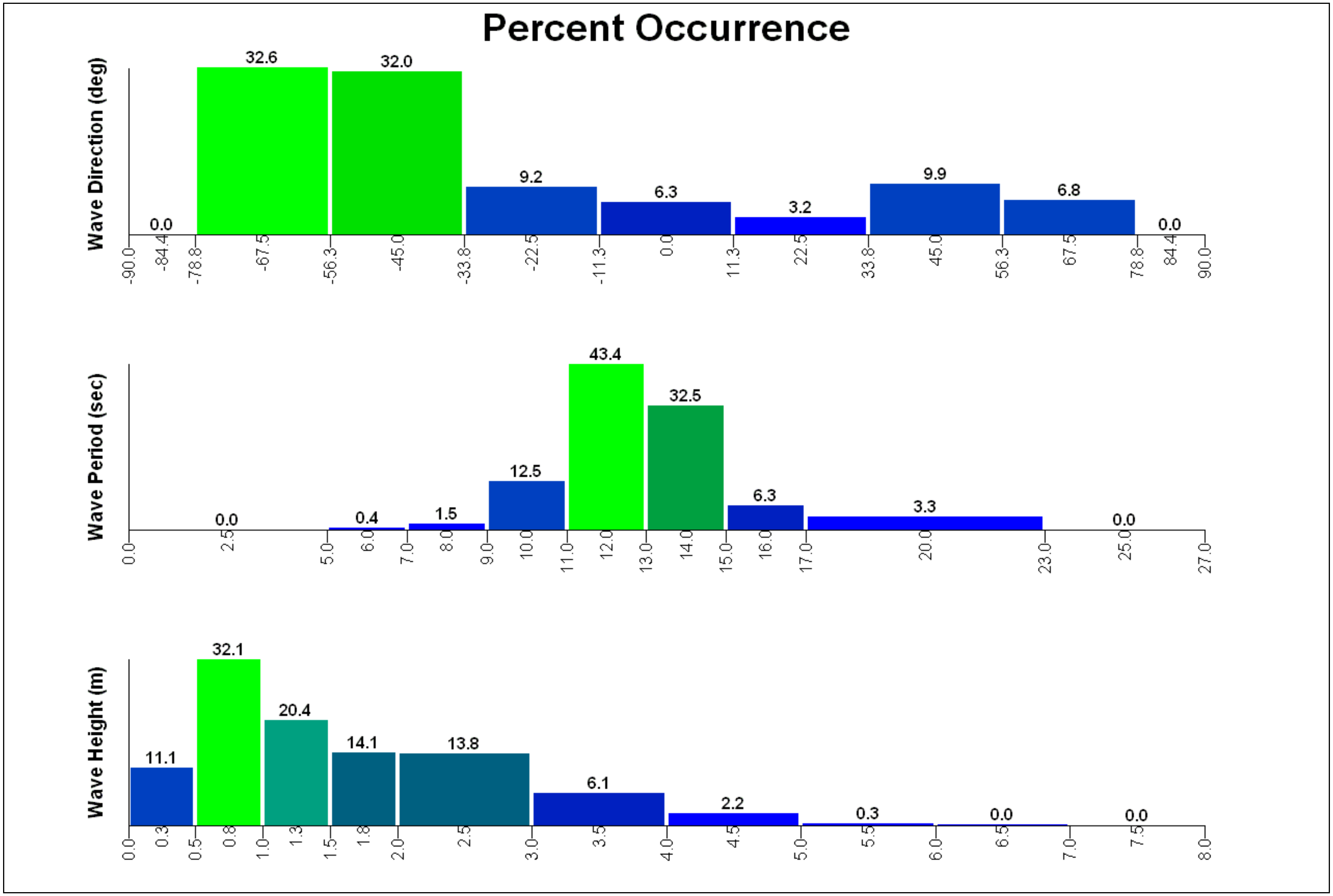


Figure 14. 1992 Percent Occurrences for Wave Height, Peak Period, and Mean Direction for WIS Station 120

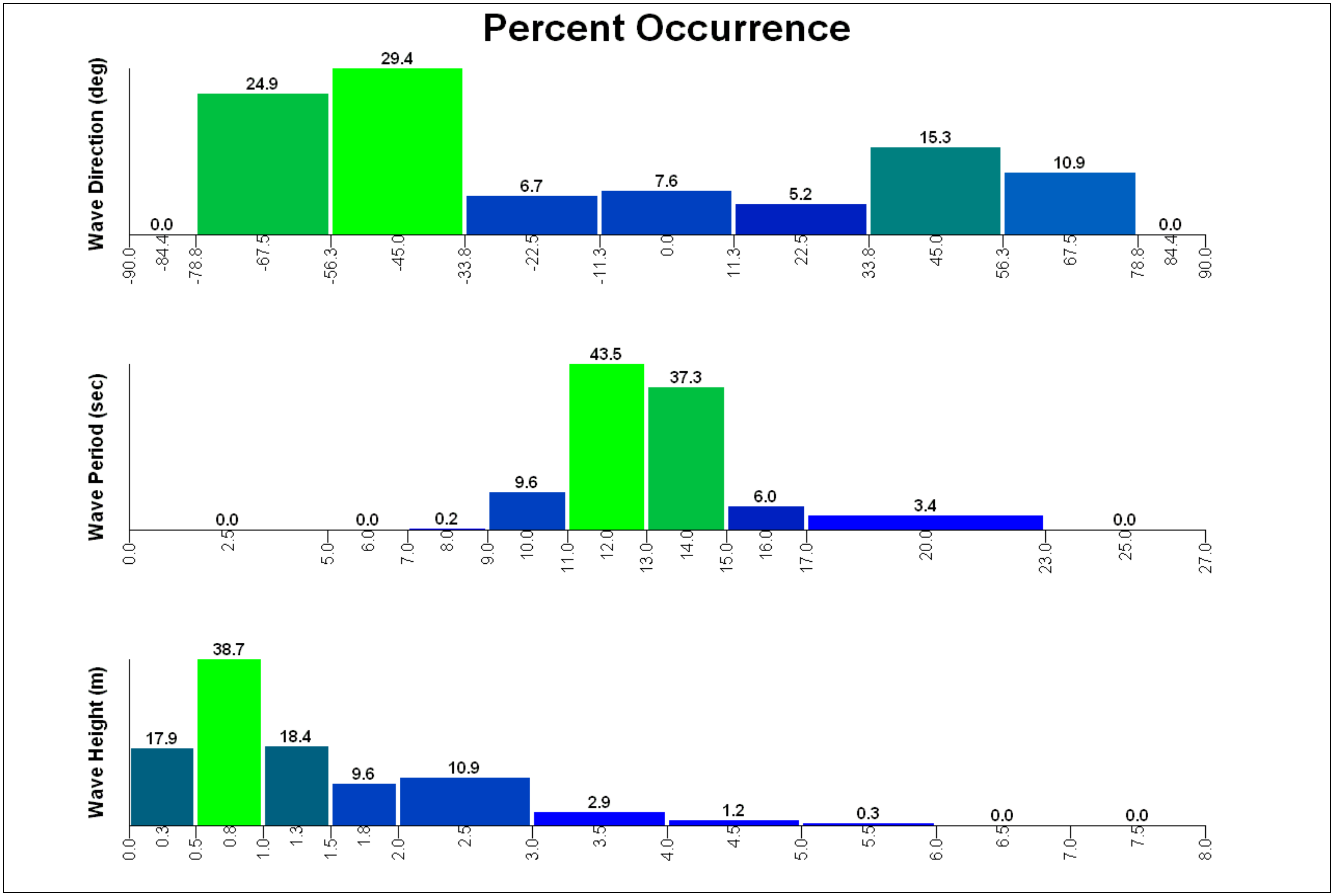


Figure 15. 1994 Percent Occurrences for Wave Height, Peak Period, and Mean Direction for WIS Station 120

Table 2 provides a summary of the mean and maximum wave statistics for the years 1984, 1992, and 1994. Tables 3, 4 and 5 provide wave parameters used to complete nearshore wave model runs and to build a lookup table to be used in simulating nearshore wave climatology.

Table 2. Mean and Maximum Statistics – Kekaha Region Waves

	1984	1992	1994
Mean Wave Height (m)	1.3	1.4	1.2
Mean Peak Period (s)	12.8	12.7	13
Largest Wave Height (m)	5.2	6.2	5.9
Peak of Largest Height (s)	19.8	18	16.3
Direction Bin of Largest Height (deg)	300	322.5	300

Table 3. Typical Conditions – Kekaha Region Waves (392 conditions)

Significant Wave height, m	Wave period, sec	Wave Direction, deg from grid x-axis	Wave Direction, deg meteorological convention
0.5 (1)	6 (1)	-67.5 (1)	from 320 deg
1.0 (2)	8 (2)	-45 (2)	from 305 deg
1.5 (3)	10 (3)	-22.5 (3)	from 282.5 deg
2.0 (4)	12 (4)	0 (4)	from 260 deg
2.5 (5)	14 (5)	22.5 (5)	from 237.5 deg
3.0 (6)	16 (6)	45 (6)	from 215 deg
4.0 (7)	20 (7)	67.5 (7)	from 200 deg
5.0 (8)			

Table 4. Extreme Conditions – Kekaha Region Waves (16 conditions)

Significant Wave height, m	Wave Period, sec	Wave Direction, deg from STWAVE axis	Wave Direction, deg met convention
6 (9)	12 (4)	-67.5 (1)	from 320 deg
7 (10)	14 (5)	-45 (2)	from 305 deg
	16 (6)		
	20 (7)		

Table 5. Long-period Conditions – Kekaha Region Waves (4 conditions)			
Significant Wave height, m	Wave Period, sec	Wave Direction, deg from STWAVE axis	Wave Direction, deg met convention
1.5 (3)	25 (8)	-45 (2)	from 305 deg
2.0 (4)			
2.5 (5)			
3.0 (6)			

Nearshore STWAVE grids were generated for the Kekaha and Poipu regions using the island-wide bathymetry data developed for the Surge and Wave Island Modeling Studies (SWIMS) being conducted by the US Army Corps of Engineers, the University of Hawaii, and Notre Dame University in combination with high-resolution Light Detection and Ranging (LiDAR) data in the nearshore (from USACE Joint Airborne LiDAR Bathymetry Technical Center of Expertise). The SWIMS dataset incorporates various sources of data and was used for areas of deep water (> 30m), because it has relatively low resolution (~300 meters). The LiDAR data was used to augment shallow, nearshore areas, and has resolution as fine as 1 meter. The STWAVE grid encompasses the entire Kekaha RSM region, as shown in Figure 16 below, with a grid resolution of 50m.

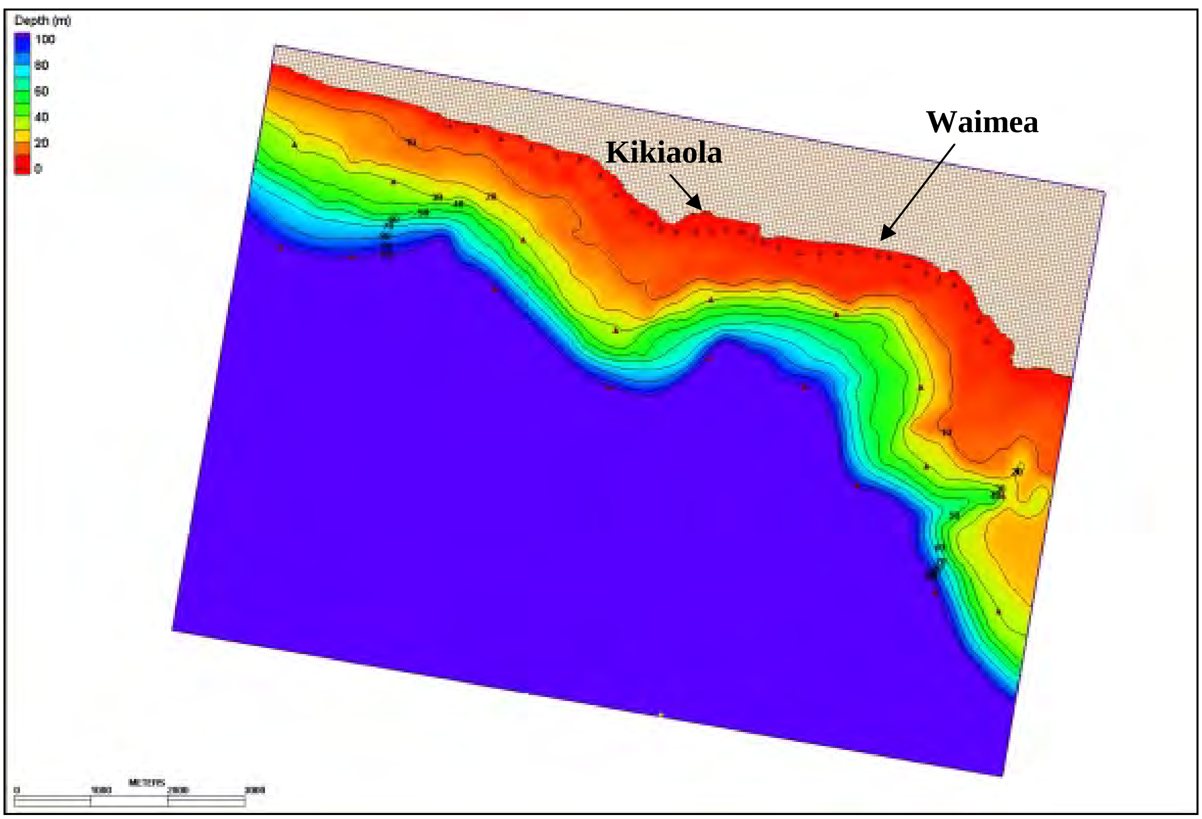


Figure 16. STWAVE grid extents for Kekaha Region (10 m contours shown)

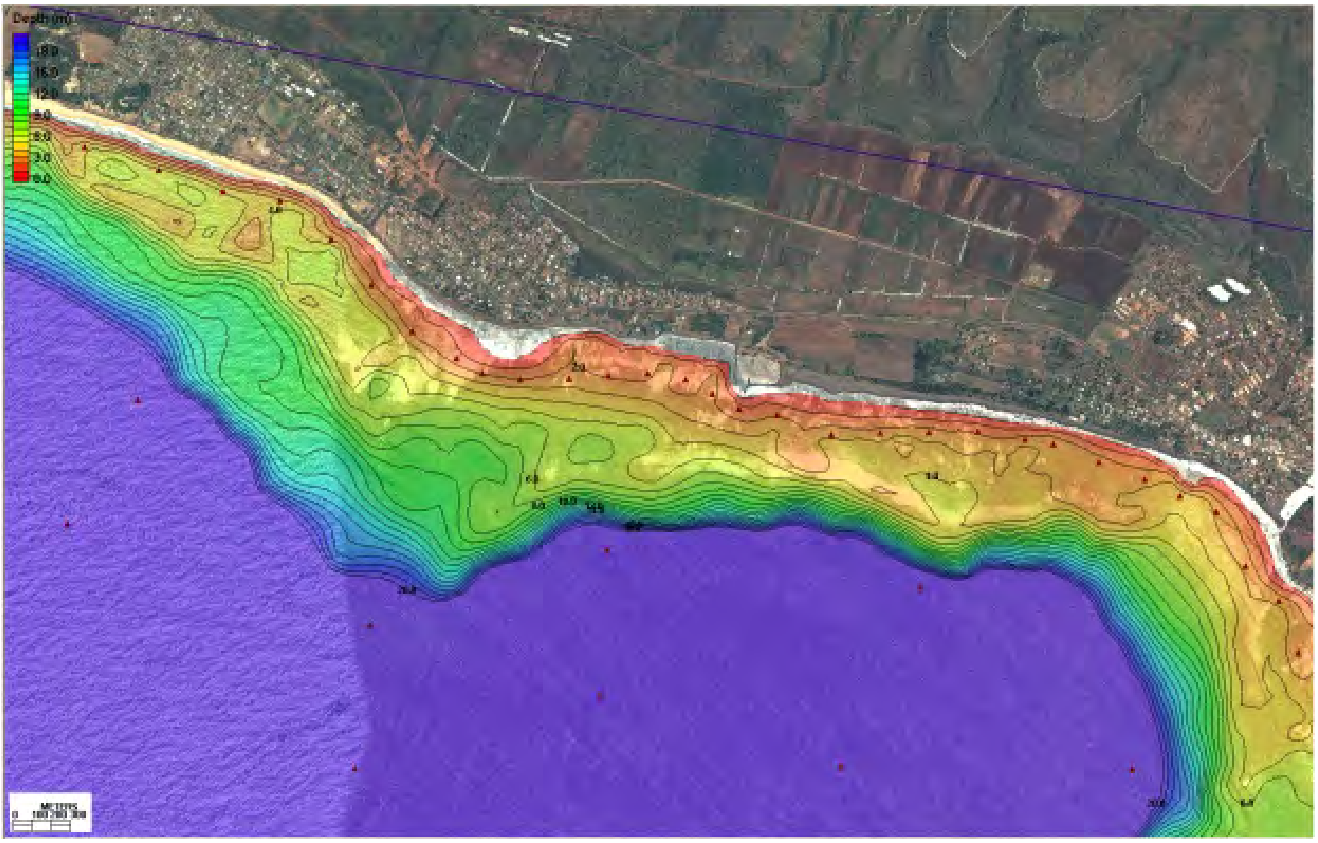


Figure 17. STWAVE Nearshore Grid Adjacent to Kikiaola Harbor in Kekaha Region (1m contours shown)

Wave parameters from Tables 3, 4 and 5 were used to generate wave input spectra for the Kekaha grid. The parameters were entered into the Surfacewater Modeling System (SMS) and wave spectra files were generated for each case using the TMA (named for TEXEL, MARSEN and ARSLOE storm data sets) shallow water spectra option and the recommended values of n (directional peak spreading factor) and gamma (spectral peak spreading factor). These wave spectra were used to force the offshore boundary of each grid, and the wave transformation was carried out by STWAVE.

Wave height (meters), wave period (seconds) and wave direction (degrees) were saved for each wave case at all ocean cells within the grid. An example of the resulting wave height information (in color) and wave direction (arrows) for the Kekaha grid is shown in Figure 18. In addition, observation points were placed along the nearshore at approximately 1 to 3 meters depth, and along the 30 m and 100 m contours (also visible in Figure 18 as black squares). Wave parameters for these selected locations were saved in a separate file for use in the next step of the process.

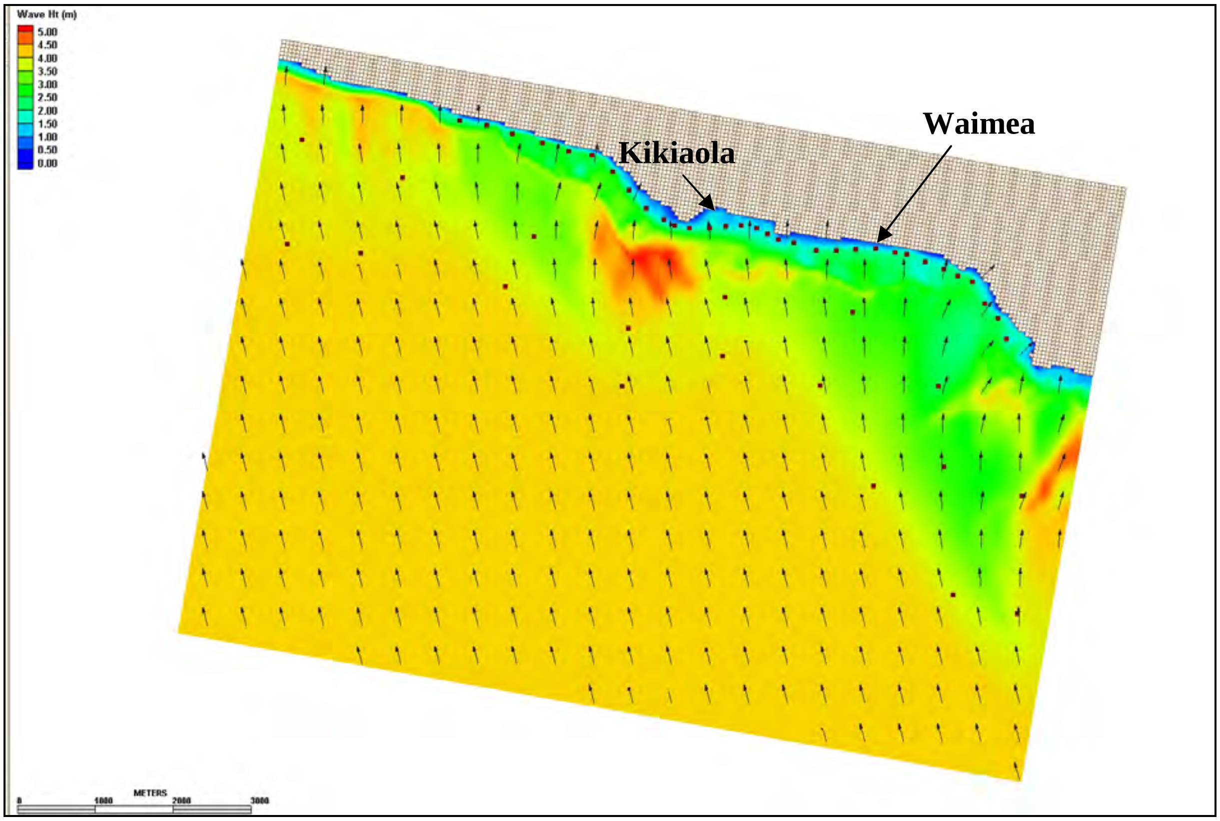
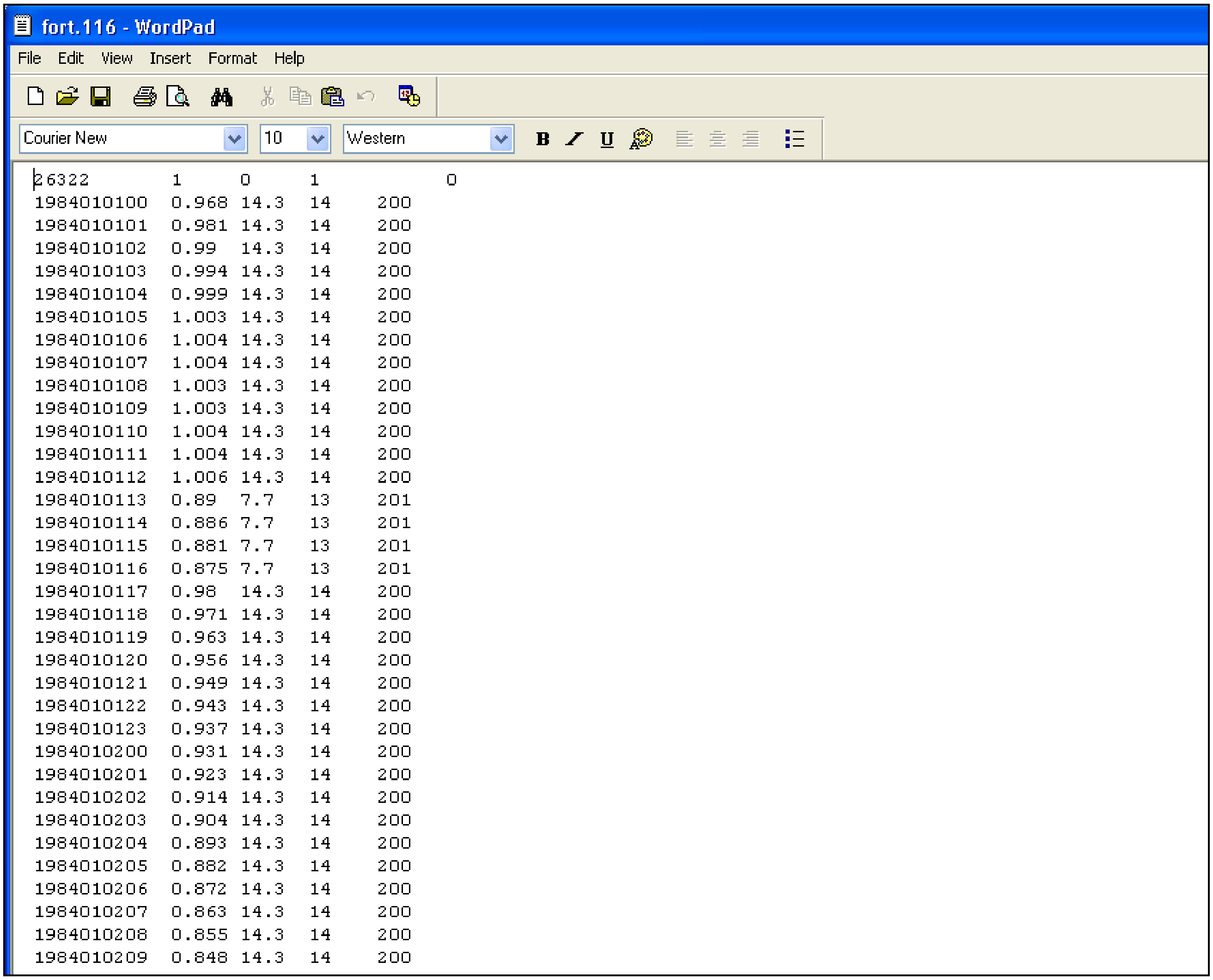


Figure 18. Resulting Wave Height (color scale) and Wave Direction (arrows) in Kekaha Region for Case 754 (Ho = 4m, T= 14s, Dir=190) and Location of Observation Points (black squares)

A database (or "lookup table") of wave parameters that correlates the most frequent offshore wave conditions at the WIS station (from Tables 3, 4 and 5 for Kekaha) to the resulting nearshore wave conditions at the selected observation points has been developed from the application of STWAVE for several hundred wave transformations for each region.

The next step carried out was to develop a FORTRAN program to automate the "lookup table" process, so that the hourly time series of wave data from the three representative years (1984, 1992, and 1994) of WIS data could be converted to nearshore wave parameters at each observation point. This program required inputs of the WIS time series data, the output wave parameter file from the STWAVE runs, as well as a file denoting the angle of the "onshore" direction (relative to TN) at each nearshore observation point so that a relative wave angle could be determined. Since it was not possible to model each specific wave case that occurs in the WIS time series, the hourly parameter data was binned to find the closest matching wave case that was defined in the model runs. If no such case existed, the program returned a result of 0.0 and the nearshore wave parameters were not calculated for that time step. Since the most frequent wave occurrences were determined as described previously, it is assumed that this condition does not represent a significant quantity of the WIS time series, and therefore the nearshore wave climate. A cursory examination of output files suggests this condition occurred < 5% of the time. An output nearshore time series including all three years of WIS data was calculated for each nearshore observation point, in both the Kekaha and Poipu grids. A portion of an output file resulting from the application of the FORTRAN program is shown in Figure 19 for reference. Output parameters are date/ time, wave height, wave period, wave direction (relative to shoreline) and wave direction (relative to TN).




```
26322        1     0     1           0
1984010100  0.968 14.3  14    200
1984010101  0.981 14.3  14    200
1984010102  0.99  14.3  14    200
1984010103  0.994 14.3  14    200
1984010104  0.999 14.3  14    200
1984010105  1.003 14.3  14    200
1984010106  1.004 14.3  14    200
1984010107  1.004 14.3  14    200
1984010108  1.003 14.3  14    200
1984010109  1.003 14.3  14    200
1984010110  1.004 14.3  14    200
1984010111  1.004 14.3  14    200
1984010112  1.006 14.3  14    200
1984010113  0.89  7.7   13    201
1984010114  0.886 7.7   13    201
1984010115  0.881 7.7   13    201
1984010116  0.875 7.7   13    201
1984010117  0.98  14.3  14    200
1984010118  0.971 14.3  14    200
1984010119  0.963 14.3  14    200
1984010120  0.956 14.3  14    200
1984010121  0.949 14.3  14    200
1984010122  0.943 14.3  14    200
1984010123  0.937 14.3  14    200
1984010200  0.931 14.3  14    200
1984010201  0.923 14.3  14    200
1984010202  0.914 14.3  14    200
1984010203  0.904 14.3  14    200
1984010204  0.893 14.3  14    200
1984010205  0.882 14.3  14    200
1984010206  0.872 14.3  14    200
1984010207  0.863 14.3  14    200
1984010208  0.855 14.3  14    200
1984010209  0.848 14.3  14    200
```

Figure 19. Sample Nearshore Observation Point Time Series Output File from FORTRAN Program (date/time, Wave Height (m), Wave Period (s), Wave Direction (relative degrees), Wave Direction (relative TN))

Finally, the time series for each observation point was used to develop a histogram for that location indicating the percent occurrence of wave approach direction (separated into 10 degree direction bins) as well as the frequency of significant wave height within each wave bin (separated into 0.5m wave height bins). An example histogram for an observation point near east of Kikiaola Harbor is shown in Figure 20. This figure shows that 9% of waves during the 3 selected years approached from 160-170 degrees TN, and that the significant wave heights at this location were in the 0.0 to 0.5m range. Similarly, 12% of waves approached from 170– 180 degrees TN, with waves in the 0.0 to 0.5m and 0.5 to 1.0 m ranges, and so on. The column on the far right of the figure shows that 58% of waves approached from 200-210 degrees TN, however the wave heights from this direction range from less than 0.5m up to the 2.0 to 2.5m range. Another histogram of an observation point to the west of Kikiaola Harbor is shown in Figure 21, and indicates a similar directional spread but slightly less variability in significant wave height. This may be due to differences in the offshore bathymetry at the observation points.

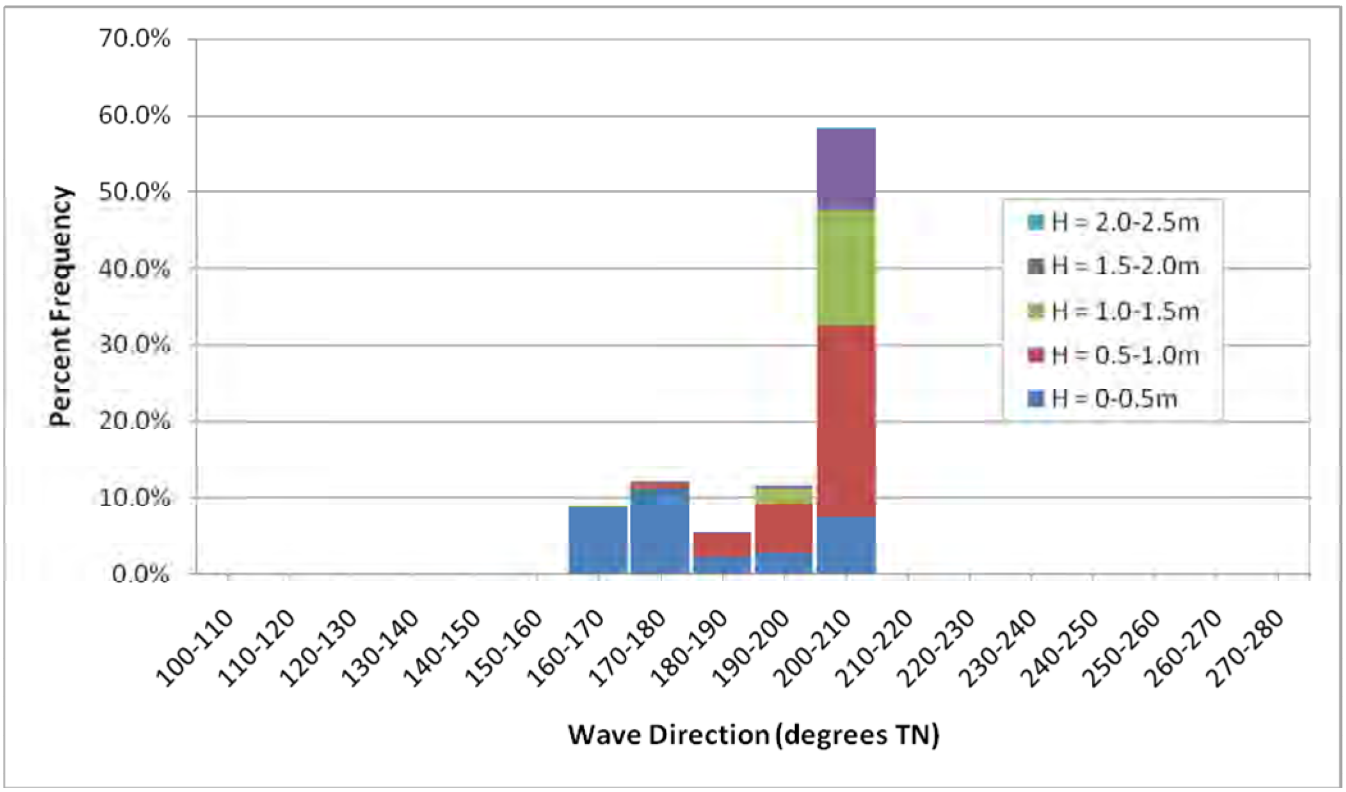


Figure 20. Histogram of Wave Height and Direction at Nearshore Observation Point East of Kikiaola Harbor (Shore normal = 187 degrees TN)

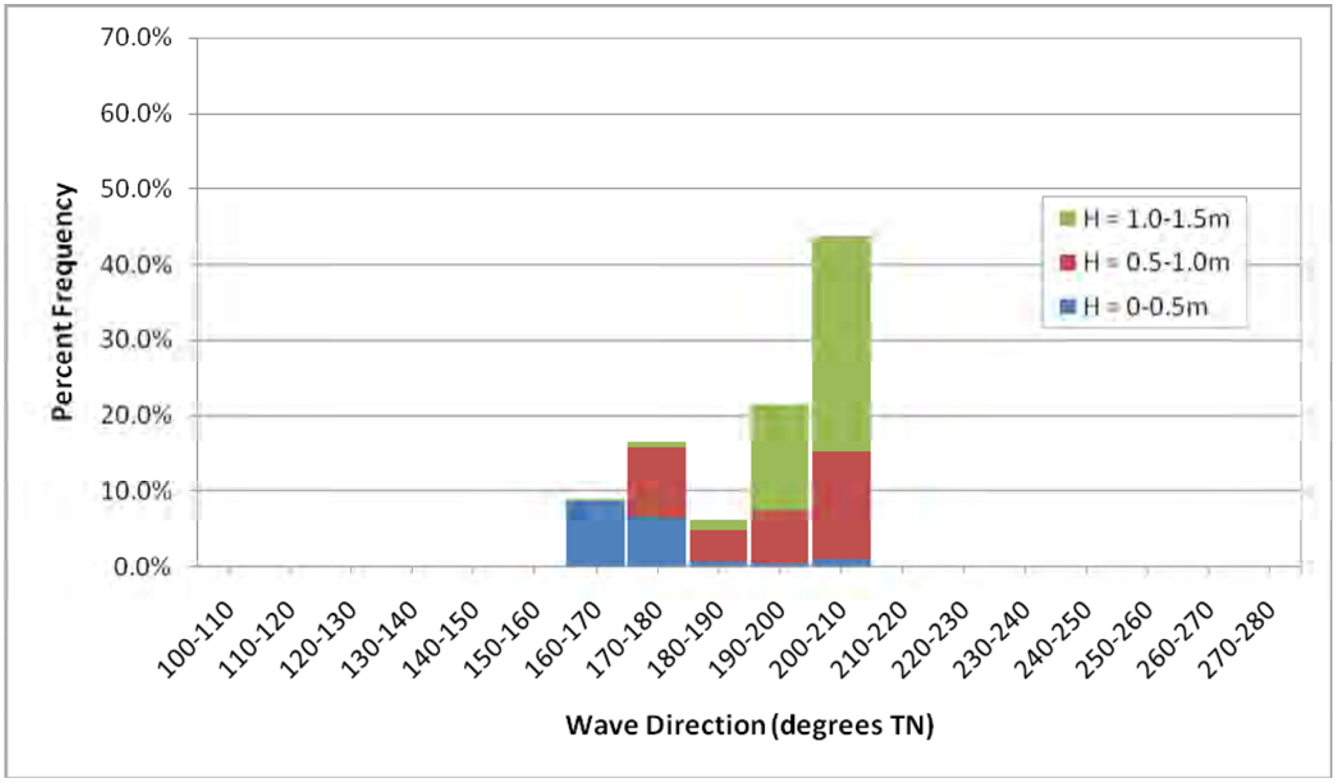


Figure 21. Histogram of Wave Height and Direction at Nearshore Observation Point West of Kikiaola Harbor (Shore normal = 184 degrees TN)

Poipu Region

Poipu is on the south shore of the Kauai with exposure to waves arriving from approximately 90 to 270 deg. The Wave Information Studies (WIS) save point directly south of Poipu is Station 119 located at 23 deg North and 159.5 deg West in a depth of 4,530 m (14,860 ft). Station 119 is shown in Figure 22 with a yellow circle. A wave rose for Station 119 for 1981-2004 is given in Figure 23. The wave rose shows distribution of wave height with wave direction. The largest wave heights come from storms out of the northwest.

Three representative years were chosen for further study and nearshore wave transformation. The three years are a low wave condition year (1984), a medium wave condition year (1992) and a high wave condition year (1994).

Since the WIS save points are in deep water and away from Kauai, the wave heights include energy from both waves moving toward and away from the island. To eliminate energy moving away from Poipu, the WIS spectra for these three years were truncated to include only energy from 92.5 to 267.5 deg (180 deg +/-87.5 deg). Then, the truncated spectra were used to recalculate wave height, peak wave period, and mean wave direction.

These wave parameters from the truncated spectra were then analyzed using the Coastal Engineering Design and Analysis System (CDAS) to quantify the distributions of wave height period and direction.

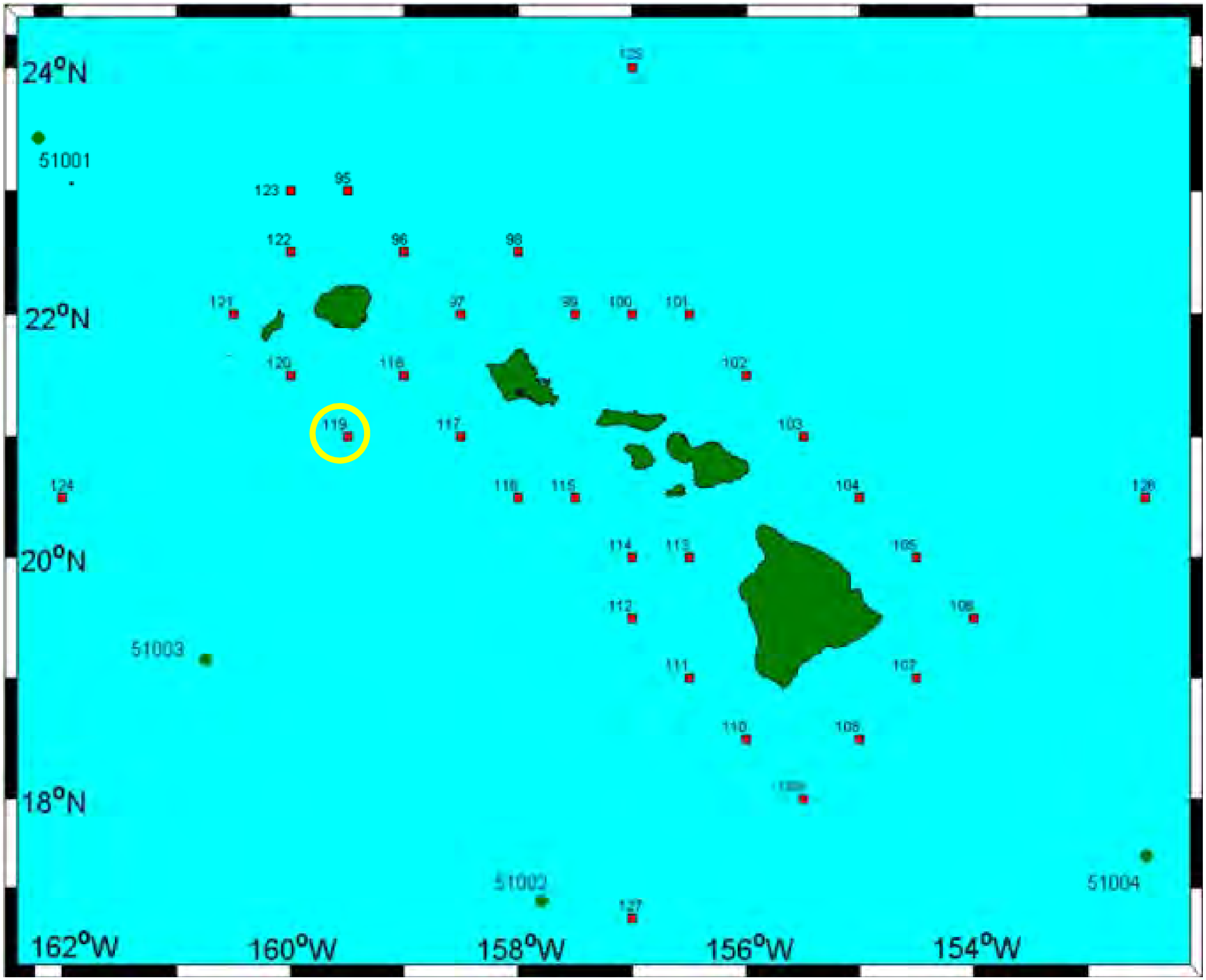


Figure 22. WIS Station Location – Poipu Region

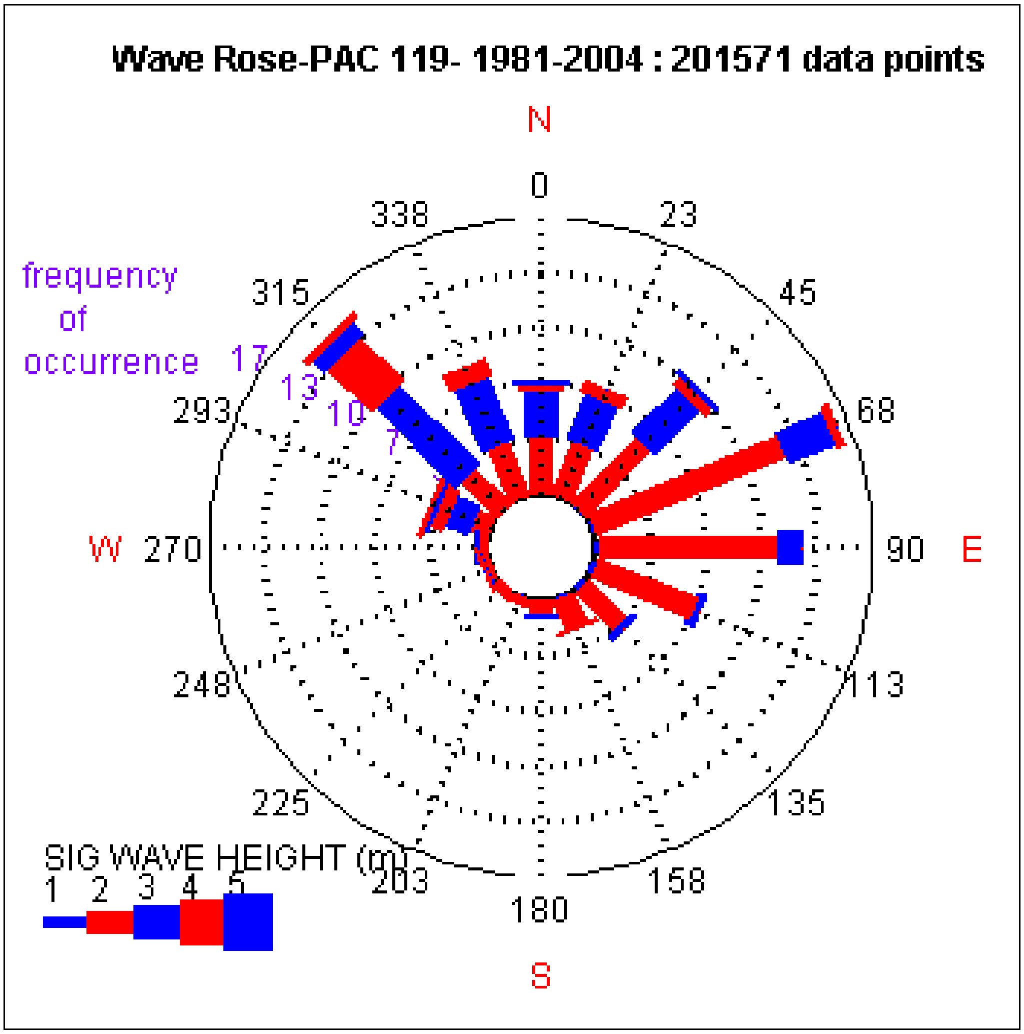


Figure 23. Wave Rose for 1981-2004 for WIS Station 119

A summary of the percent and number of occurrence plots are shown in Figure 24for 1984, Figure 25 for 1992, and Figure 26 for 1994. The individual plots are provided in Appendix C. The directions on these plots are relative to the normal of the local wave grid (0 deg in the relative system is a wave from 180 deg clockwise from north, +45 deg is 135 deg, and -45 deg is 225 deg). The plots are useful is assessing wave height, period, and direction combinations to be run for the nearshore wave transformation analysis.

Table 6 provides a summary of the mean and maximum wave statistics for the years 1984, 1992, and 1994. Tables 7 and 8 provide wave parameters used to complete nearshore wave model runs and to build a lookup table to be used in simulating nearshore wave climatology.

Note that the “typical conditions” are the same as for Kekaha (relative to the grid), so the same boundary conditions could be used. Some height-period-direction combinations can be eliminated, e.g., wave heights above 1.5 m and periods above 9 sec were not observed for the -67.5 deg wave direction.

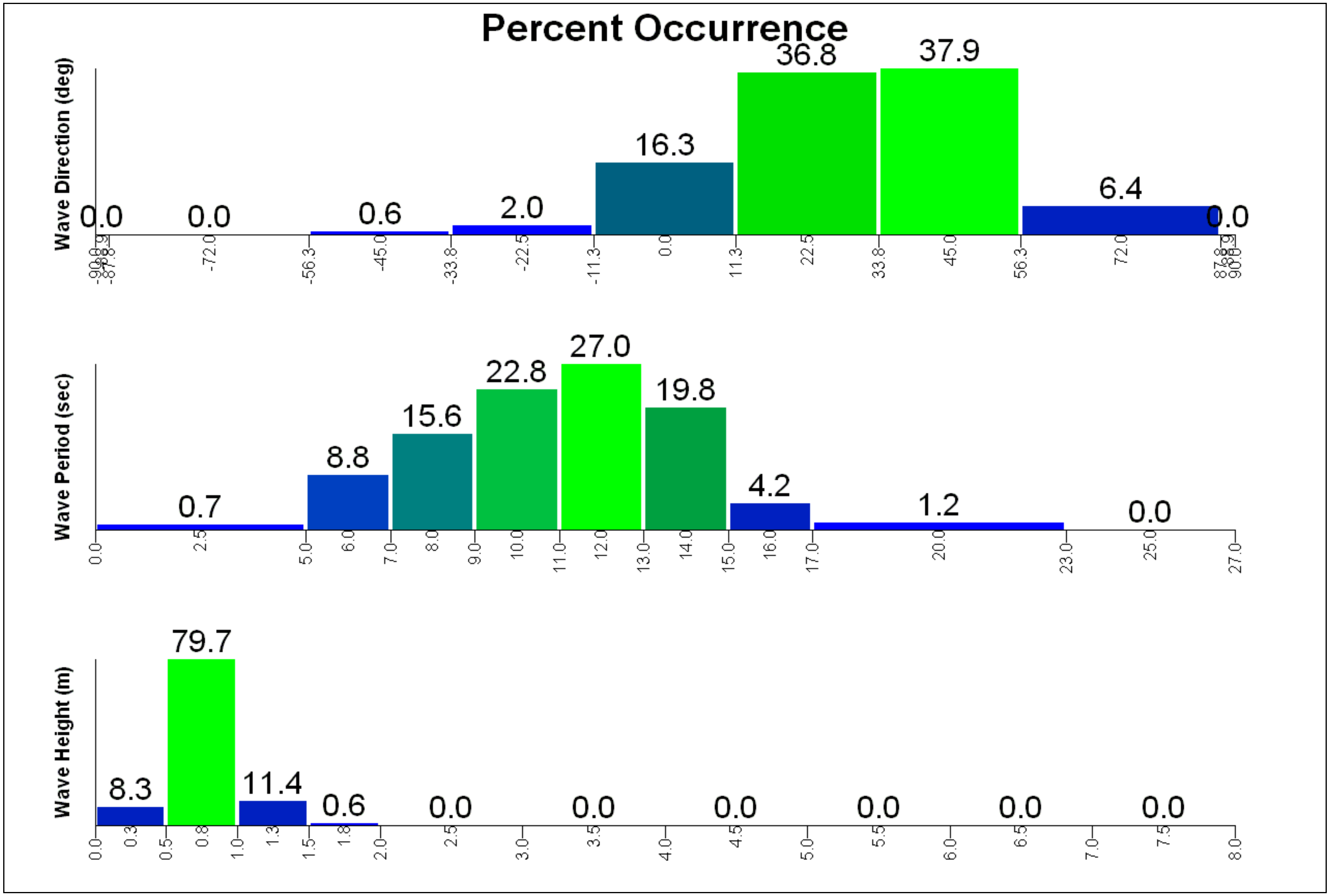


Figure 24. 1984 Percent Occurrences for Wave Height, Peak Period, and Mean Direction for WIS Station 119

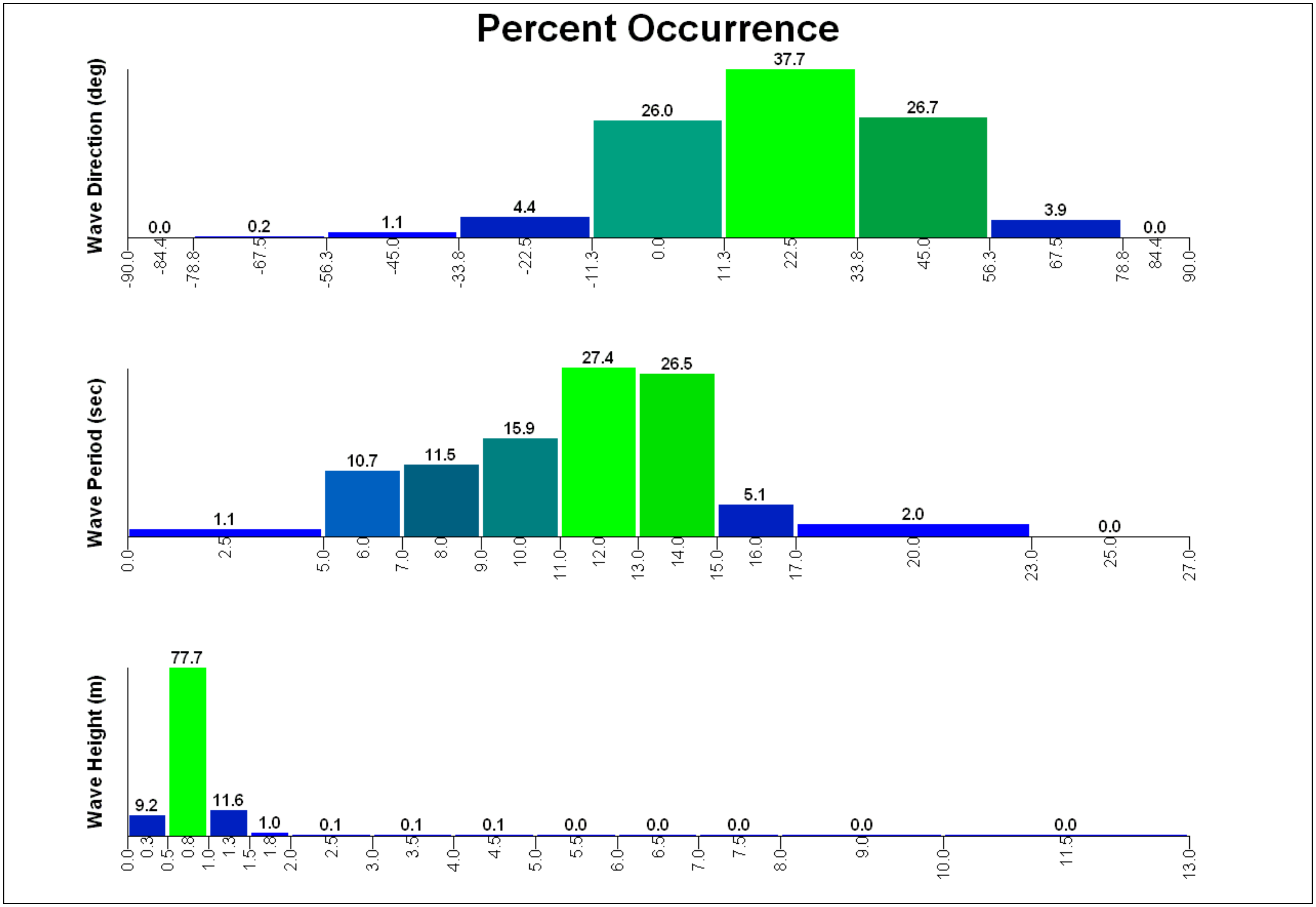


Figure 25. 1992 Percent Occurrences for Wave Height, Peak Period, and Mean Direction for WIS Station 119

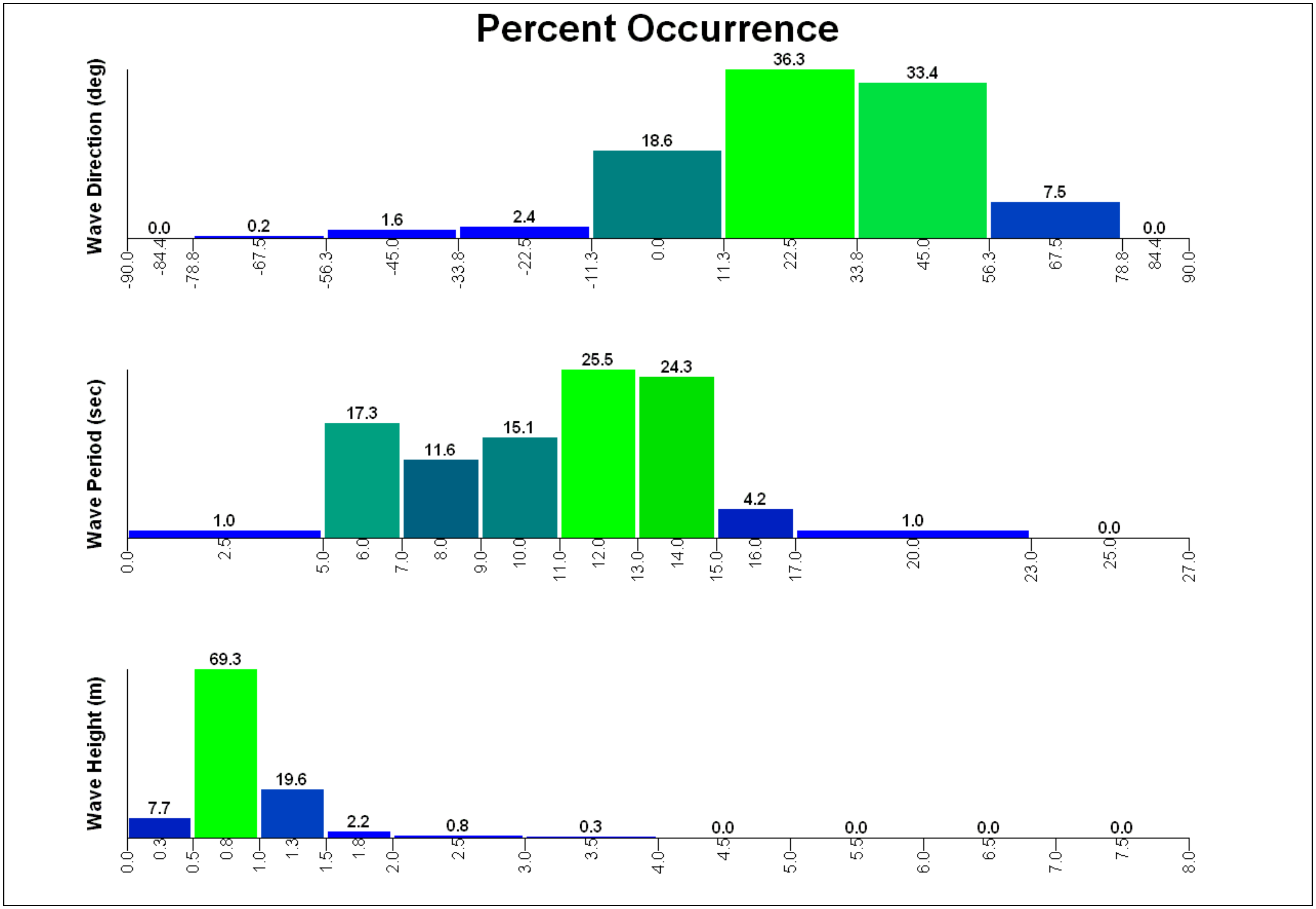


Figure 26. 1994 Percent Occurrences for Wave Height, Peak Period, and Mean Direction for WIS Station 119

Table 6. Mean and Maximum Statistics – Poipu Region Waves			
Year	1984	1992	1994
Mean Wave Height (m)	0.8	0.8	0.9
Mean Peak Period (s)	10.9	11.3	10.8
Largest Wave Height (m)	1.7	12.3	3.4
Peak of Largest Height (s)	7.6	13.5	11.2
Direction of Largest Height (deg)	112.5	157.5	135

Table 7. Typical Conditions - Poipu Region Waves (343 conditions)			
Significant Wave Height, m	Wave Period, sec	Wave Direction, deg from grid x-axis	Wave Direction, deg meteorological convention
0.5 (1)	6 (1)	-67.5 (1)	from 247.5 deg
1.0 (2)	8 (2)	-45 (2)	from 225 deg
1.5 (3)	10 (3)	-22.5 (3)	from 202.5 deg
2.0 (4)	12 (4)	0 (4)	from 180 deg
2.5 (5)	14 (5)	22.5 (5)	from 157.5 deg
3.0 (6)	16 (6)	45 (6)	from 135 deg
4.0 (7)	20 (7)	67.5 (7)	from 112.5 deg

Table 8. Extreme Conditions - Poipu Region Waves (36 conditions)			
Significant Wave Height, m	Wave Period, sec	Wave Direction, deg from STWAVE axis	Wave Direction, deg met convention
5 (8)	10 (3)	0 (4)	from 180 deg
6 (9)	12 (4)	22.5 (5)	from 157.5 deg
7 (10)	14 (5)		
8 (11)			
9 (12)			
12 (13)			

The STWAVE grid encompasses the entire Poipu RSM region, as shown in Figure 27 below, with a grid resolution of 50m. The Poipu grid is oriented such that its offshore boundary (at approximately 300 m depth) faces south at 180 degrees TN. The bathymetry along the nearshore areas includes the well-resolved features of the reef and other features such as channels and headlands. Figure 27 shows the rocky and jagged shoreline of the Poipu area. A detailed view of the STWAVE grid in the nearshore areas adjacent to Poipu Beach Park is shown in Figure 28.

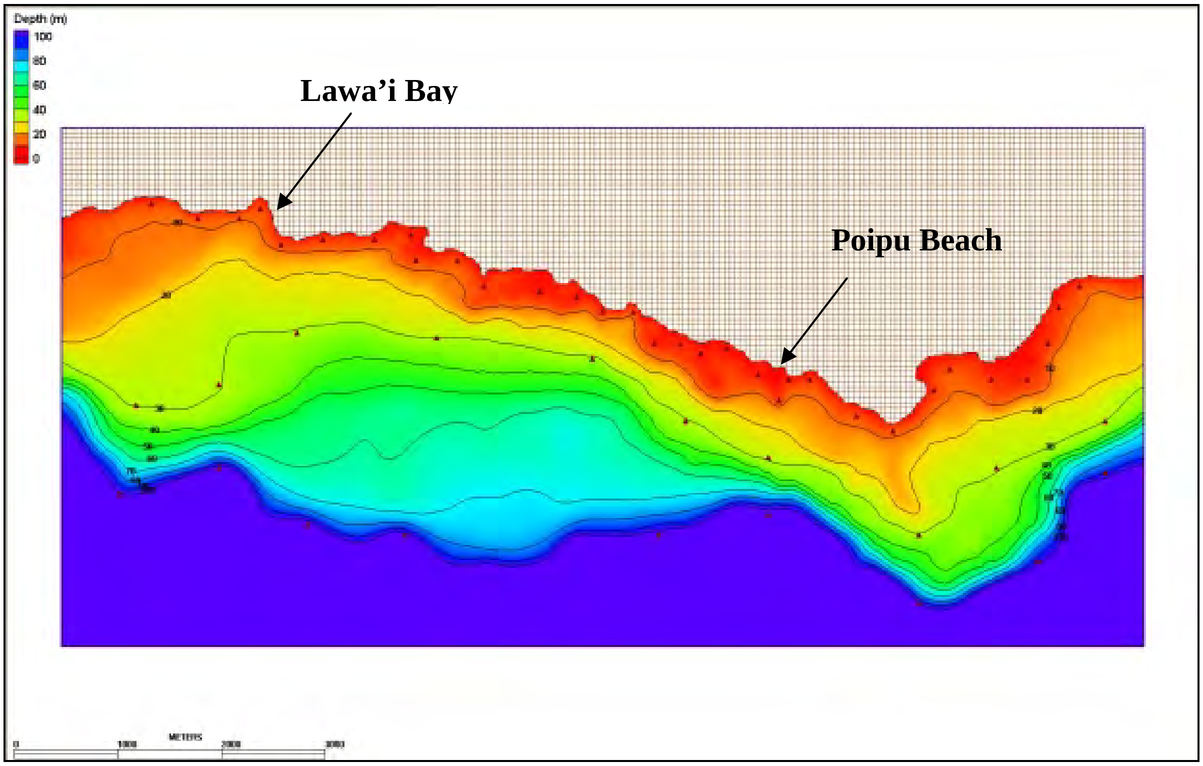


Figure 27. STWAVE Grid Extents for Poipu Region (10 m contours shown)

Figure 28. STWAVE Nearshore Grid Adjacent to Poipu Beach in Poipu Region
(1m contours shown)

Wave parameters from Tables 7 and 8 were used to generate wave input spectra for the Poipu grid. An example of the resulting wave height information (in color) and wave direction (arrows) for the Poipu grid is shown in Figure 29. In addition, observation points were placed along the nearshore at approximately 1 to 3 meters depth, and along the 30 m and 100 m contours (also visible in Figure 29 as black squares). Wave parameters for these selected locations were saved in a separate file for use in the next step of the process.

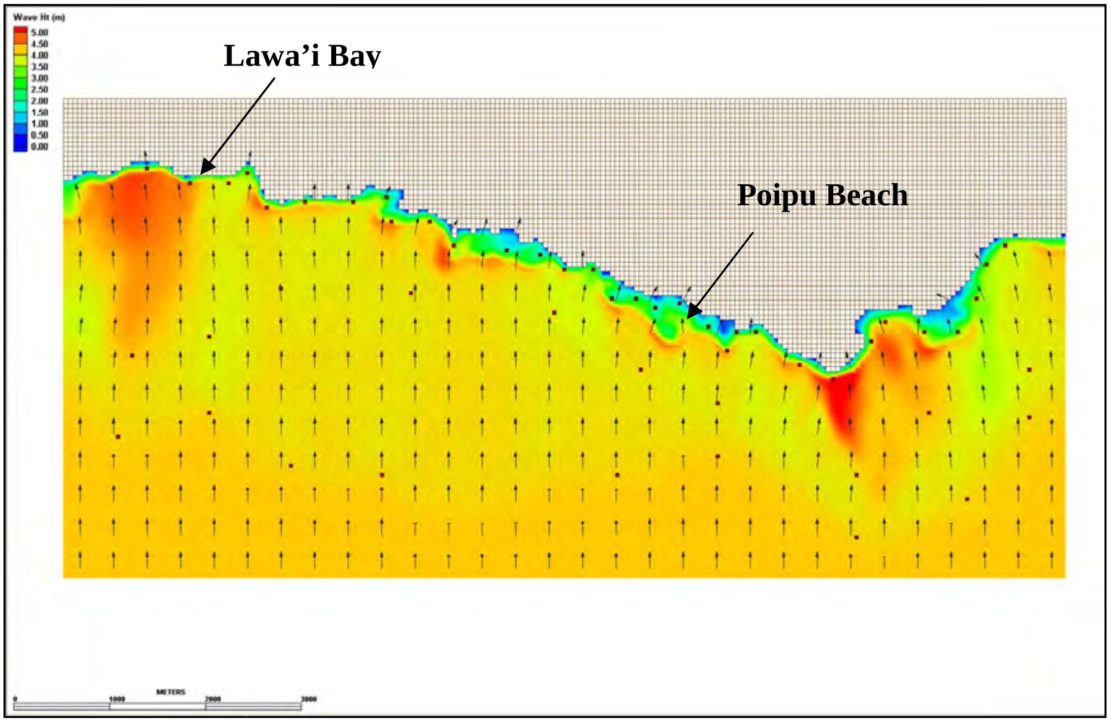


Figure 29. Resulting Wave Height (color scale) and Wave Direction (arrows) in Poipu Region for Case 754 (Ho = 4m, T= 14s, Dir=180) and Location of Observation Points (black squares)

A database (or "lookup table") of wave parameters that correlates the most frequent offshore wave conditions at the WIS station (from Tables 7 and 8) to the resulting nearshore wave conditions at the selected observation points has been developed from the application of STWAVE for several hundred wave transformations for each region.

The next step carried out was to develop a FORTRAN program to automate the "lookup table" process, so that the hourly time series of wave data from the three representative years (1984, 1992, and 1994) of WIS data could be converted to nearshore wave parameters at each observation point. An output nearshore time series including all three years of WIS data was calculated for each nearshore observation point in the grid.

Finally, the time series for each observation point was used to develop a histogram for that location indicating the percent occurrence of wave approach direction (separated into 10 degree direction bins) as well as the frequency of significant wave height within each wave bin (separated into 0.5m wave height bins). Histograms of two locations in the Poipu region, east and west of the Poipu Beach Park and Brennecke Beach areas, are shown in Figures 30 and 31, respectively.

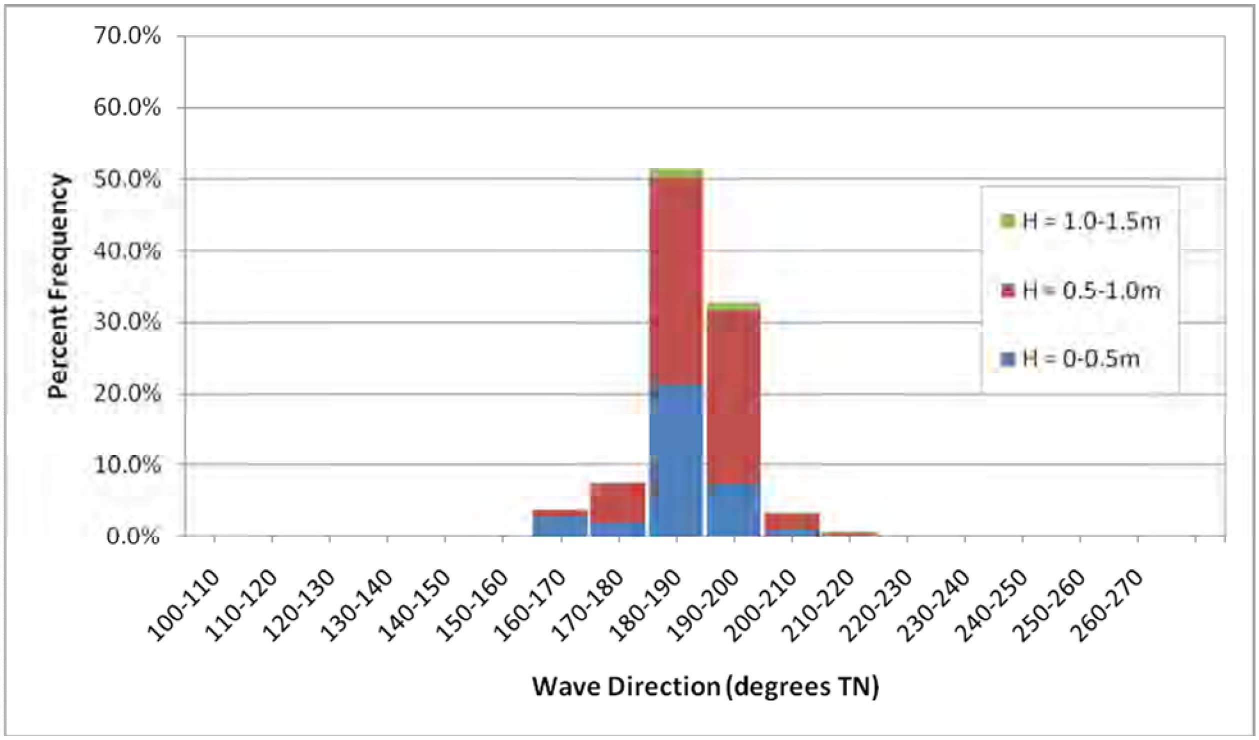


Figure 30. Histogram of Wave Height and Direction at Nearshore Observation Point East of Poipu Beach Park (Shore normal = 153 degrees TN)

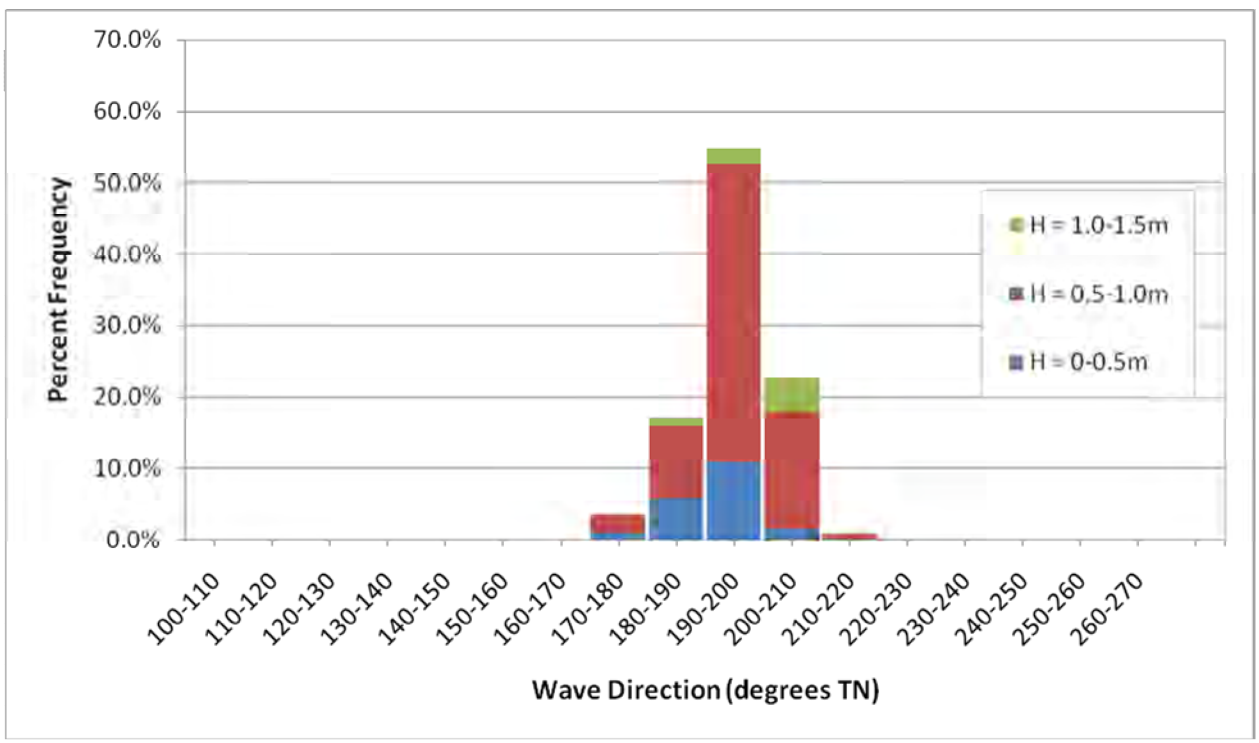


Figure 31. Histogram of Wave Height and Direction at Nearshore Observation Point West of Poipu Beach Park (Shore normal = 201 degrees TN)

This information (in combination with the shoreline orientation angle) may be useful in determining the dominant direction of wave approach at the selected observation points, and from that an estimate of sediment transport direction may be inferred and used to add arrows to the sediment budget. In addition, comparison of histograms for various locations indicates how much variability exists in the wave height directional spread of the nearshore waves. As an example, Figure 31 indicates that while the onshore normal direction at this observation point (Brennecke Beach) is approximately 153 degrees TN, most of the nearshore waves are approaching from an angle of 160 degrees TN or greater. This would seem to indicate that sediment transport at this location is from west to east, because of the obliquity of the incoming waves with the shoreline. However, since this area is a “pocket beach” with headlands on either side and a complex bathymetry, this scenario is not supported or refuted by examination of aerial photography.

This correlation of nearshore wave height and direction to sediment transport direction was not completed for all locations within the Kauai RSM regions for Fiscal Year 2010, due to funding constraints. If funding becomes available in the future, this data will be used to estimate sediment transport directions and complete the regional sediment budgets.

VII. Coastal Erosion, Beach Loss and Coral Reef Degradation

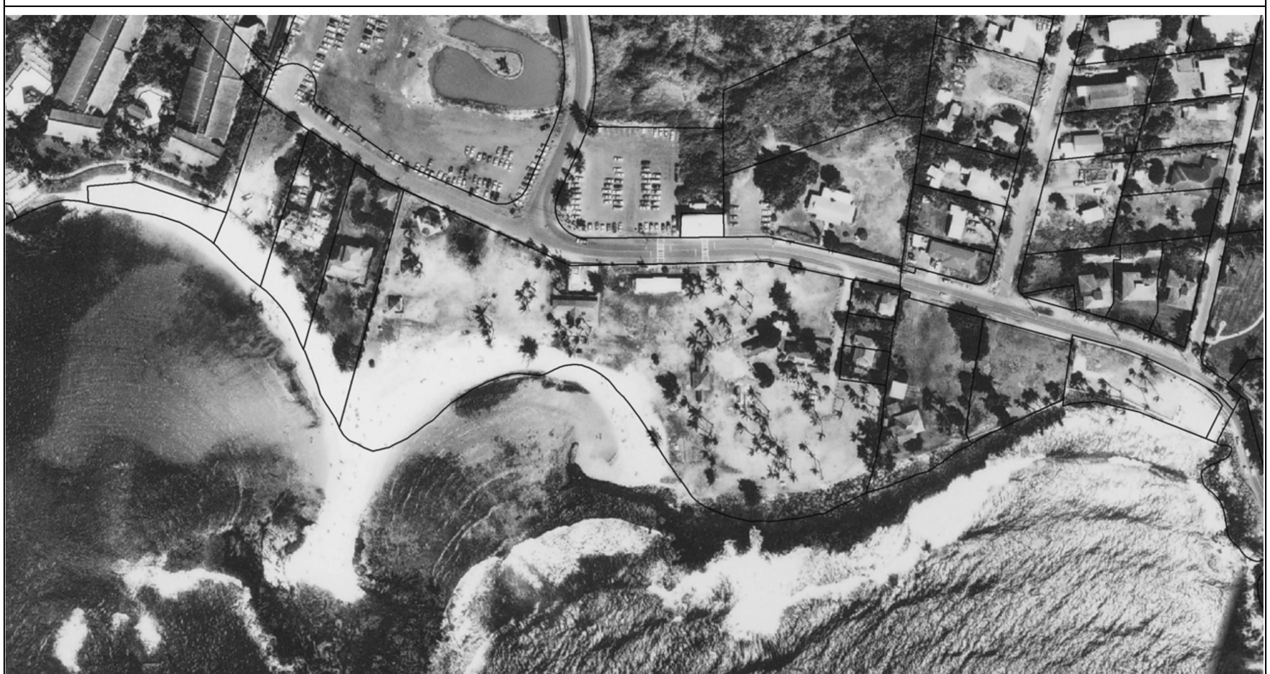
A. Beach Dynamics and Sediment Production

A beach is a dynamic system. Seasonal fluctuations in the width and slope of a beach are overlaid on long-term changes in the beach caused by long-term changes in sediment supply and littoral transport.

Sand is transported by waves (which mobilize the sand) and tidal or wave-generated currents (which transport the sand). Additional sand can enter the littoral system as the beaches retreat and the underlying substrate erodes. Beach loss occurs if the amount of sand entering the littoral system from sources such as biological production, dune erosion and beach nourishment is less than the amount leaving the littoral system – either offshore into deep water or alongshore to locations such as Kikiaola Harbor.

Structures along the shoreline, such as groins, also affect the beach dynamics and associated sand transport. In the Poipu region, a natural tombolo formed by Nukumoi Point (Figure 32) affects the beach dynamics. Figure 32 shows historic aerial photographs provided by the County of Kauai (Dave Caylor) showing the evolution of the beaches to the east and west of the tombolo, as well as a ground photograph of Poipu Beach Park taken in January 2011.

March 1960 Condition when Tombolo Formed (Photo Provided by County of Kauai)
Black Line in Photo Provides Reference Line



March 1988 Condition when Tombolo Formed (Photo Provided by County of Kauai)

Sept.1992 Condition when Tombolo Breached (Photo Provided by County of Kauai)

October 2007 Condition when Tombolo Breached (Photo Provided by County of Kauai)

Poipu Beach Park - January 2011

Figure 32. Tombolo at Poipu Beach Park

Towards the western part of the Kekaha region, winter North Pacific swell approaches the Kekaha Beach shoreline from the northwest. This wave direction produces a southeasterly nearshore current which moves littoral material along the coast in a southeasterly direction (USACE 1978) and thus Kekaha Beach is nourished by sand from the wider beaches to its north/west. But, this occurs only intermittently.

More frequent trade wind waves refract and diffract primarily around the southeast end of Kauai and approach the Poipu and Kekaha regions from the southeast and south. These waves, along with the southern swell waves approaching from generally the same direction, produce nearshore currents which move littoral material in the northwesterly direction. In the Kekaha region, this northwesterly transport is possibly interrupted by Kikiaola Harbor. Relevant to the Poipu region, it can also be interrupted by one or a combination of the following three conditions: 1) if the trade winds stop blowing, 2) if the area comes under the influence of a large north or westerly swell which normally occurs in winter, or 3) if the area is affected by a Kona storm wave.

Photographs of some of the structures in the Kekaha region are shown in Figure 33. A rock revetment protects Kekaha State Beach and the highway around Oomano Point (photos 33.a and 33.b). Towards the center of the region is Kikiaola Harbor formed by two breakwaters and a jetty (photo 33.c), and further east is the Waimea pier (photo 33.d).   Additional details about these structures and maps showing the locations of these structures are provided in Appendix F.

33a. Kekaha Beach Revetment

33b. Oomano Point Revetment

Figure 33. Structures within the Kekaha Region

33c. Kikiaola Harbor

33d. Waimea Pier

Figure 33. Structures within the Kekaha Region (cont.)

The Kikiaola Harbor is located along the central portion of the Kekaha region's shoreline. It appears that the harbor has interrupted the flow of westward-directed sediment since it was constructed in 1959, as evidenced by the presence of sediment accretion (impoundment) just upcoast of the harbor and erosion just downcoast of the harbor. A report by Sea Engineering (1996) also indicates that a deep channel offshore of Kikiaola Harbor may act as a permanent sink for sand that is forced offshore by the Kikiaola jetty/breakwater. Figure 34 (Sea Engineering 1996) illustrates the likely sediment transport in the area of the harbor and the presence of the sink offshore of the harbor. Sea Engineering (2008b) cites that the amount of sand impounded on one side of the harbor, and lost to erosion on the other, is on the order of 3,500 to 5,000 cy per year.

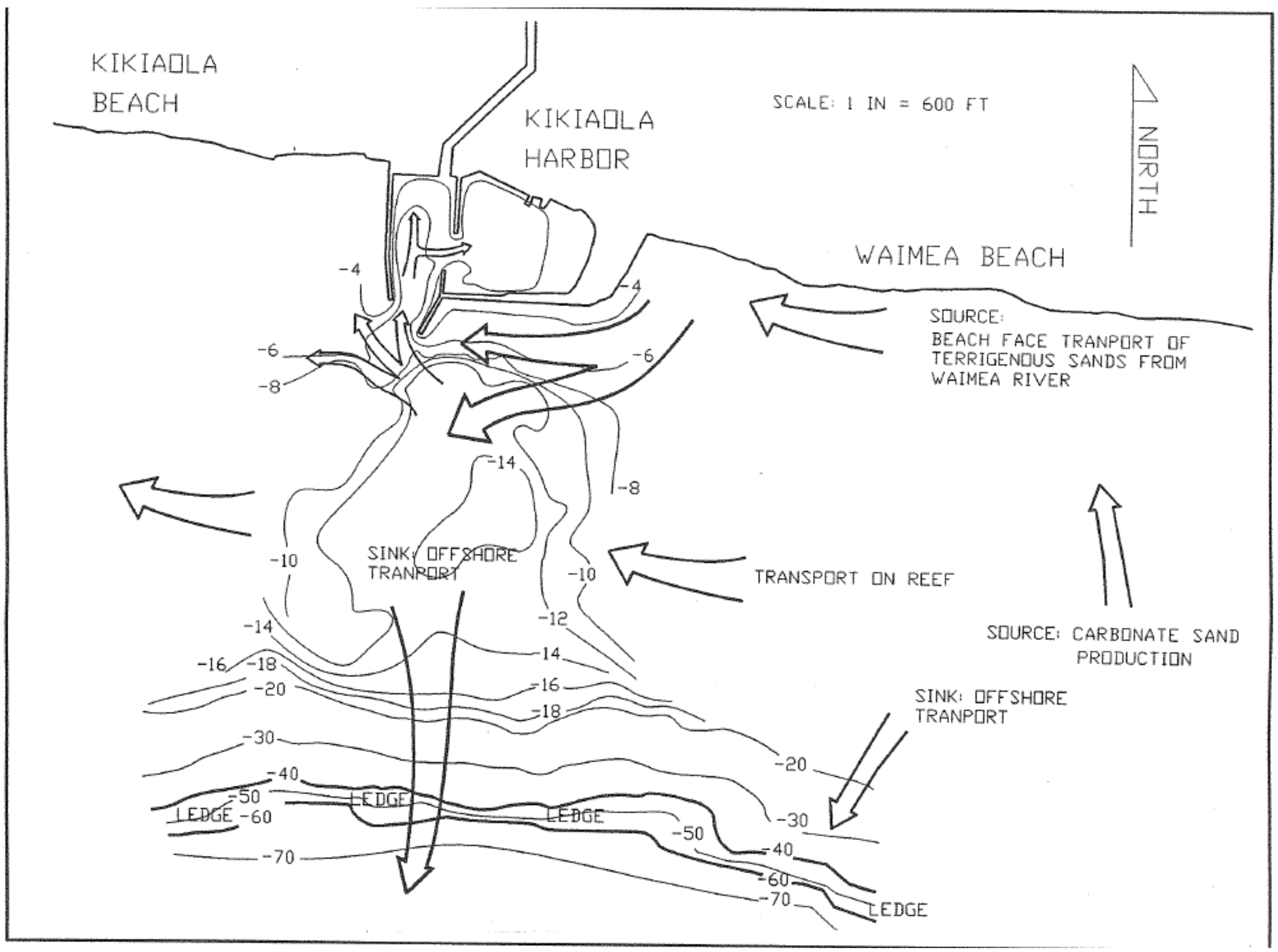


Figure 34. Sediment Transport in the Area of Kikiaola Harbor
(Sea Engineering 1996)

Sea Engineering (2008b) provides further information about the sediment transport processes in the vicinity of Kikiaola Harbor. Figure 35 is a graph of shoreline change east (updrift) and west (downdrift) from the harbor. It indicates that the greatest change is in the initial 1,000-ft reach west of the harbor, gradually tapering to a relatively equilibrated condition at approximately 2,000 ft west of the harbor (approximately 500 ft west of Mamo Road). The graph also indicates anomalous erosion east of the harbor and similarly anomalous accretion west of the harbor between 2002 and 2004.

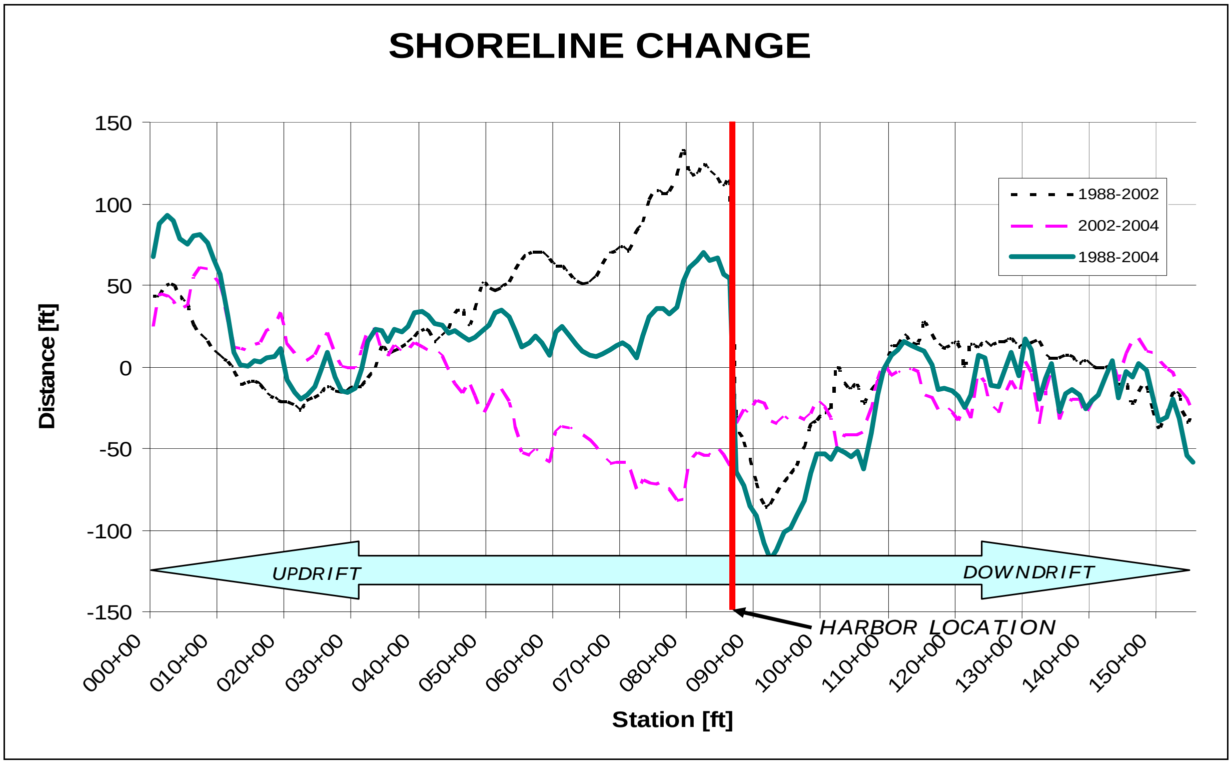


Figure 35. Erosion and Accretion in the Vicinity of Kikiaola Harbor from the USACE 2005 Report (Sea Engineering 2008(b))

It is possible that some of this anomalous behavior may have been due to the re-distribution of sand from the Mamo Road (Kikiaola Beach nourishment) project during this time period. Although excavation for the project east of the harbor occurred predominately landward of the beach berm – outside the reach of normal littoral action, the actual footprint of excavation is not really known and the effects may have become noticeable. Sand placement occurred downdrift of the harbor, but there are indications that some transport on the west side may also occur in reverse of the regional trend, i.e. toward the harbor. There was little or no monitoring, so the project effects are simply not well known. There may also have been other forcing factors for the unusual transport patterns, such as anomalously frequent wave events from the west.

Figure 36 is a diagram of Kikiaola Beach showing relative changes in shoreline position (both vegetation line and water line) between 1950 and 2002. Prior to construction of the harbor, Waimea Beach (west of the harbor) was a relatively narrow sand strip, while Kikiaola Beach, was relatively wide. Of particular note is the salient that formed in the lee of the existing shoal. Figure 36 also shows wave patterns taken from 1966 and 1988 aerial photographs that show waves approaching from both sides of the shoal. With the retreat of the shoreline, it appears that the salient morphology has been lost. One of the major lessons that can be learned from the Mamo Road nourishment project together with the beach and wave patterns presented in Figure 36 is that stabilization at Mamo Road will likely occur only with stabilization of the entire 1,500-ft littoral cell component between Mamo Road and the west breakwater.

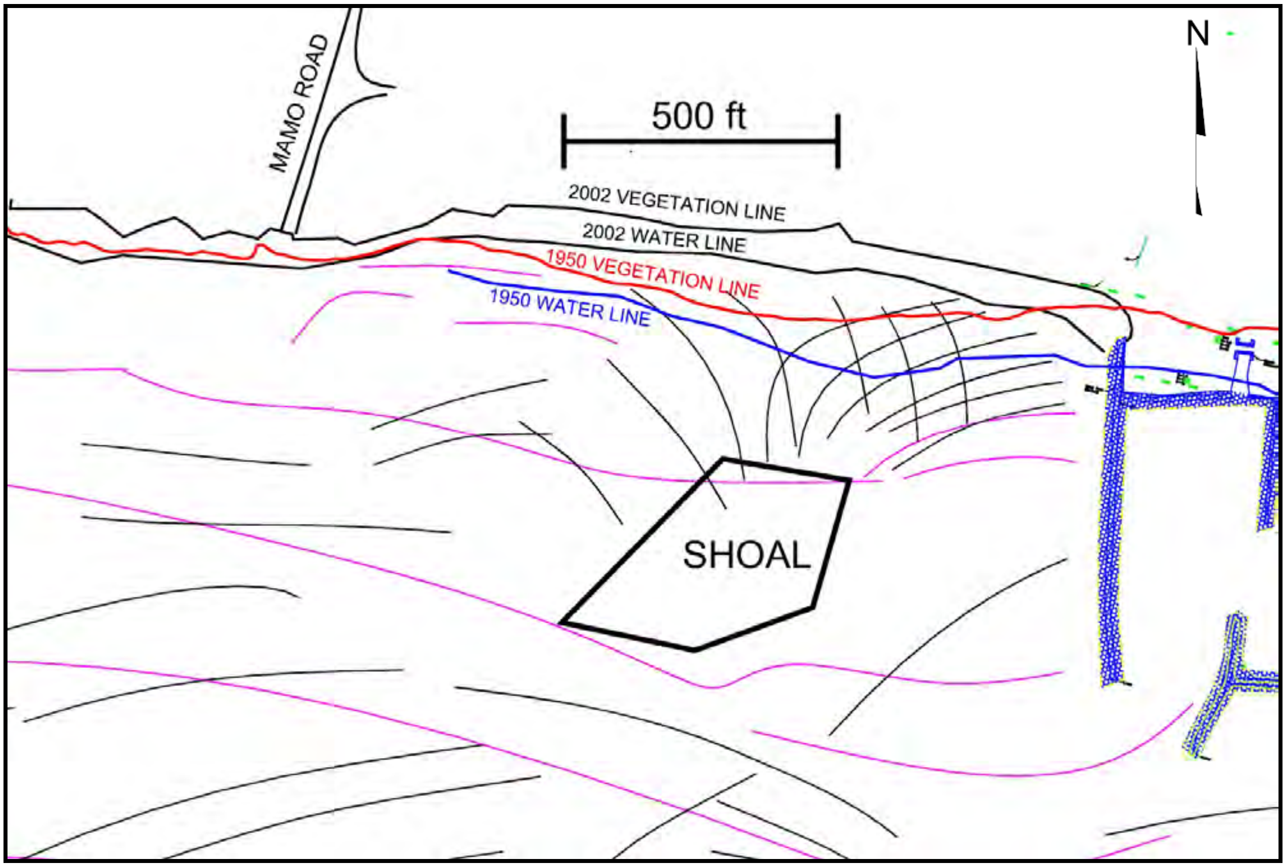


Figure 36. 1950 and 2002 Vegetation and Water Lines, and Wave Patterns from 1966 (colored) and 1988 (black) Aerial Photographs
(Sea Engineering 2008(b))

USACE (1978) suggests that some sediment <u>does</u> bypass Kikiaola Harbor based on sediment samples taken at the beach just downcoast (west) of the harbor. The percent carbonate was not significantly different between the samples taken before and after harbor construction. The present analysis does not support this conclusion.

The steep revetment along the Kekaha Beach and Oomano Point shorelines has also likely had an effect on sand movement.

The only significant improvement in the Poipu region is the Kukui'ula Harbor. There are also a limited number of rock revetments and seawalls of relatively small length fronting private homes and near Brennecke Beach and Poipu Beach Park (Figure 37).

37a. Seawall Near Brennecke Beach

Figure 37. Structures within the Poipu Region

The primary sediment sources to the two Kauai regions are:

- Biological and mechanical erosion of the coral reef framework;
- Direct sediment production upon the death of such organisms as *Halimeda* (a green macroalgae), mollusks, and foraminifera.
- Streams and rivers.

In the Kekaha region, the sediment is generally distinct to the west and to the east of Oomano Point, as seen previously in Figure 9. To the west of Oomano Point is a long stretch of sandy beach (including Kekaha Beach) which is composed primarily of calcareous sediment. On Waimea Beach, the source of beach sediment has a high terrigenous content, primarily sediment from the Waimea River the point. On Kikiaola Beach, between Kikiaola Harbor and Oomano Point, the beaches also have a darker color (terrigenous content). This may indicate that large quantities of sand do not move alongshore around Oomano Point.

B. Historical Shoreline Positions

Shoreline erosion maps, including shoreline position change rates (as derived from historical aerial photographs) along much of the study regions, have been developed by the University of Hawaii as part of their Coastal Hazard Mapping program. The specific maps for the two Kauai regions are provided in Appendices D and E. The maps were compiled for each region to provide a top-level view of the erosion rates in each region and are provided as Figures 38 and 39.

Generally, the UH-calculated shoreline position change rates indicate the following for the Kekaha Region:

- The long stretch of sandy beach from Kokole Point to Oomano Point has experienced both accretion and erosion over the period of study. The northwestern section is accreting slightly, while the southeastern section is eroding.
- The recent shorelines around Oomano Point suggest the sandy beach has generally eroded to the toe of the revetment located around this point.
- The area between the Waimea River and Kikiaola Harbor is accreting.
- In this region, a longshore transport from east to west and sediment input from Waimea River is suggested based on the maps showing: a) the coastline to the east of Kikiaola Harbor as accreting, b) the coastline to the west of the Harbor as eroding, and c) the coastline to the east of Waimea River is slightly erosional.

Generally, the change rates indicate the following for the Poipu Region:

- There are only a few sandy pocket beaches in this region and most of them are experiencing erosion. Those with the widest sandy beaches, Lawa'i Bay, Poipu, and Shipwreck, are experiencing the highest erosional rates.
- There is only one section of the region, Ho'ai Bay area, which is very slightly accretional.

These erosion maps and the underlying measurements of shoreline position, based on available aerial photography, are one of the main inputs to the regional sediment budget prepared by Moffatt & Nichol to be discussed in a following section.

VIII. Regional Sediment Budget

The sediment budgets are based on available information regarding reef productivity, stream sediment input, shoreline accretion and erosion, and the patterns of wave-driven currents. The significant uncertainties in the different elements of the budget, and the fact that the losses offshore and into the deep channels have not been quantified individually (the values are selected to balance the budget) mean that the actual numbers should only be considered a guide. However, the values are adequate for planning and evaluating potential sediment management and beach nourishment projects in the region.

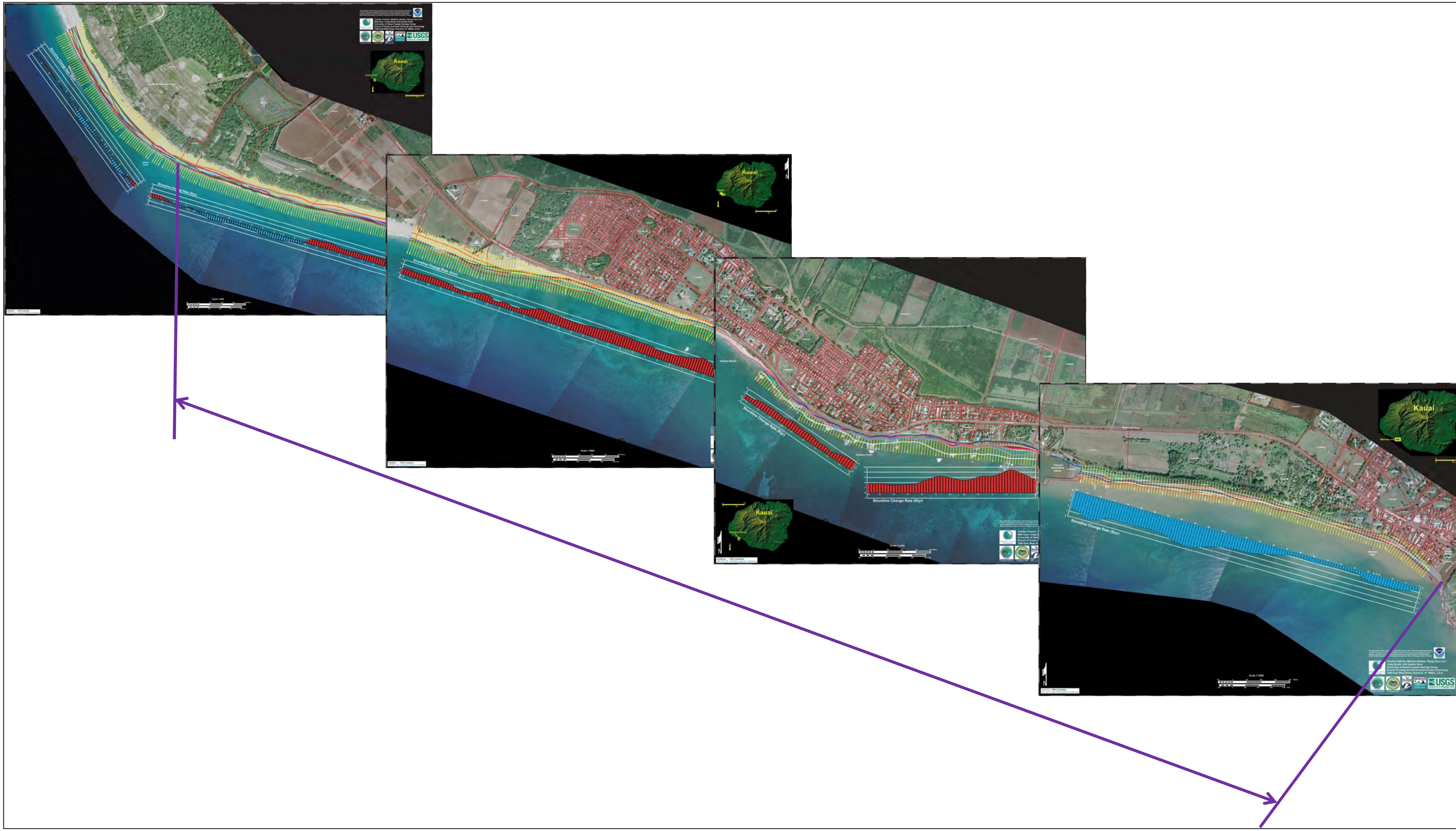


Figure 38. Shoreline Erosion Maps of Kekaha Region

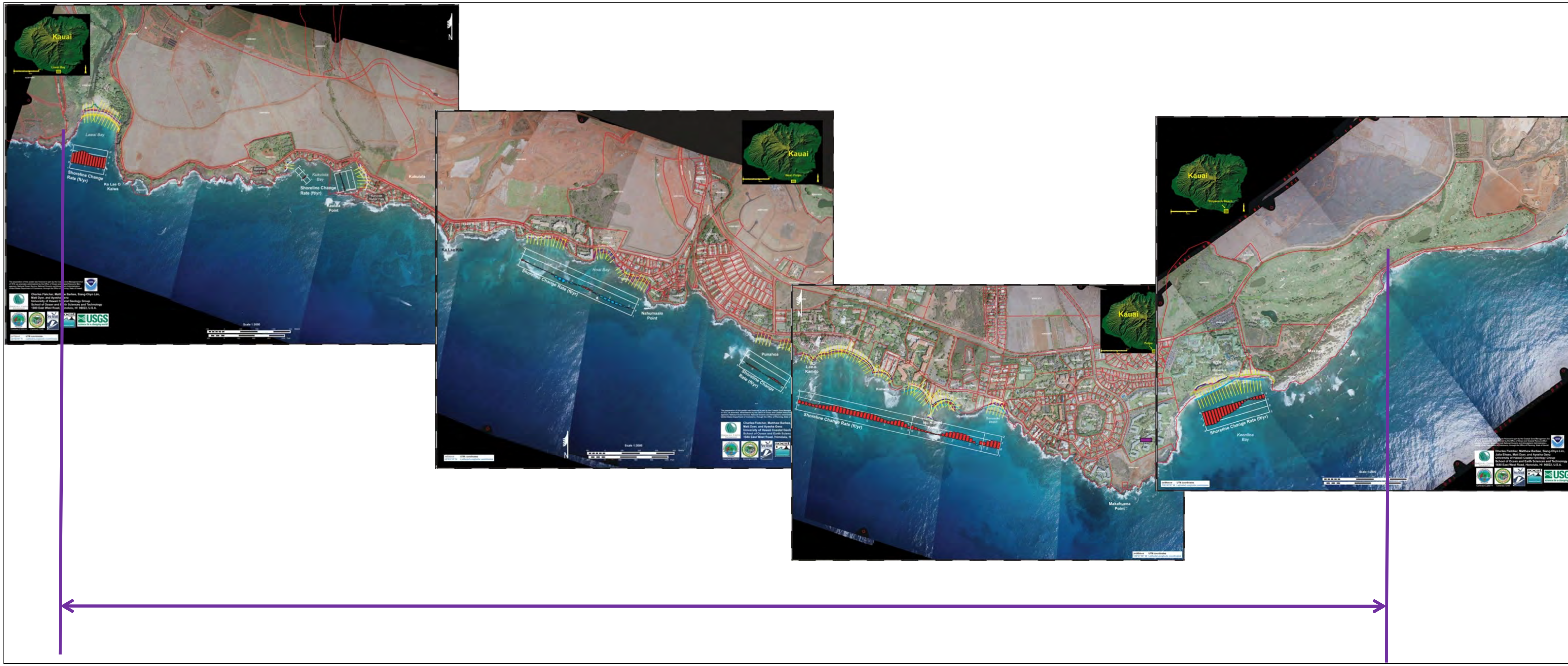


Figure 39. Shoreline Erosion Maps of Poipu Region

Three littoral cells were defined for the Kekaha region and eight littoral cells were defined for the Poipu region, shown in Figures 40 and 41, respectively. The Kekaha region has a long uninterrupted stretch of sandy beach along its shoreline and thus the fewer number of littoral cells. Each of these littoral cells is described in more detail in Appendices F and G.

The general approach to sediment budget development is as follows.

- The historical volumes of sediment on the beaches were estimated based on the historical shoreline positions developed by the University of Hawaii (Hawaii Coastal Geology Group 2009; see Section IX.B) and using a conversion factor of 0.40 cubic yards per square foot of beach area. (This conversion factor is based roughly on the results of analysis performed in the Oahu D2P study; a task for future RSM studies could be to confirm/refine this number for the Kauai RSM regions). For purposes of comparing volumetric rate changes, the total beach volume in these graphs is defined as the volume of beach in the active profile between the shoreward toe (which moves over time) and a stable back beach vegetation line (does not move over time). For each available shoreline date, the beach volume was calculated by multiplying the beach width times the length of sandy beach within the littoral cell times the 0.40 cy per square foot factor. The resultant plots of the historical beach volumes for the Kekaha and Poipu regions are shown in Figures 42 and 50, respectively. These graphs also show historical events which most likely impacted the beaches within the regions.
- The beach volume graphs were studied, relative to historical events and erosional versus accretional trends, to calculate representative average beach volume change (erosion or accretion) rates for appropriate time periods for each littoral cell. An average rate over the entire time period of shoreline records was also calculated for each littoral cell. The rates are based on a linear fit of the beach volume and seasonal fluctuation/error data using a weighted least squares approach. The rates for each littoral cell over the entire time period of shoreline record and over recent history are summarized in Tables 9 and 10, for the Kekaha region and Poipu region, respectively. The recent history rate is the most relevant for planning potential future beach nourishment projects. The historical beach volumes and change rates for each littoral cell are shown in Figures 43 – 45 for the Kekaha region and Figures 51 - 58 for the Poipu region. The most recent beach volume change rates (sediment budgets) are shown in Figures 46 – 49 for the Kekaha region and in Figures 59 – 66 for the Poipu region.
- The rates take into account historical beach nourishment, however beach nourishment on Kauai seems to be limited. There were only three projects found: 1) a 15,000 cubic yard (cy) nourishment (via sand bypassing) within the Kekaha region in 1998-2001 (Sea Engineering 2008), 2) a 1,000 cy nourishment of Poipu Beach in 2007(DLNR 2010), and 3) a 500 cy nourishment of Kukui’ula Beach in 2001 (DLNR 2011).

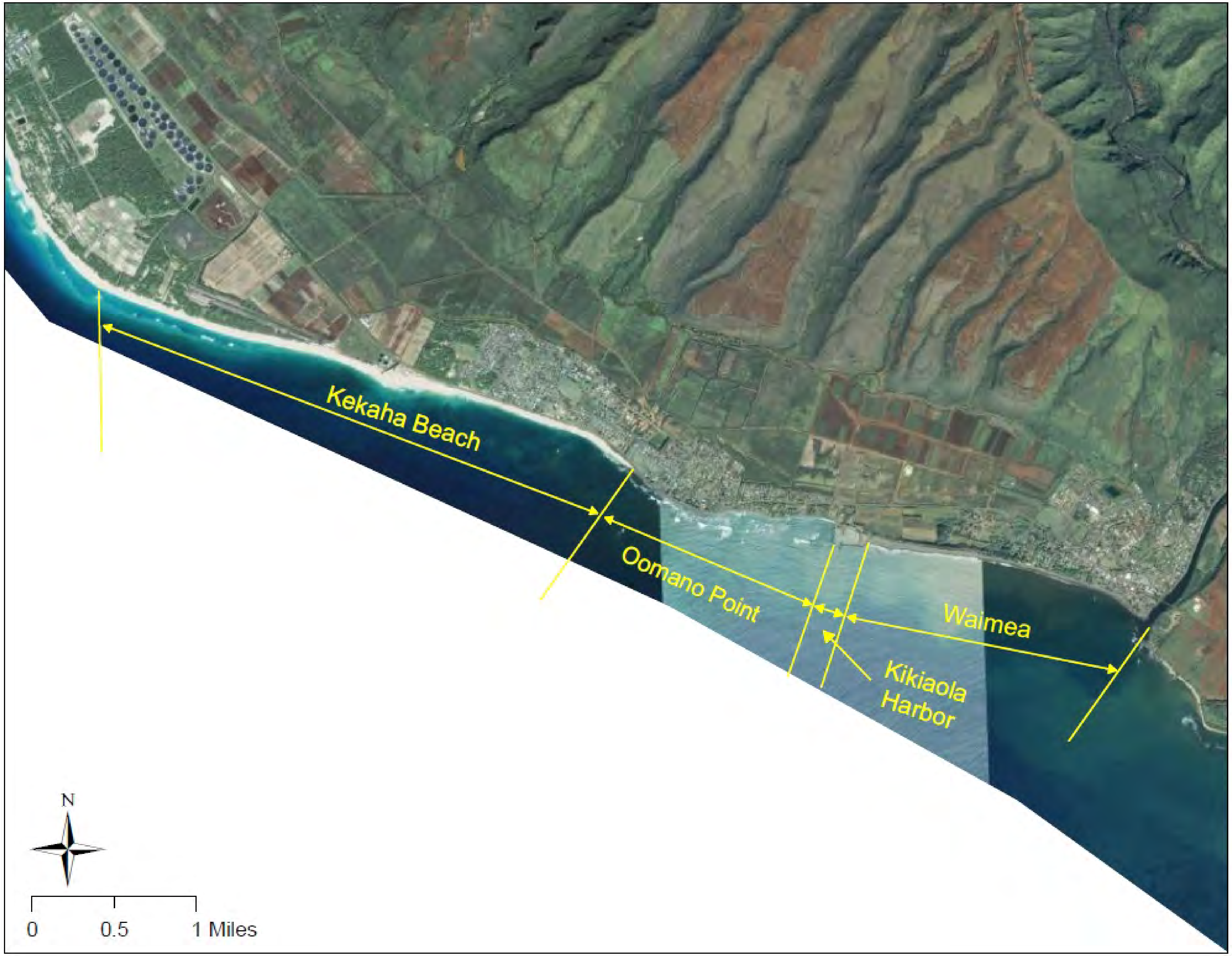


Figure 40. Kekaha Region Littoral Cells

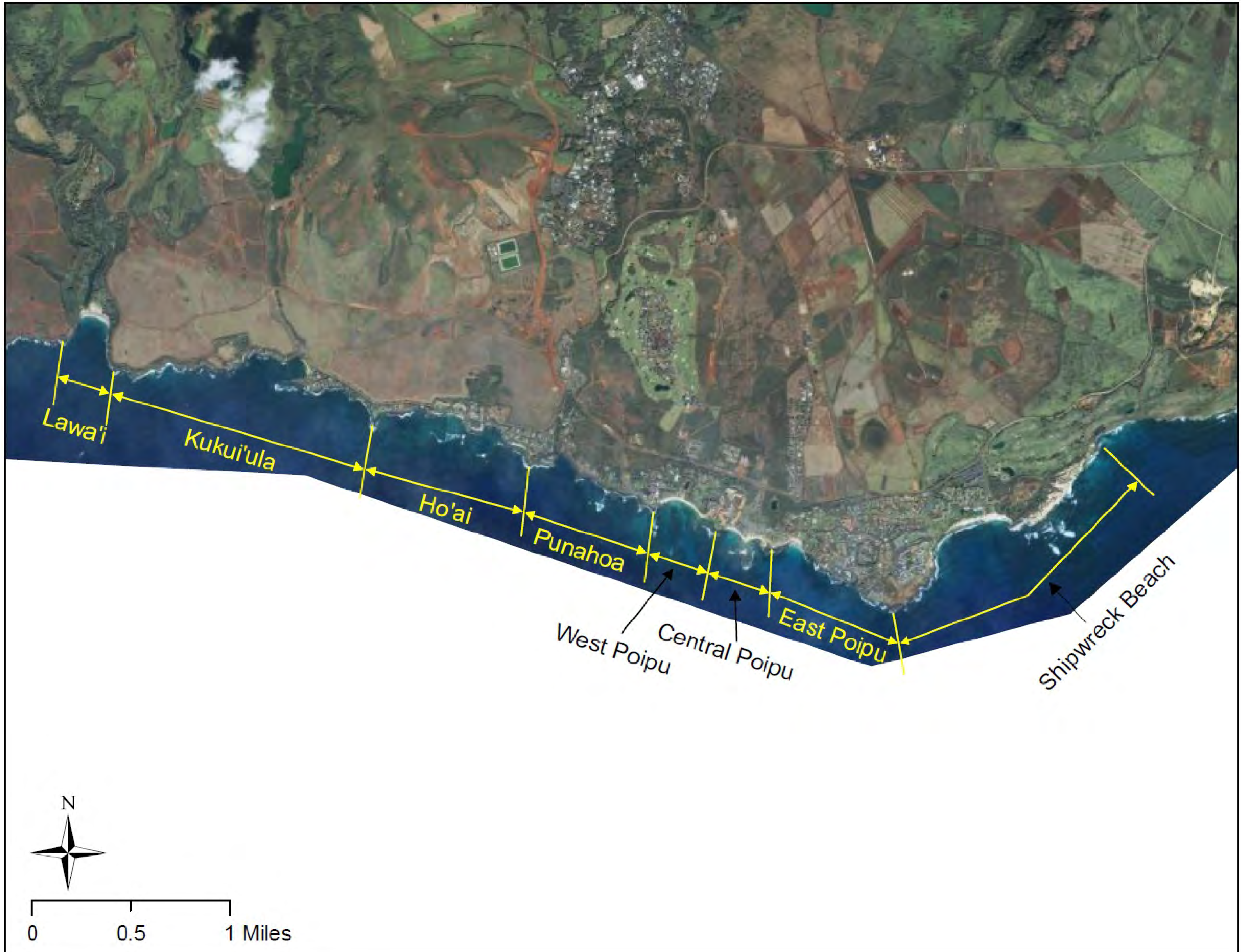


Figure 41. Poipu Region Littoral Cells

Table 9. Kekaha Region Beach Sand Volume Change Rates

Littoral Cell	Accretion(+) / Erosion(-) Rate Over Entire Time Period of Record, cubic yards per year	Accretion(+) / Erosion(-) Rate Over Recent Period, cubic yards per year
Waimea	+8,300	+10,650
Kikiaola Harbor (since 1959)	---	+600 to +3,000
Oomano Point	-5,100	-4,200
Kekaha Beach:	-7,100	-20,500

Table 10. Poipu Region Beach Sand Volume Change Rates

Littoral Cell	Accretion(+) / Erosion(-) Rate Over Entire Time Period of Record, cubic yards per year	Accretion(+) / Erosion(-) Rate Over Recent Period, cubic yards per year
Lawa'i	-600	-200
Kukui'ula	0	-250
Ho'ai	+100	-250
Punahoa	0	0
West Poipu	-400	-400
Central Poipu	-350	-800
East Poipu	-150	+50
Shipwreck Beach	-50	+200

It should be noted that the number of available historical shorelines is limited and the curves were interpolated between available shoreline data points. Accordingly, the following should be understood:

- The points do not necessarily bound the minimum and maximum beach volumes.
- It is probable that the chronological transitions from erosional to accretional conditions (and vice versa) are not at the exact date shown by the breaks in the lines in the graphs. Some examples of where this could have occurred and the likely change rate projections are shown by dashed lines in Figures 42 and 43, e.g. the Waimea shoreline probably continued to erode until the late 1950s when the harbor was built and then the region transitioned to an accretional state thereafter. However, this is not in the data because of a lack of shoreline data points in the late 1950s.

It should also be noted that the vertical scales vary between the graphs of each littoral cells.

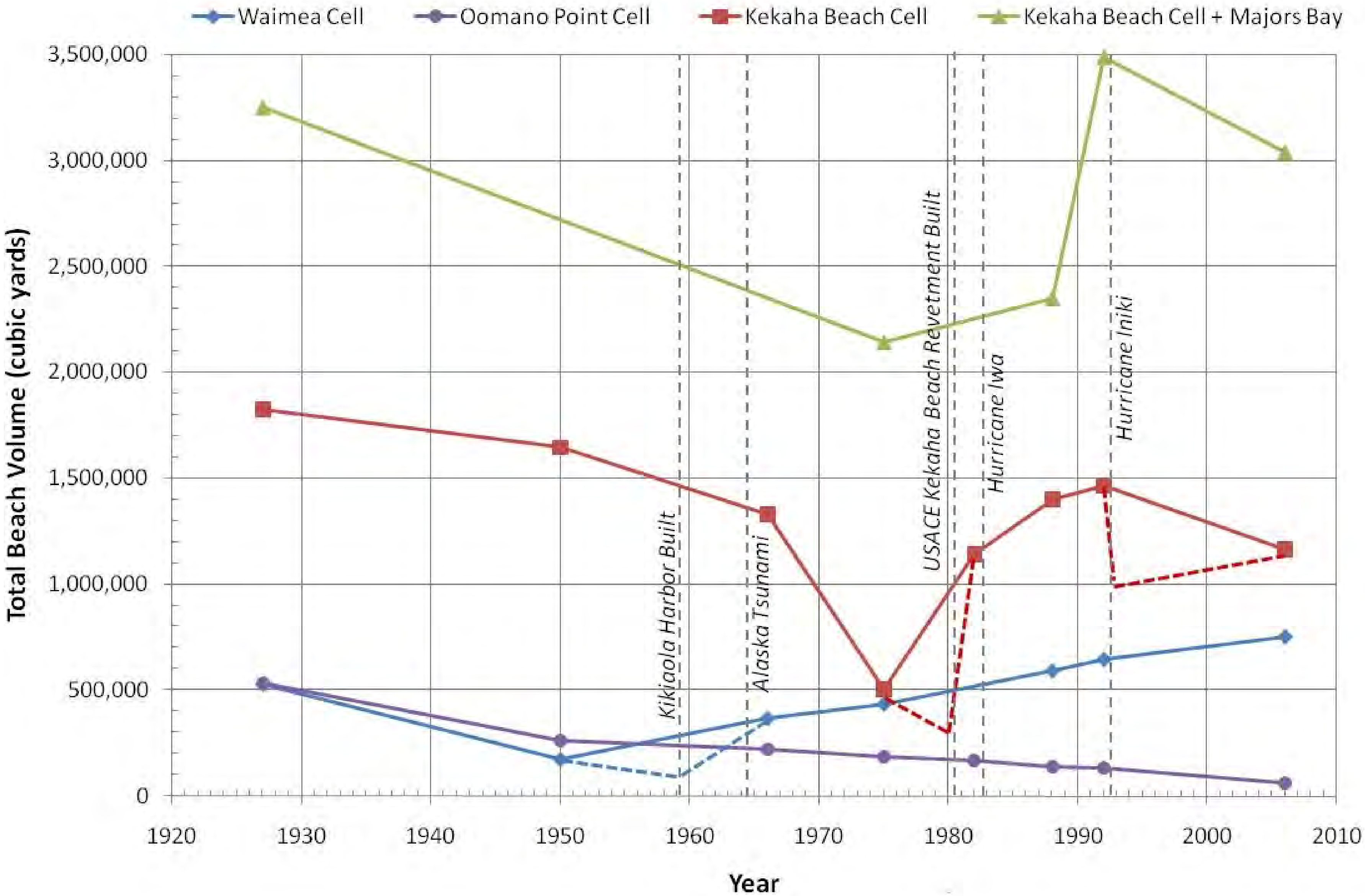


Figure 42. Historical Beach Volumes of Kekaha Region Littoral Cells

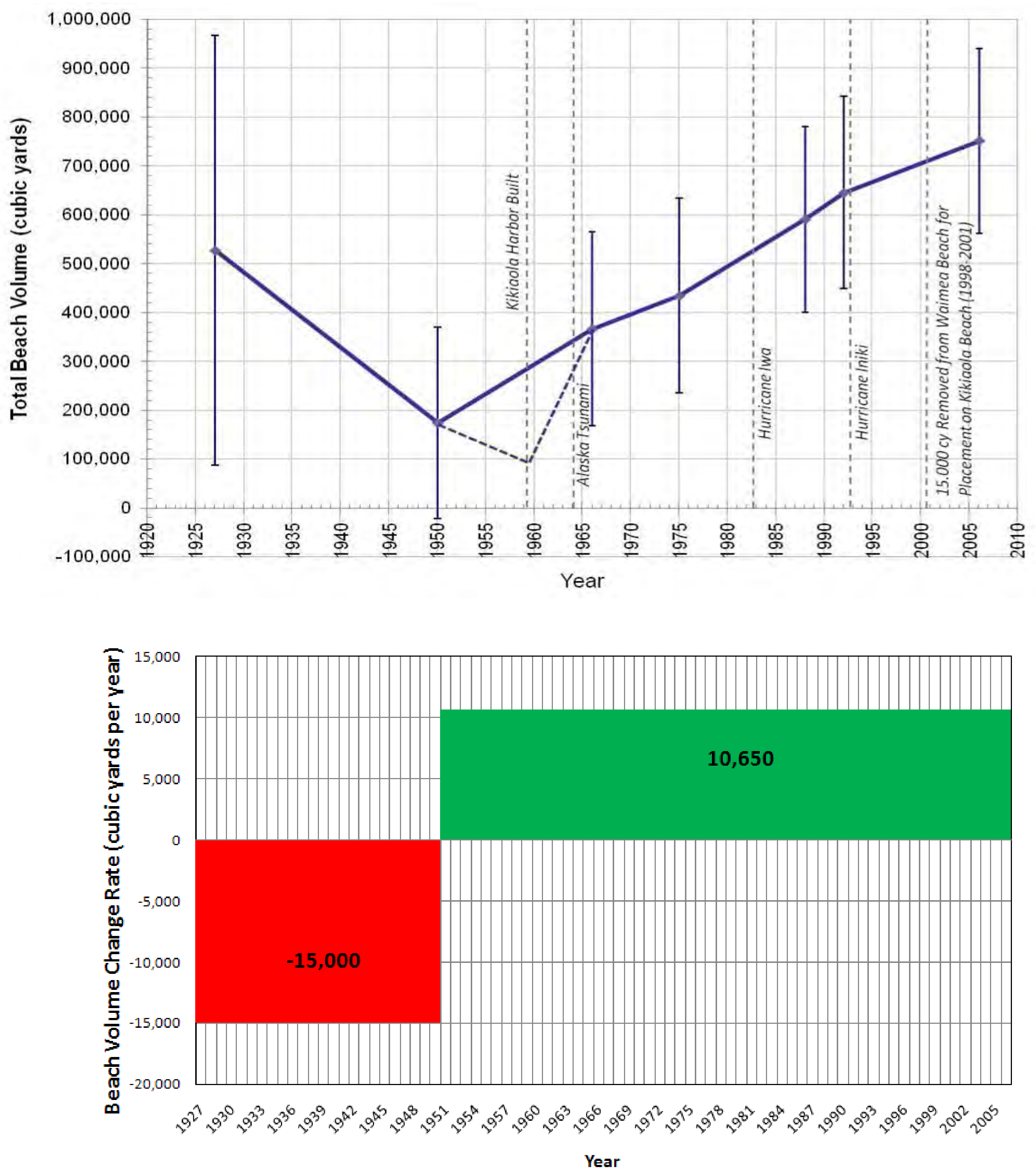


Figure 43. Historical Beach Volumes / Change Rates for Waimea Littoral Cell

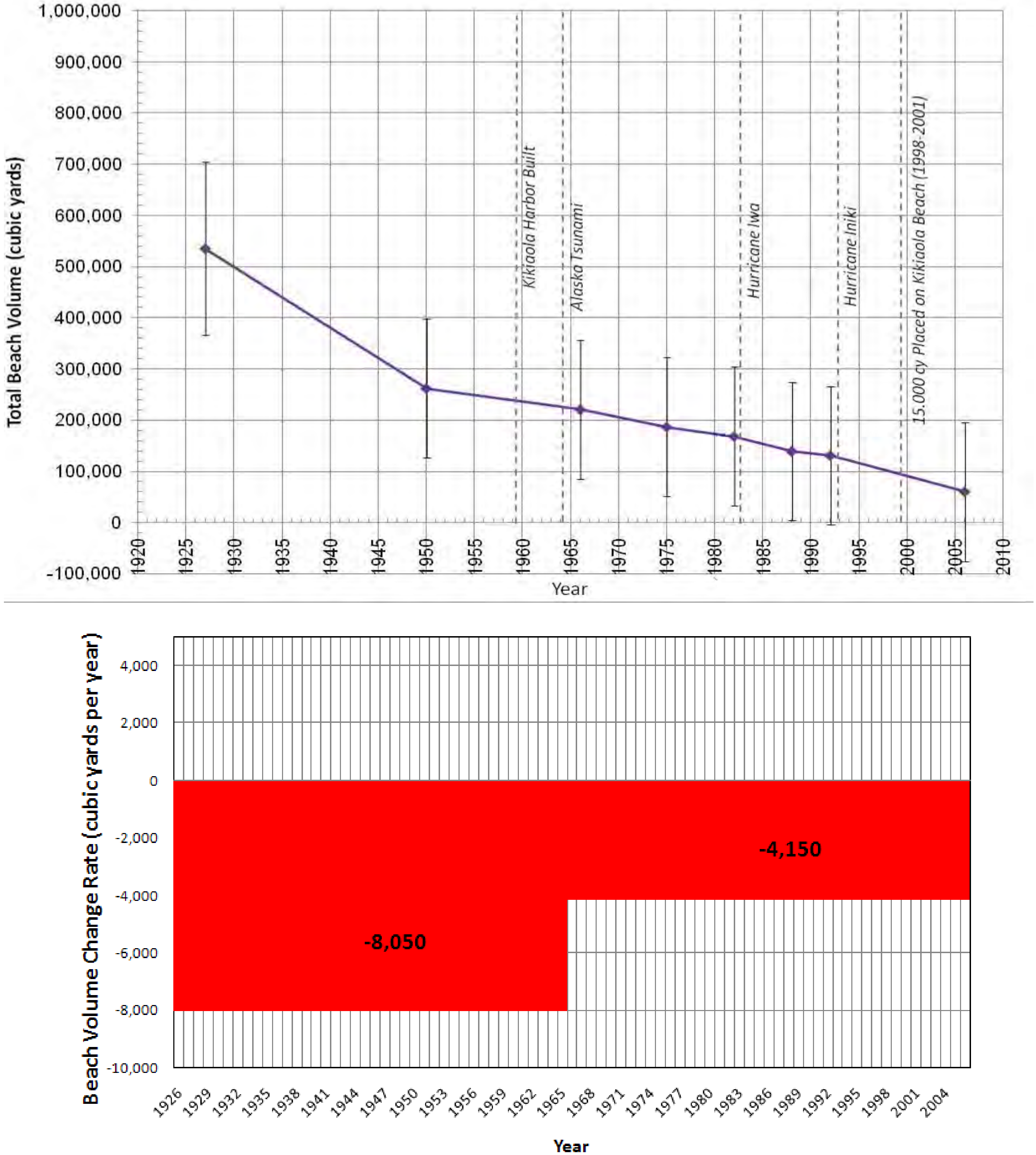
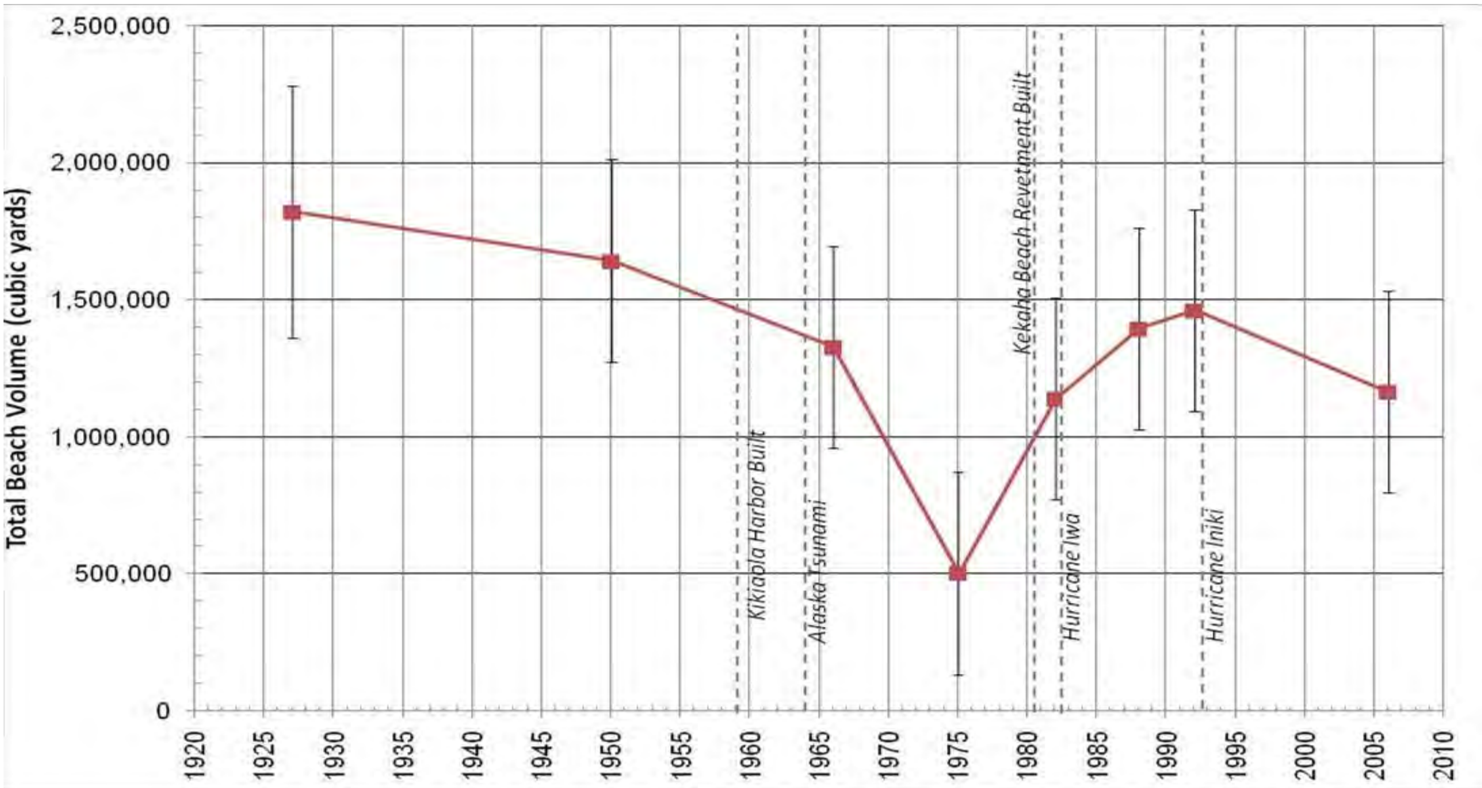


Figure 44. Historical Beach Volumes / Change Rates for Oomano Point Littoral Cell



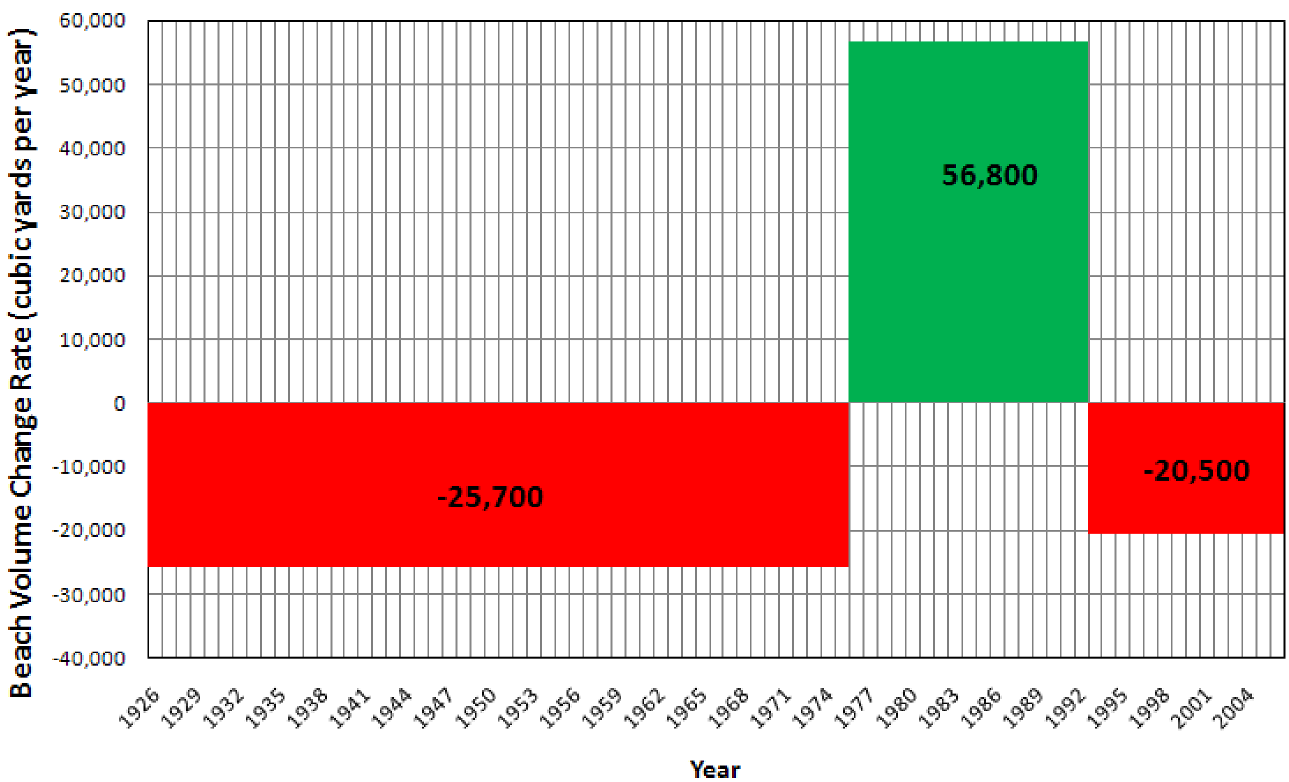


Figure 45. Historical Beach Volumes / Change Rates for Kekaha Beach Littoral Cell

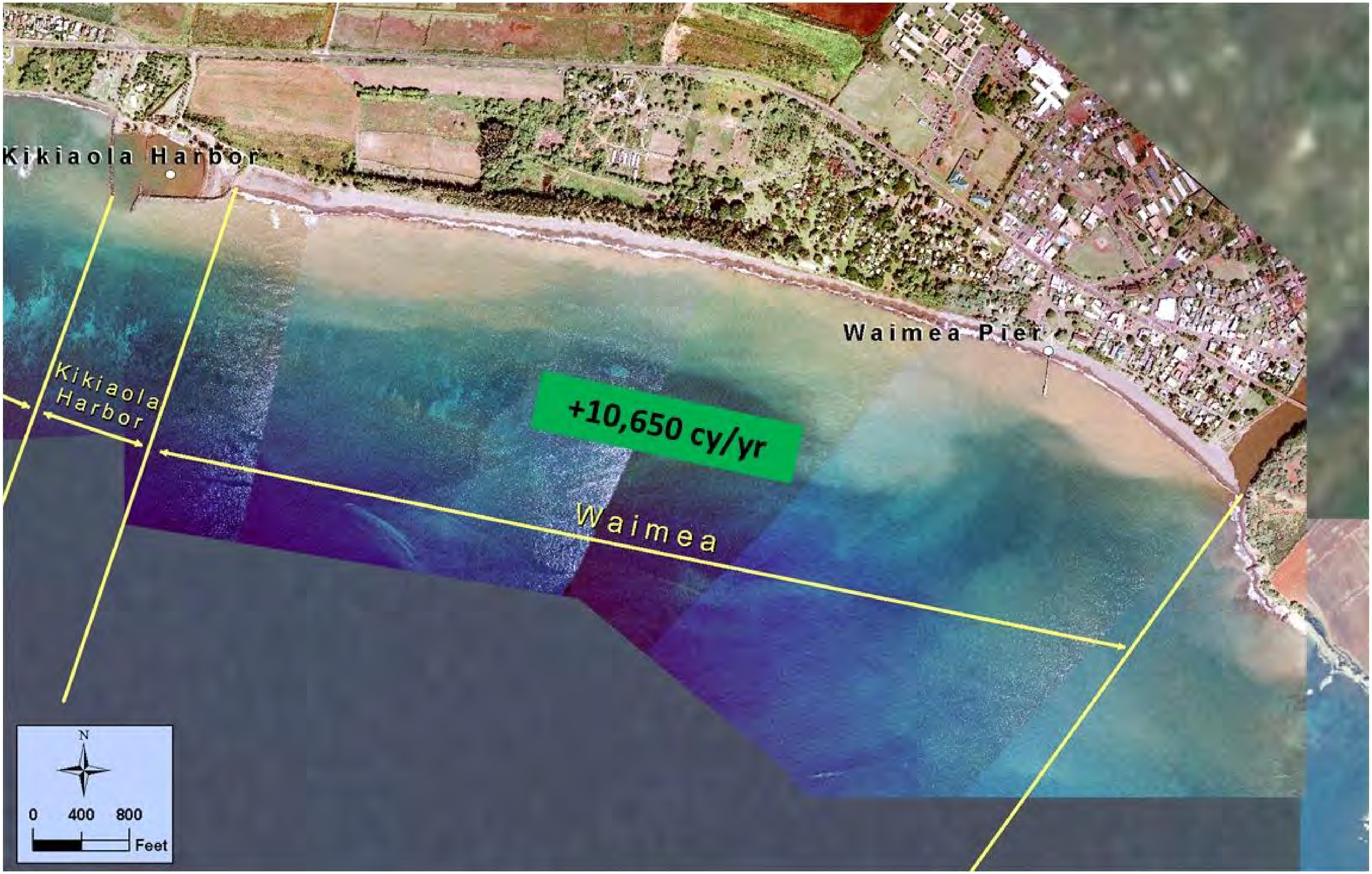


Figure 46. Beach Volume Change Rate for Waimea Littoral Cell

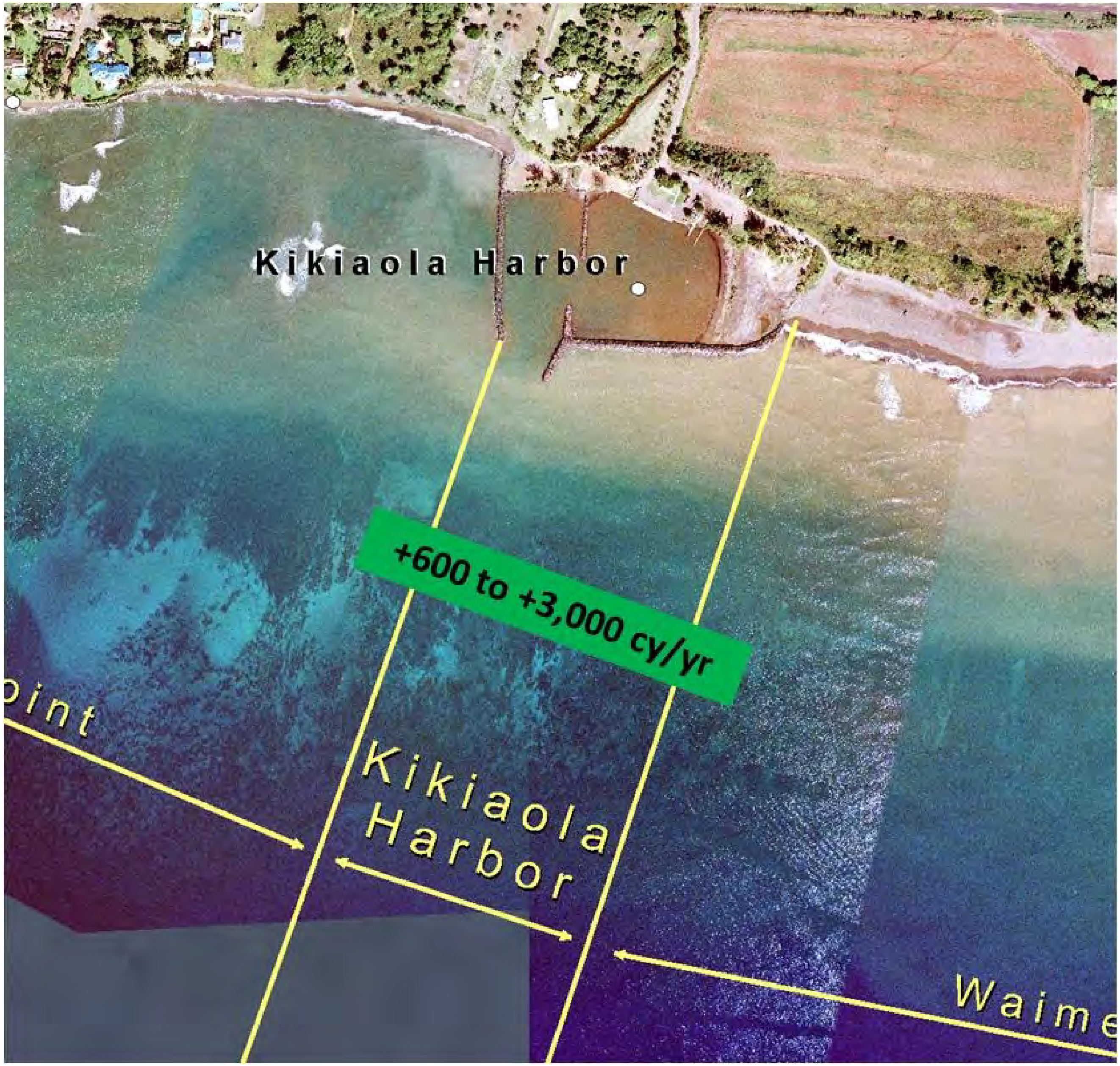


Figure 47. Beach Volume Change Rate for Kikiaola Harbor Littoral Cell

Figure 48. Beach Volume Change Rate for Oomano Point Littoral Cell

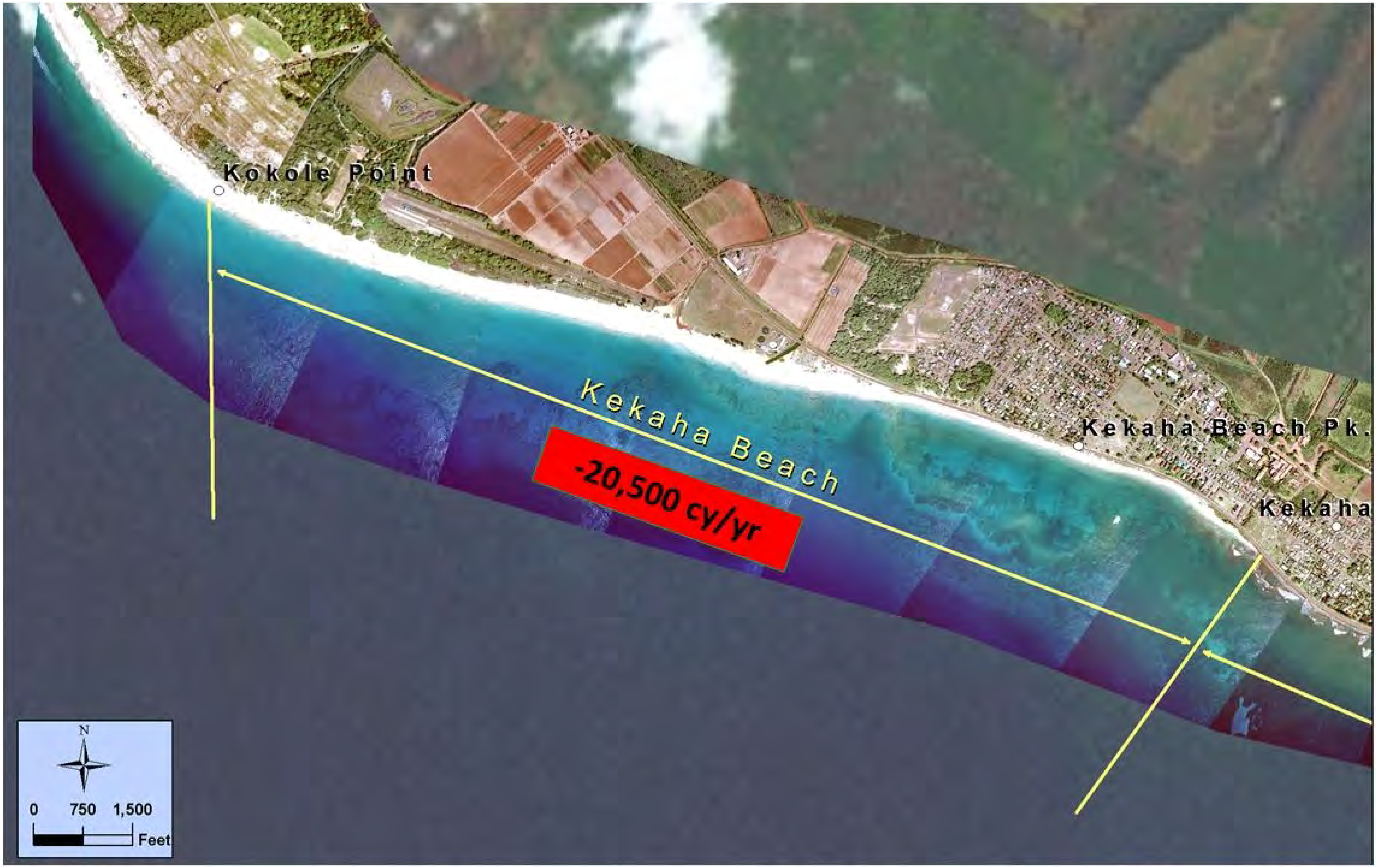


Figure 49. Beach Volume Change Rate for Kekaha Beach Littoral Cell

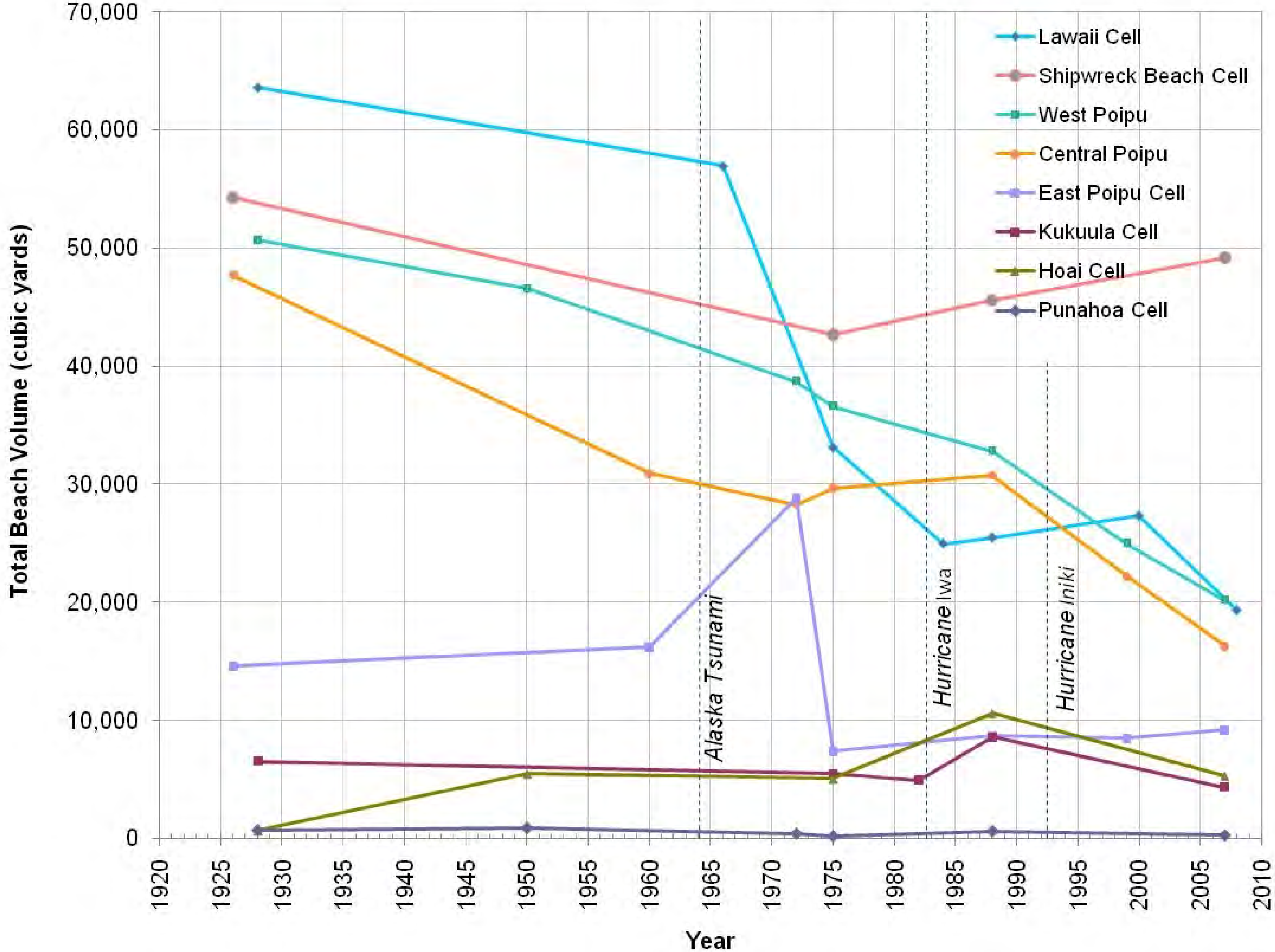


Figure 50. Historical Beach Volumes of Poipu Region Littoral Cells

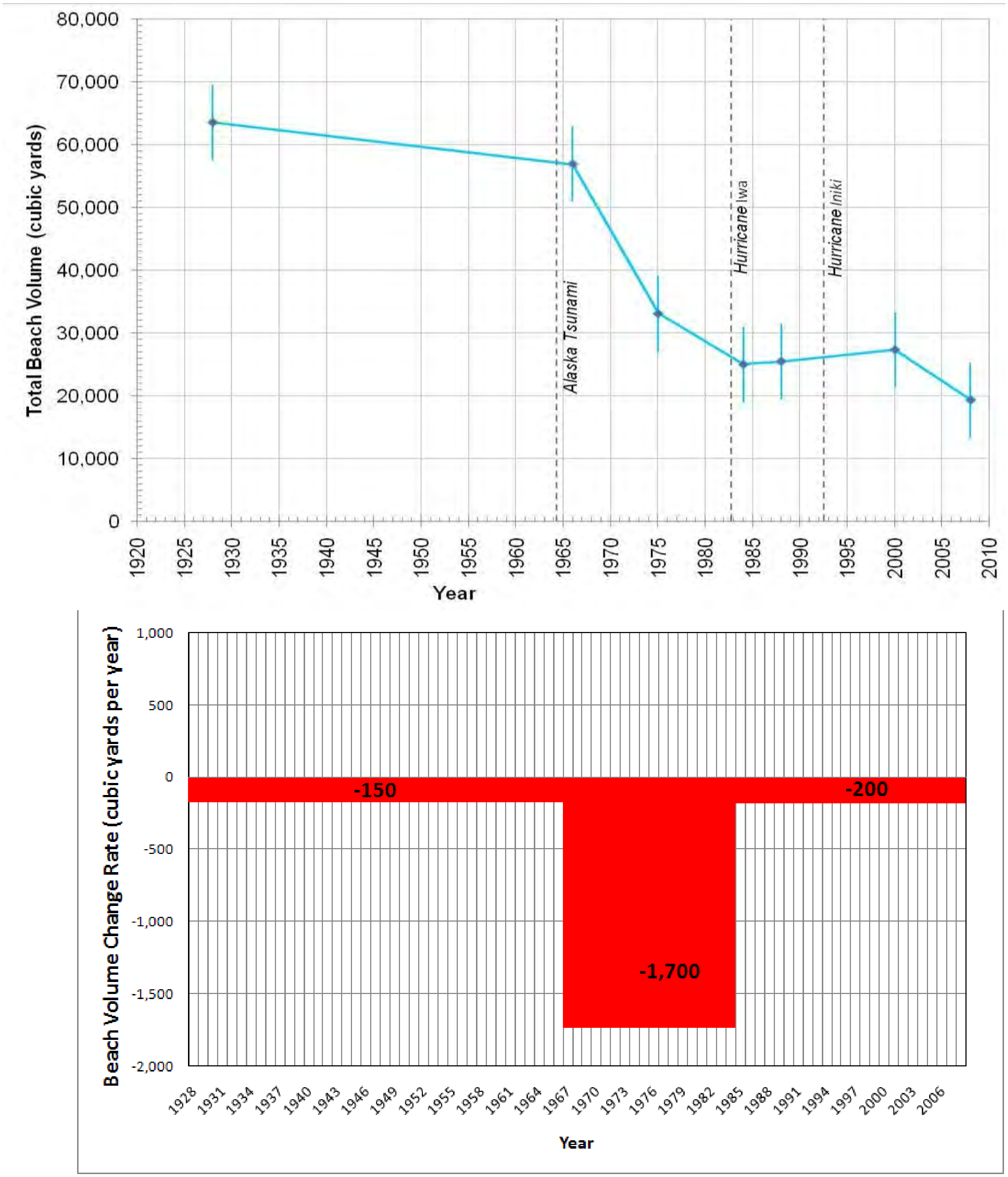


Figure 51. Historical Beach Volumes / Change Rates for Lawa'i Littoral Cell

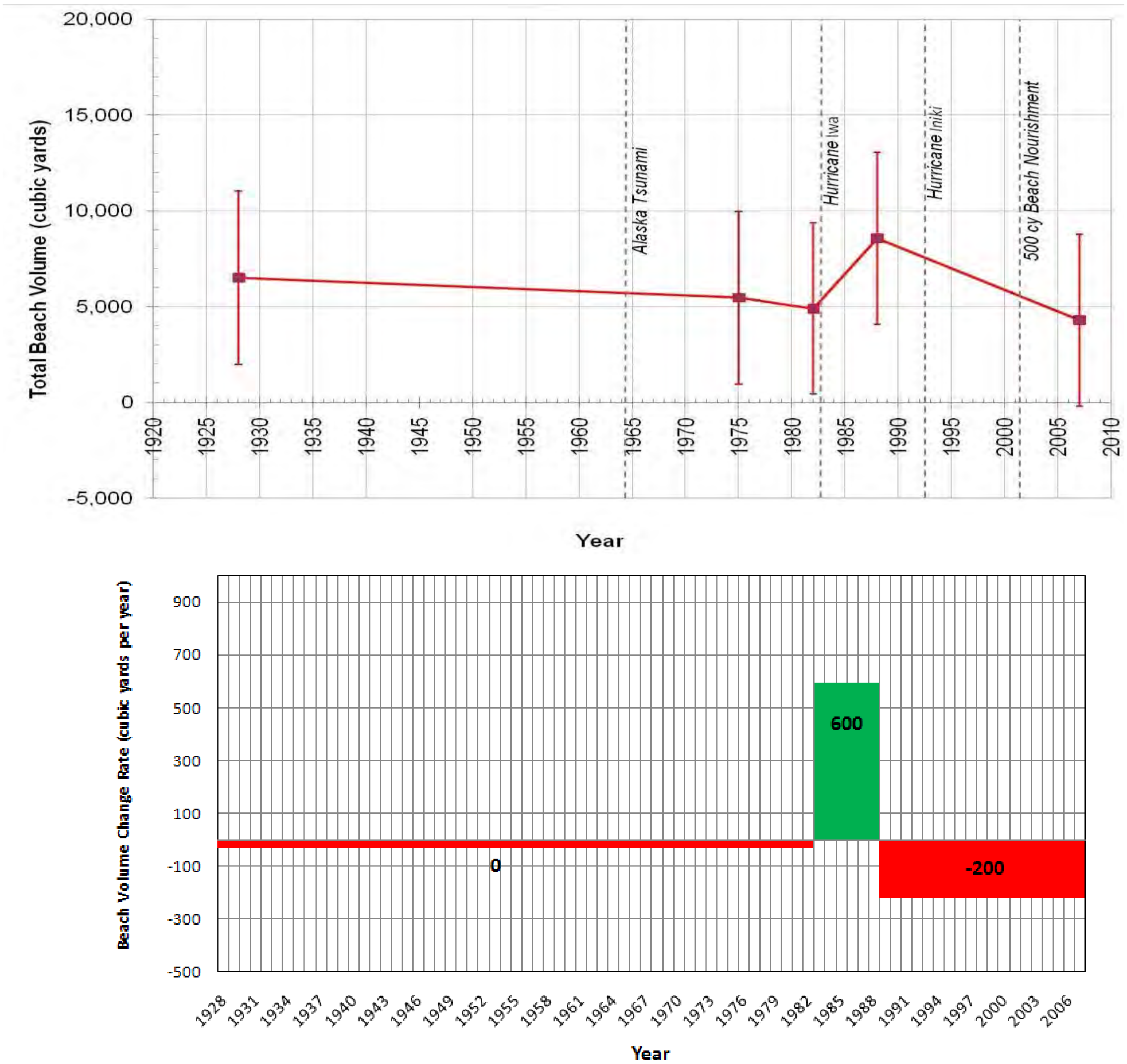
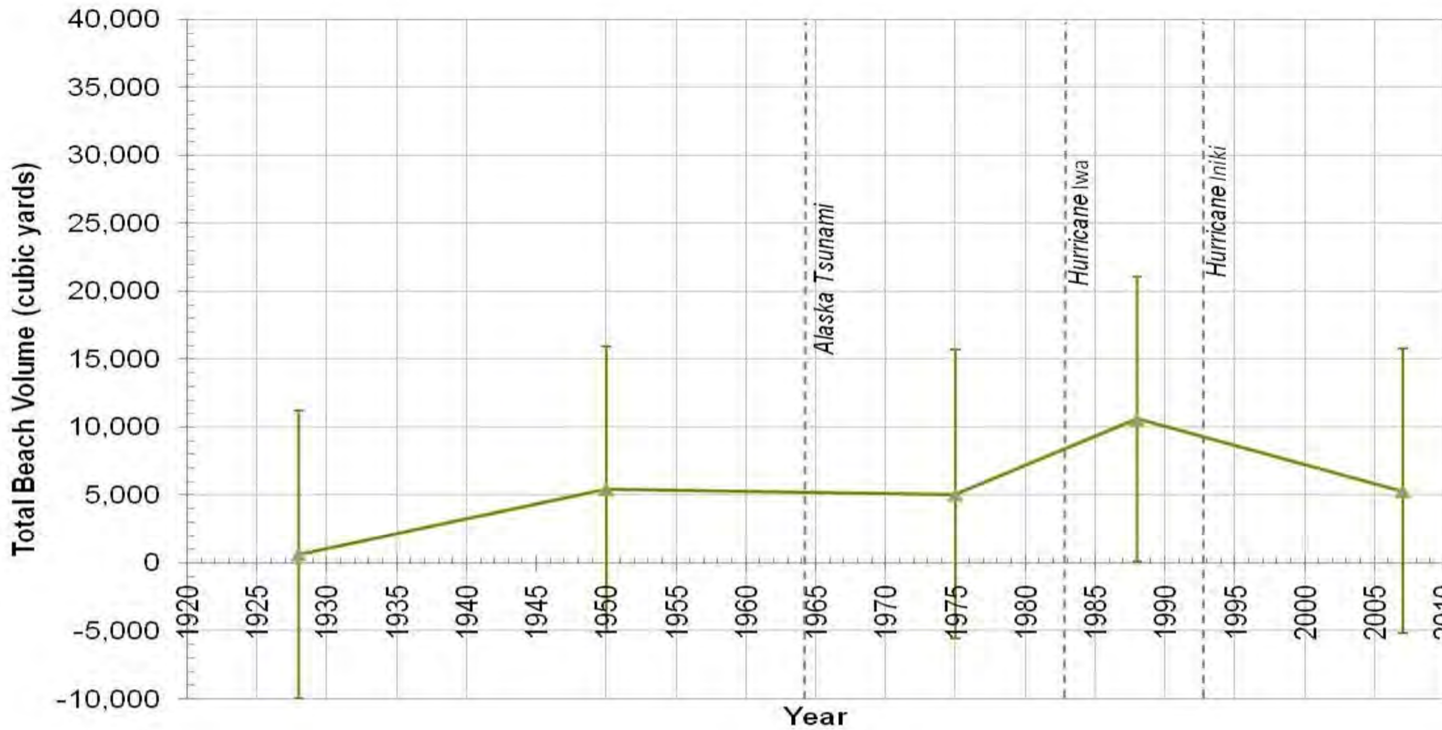


Figure 52. Historical Beach Volumes / Change Rates for Kukui'ula Littoral Cell



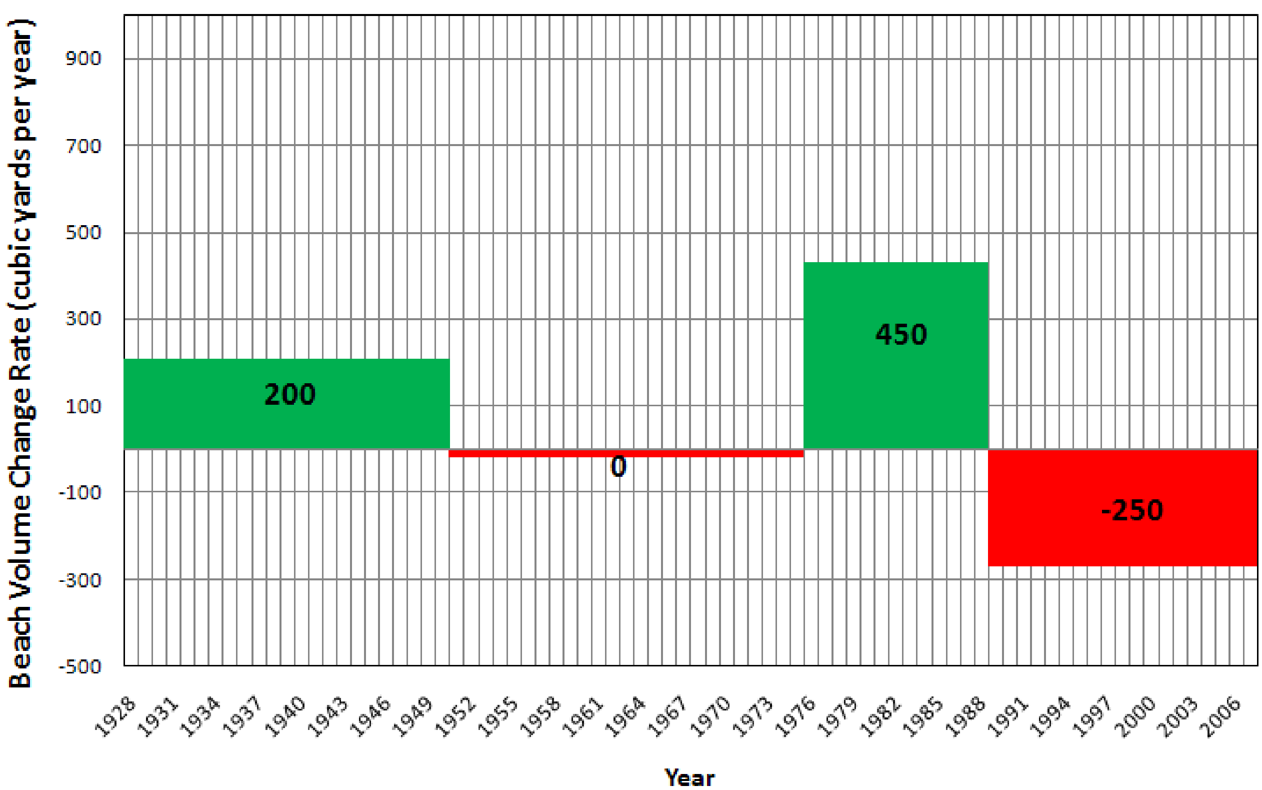
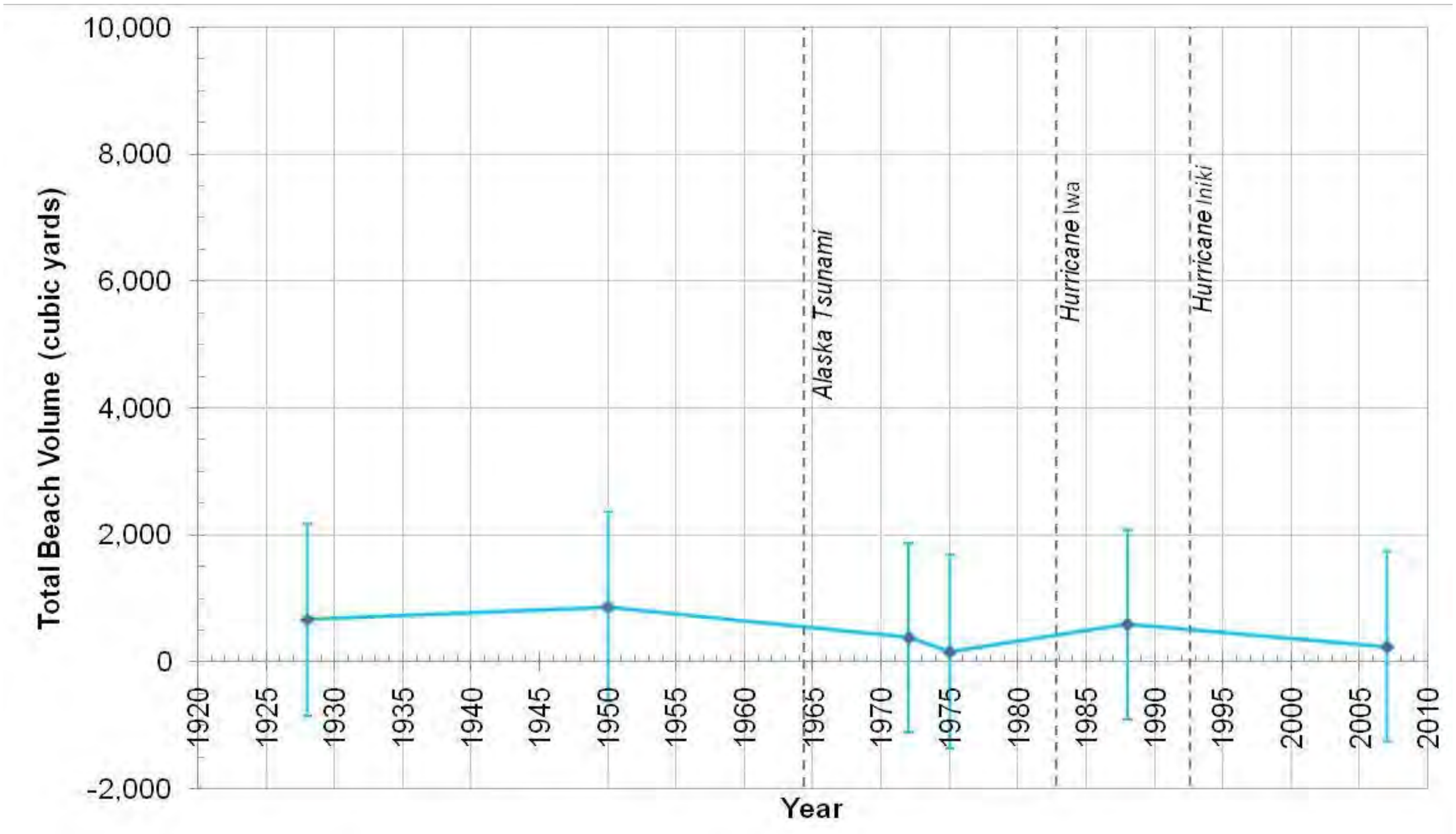


Figure 53. Historical Beach Volumes / Change Rates for Ho'ai Littoral Cell



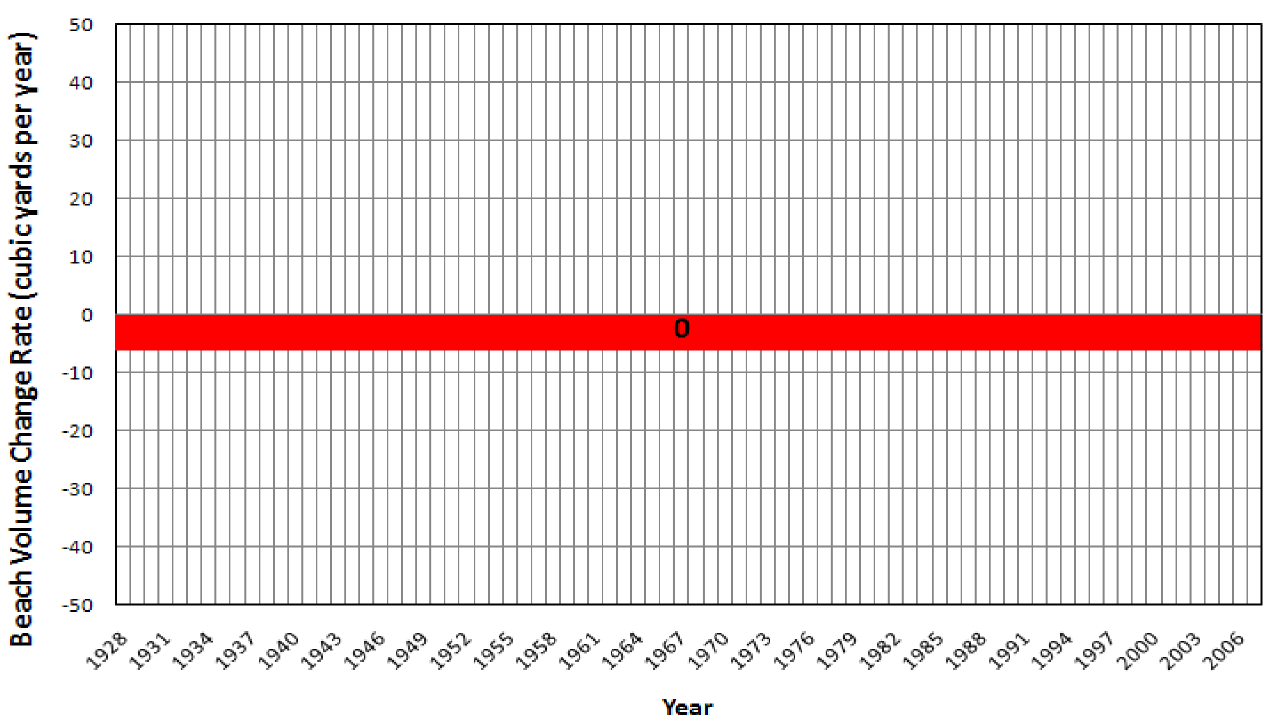


Figure 54. Historical Beach Volumes / Change Rates for Punahoa Littoral Cell

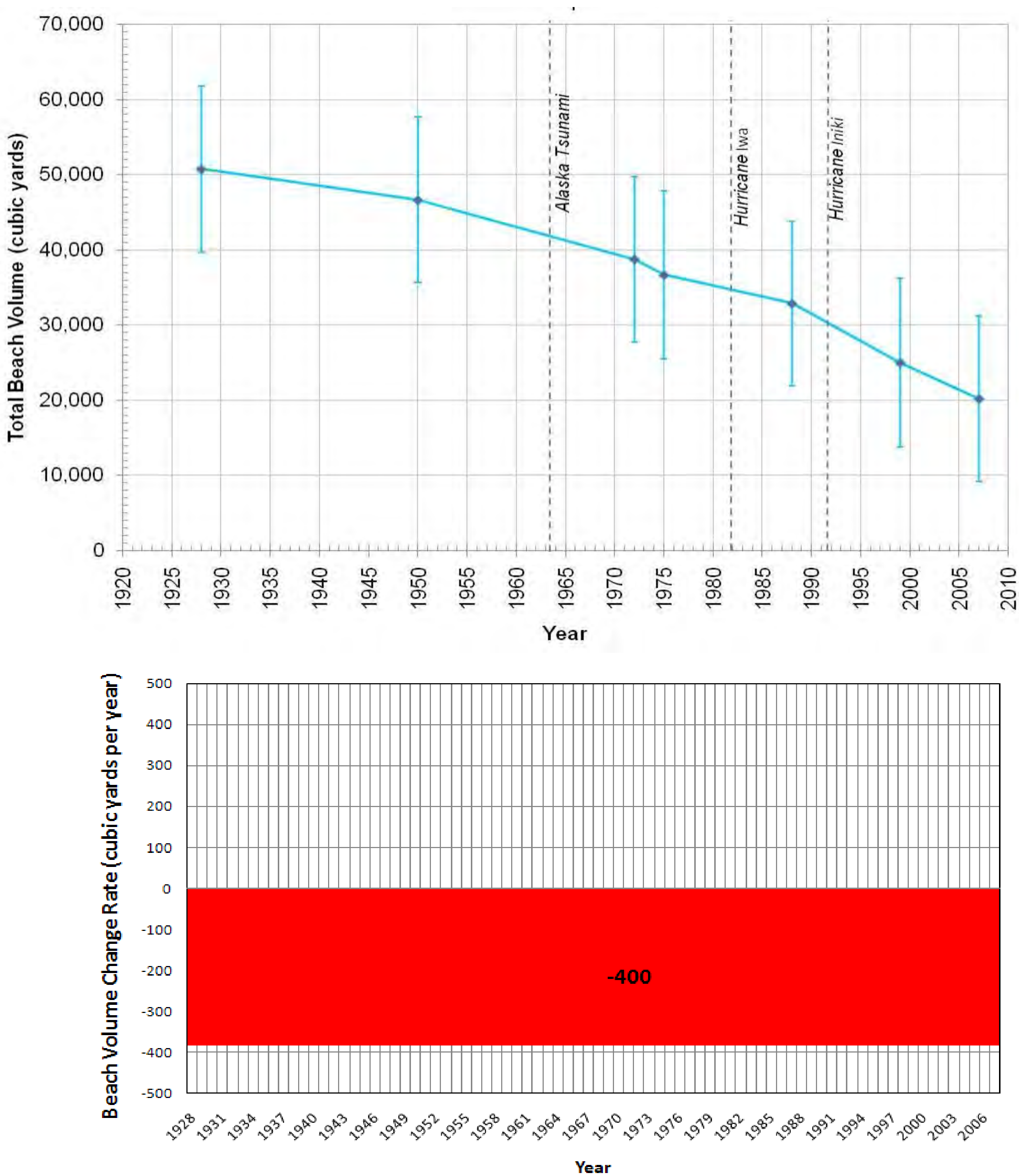


Figure 55. Historical Beach Volumes / Change Rates for West Poipu Littoral Cell

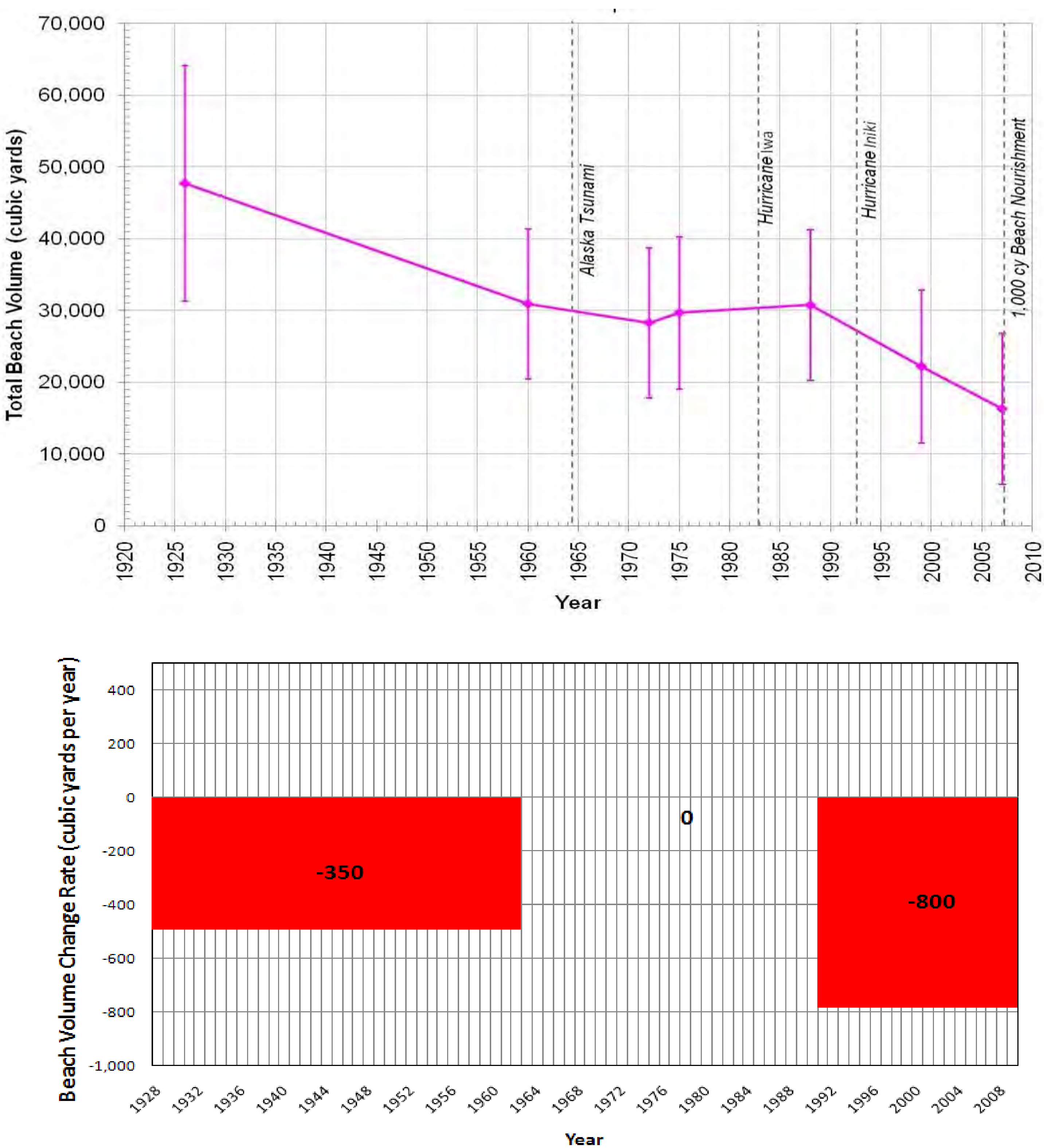


Figure 56. Historical Beach Volumes / Change Rates for Central Poipu Littoral Cell

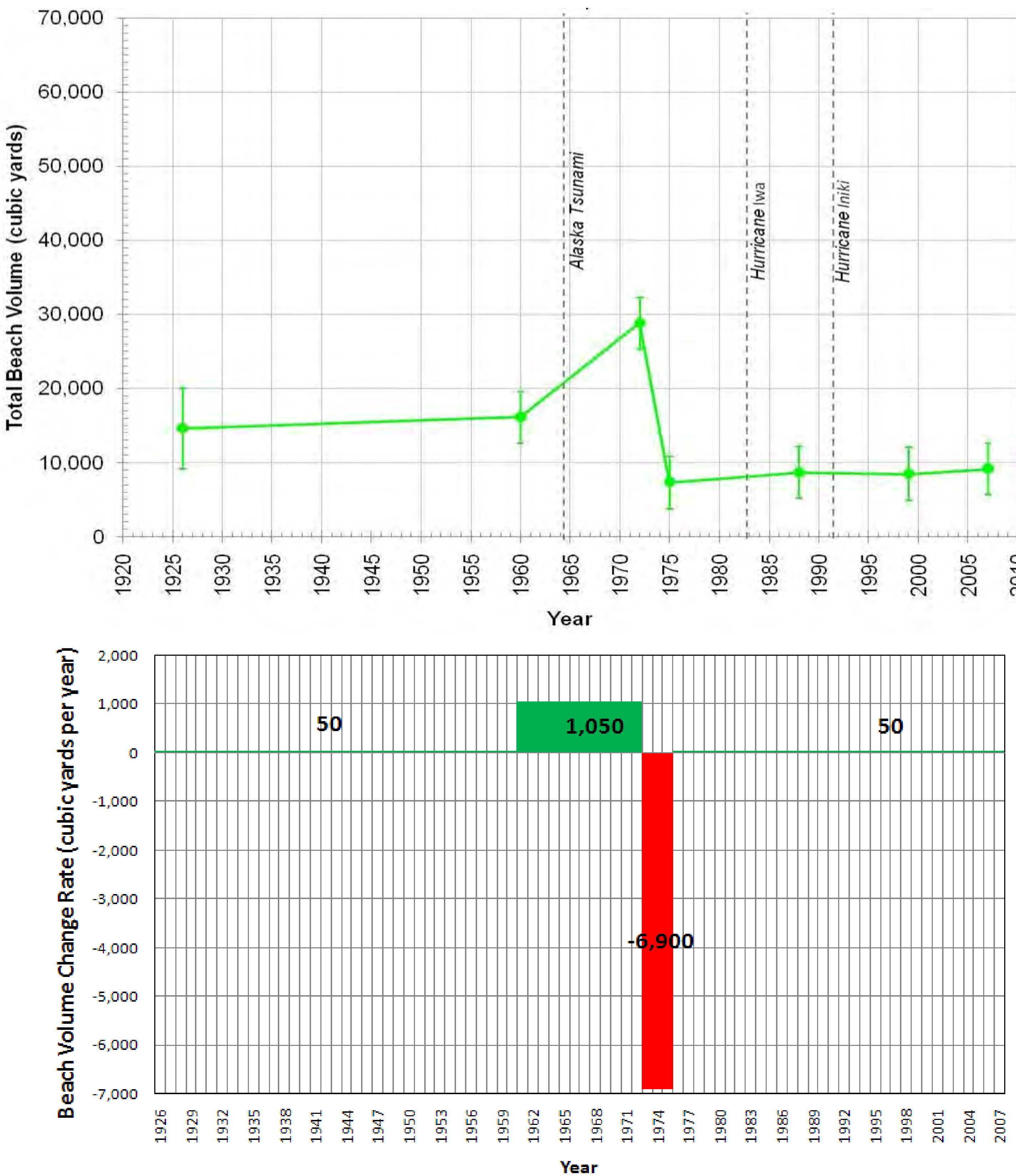
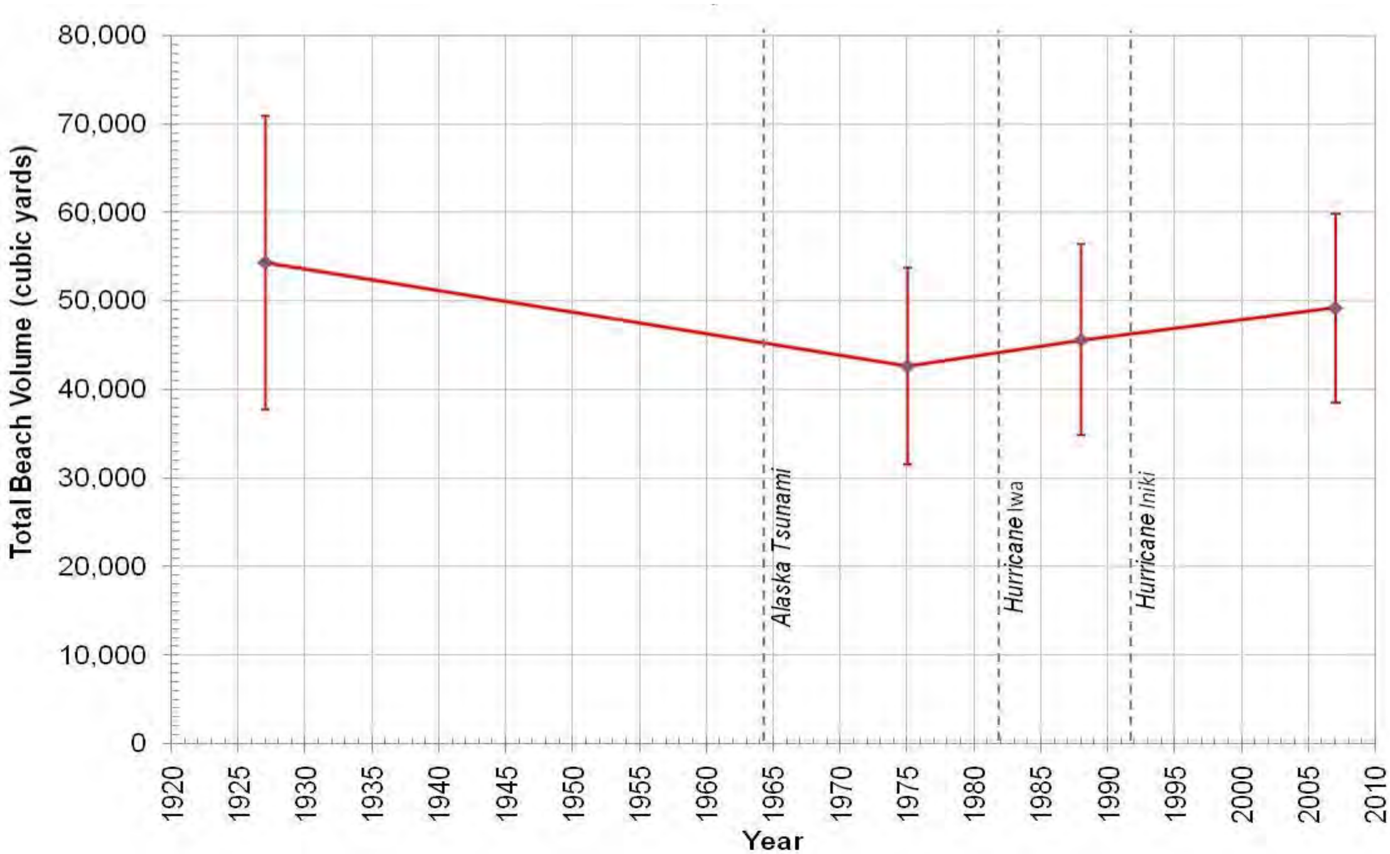


Figure 57. Historical Beach Volumes / Change Rates for East Poipu Littoral Cell



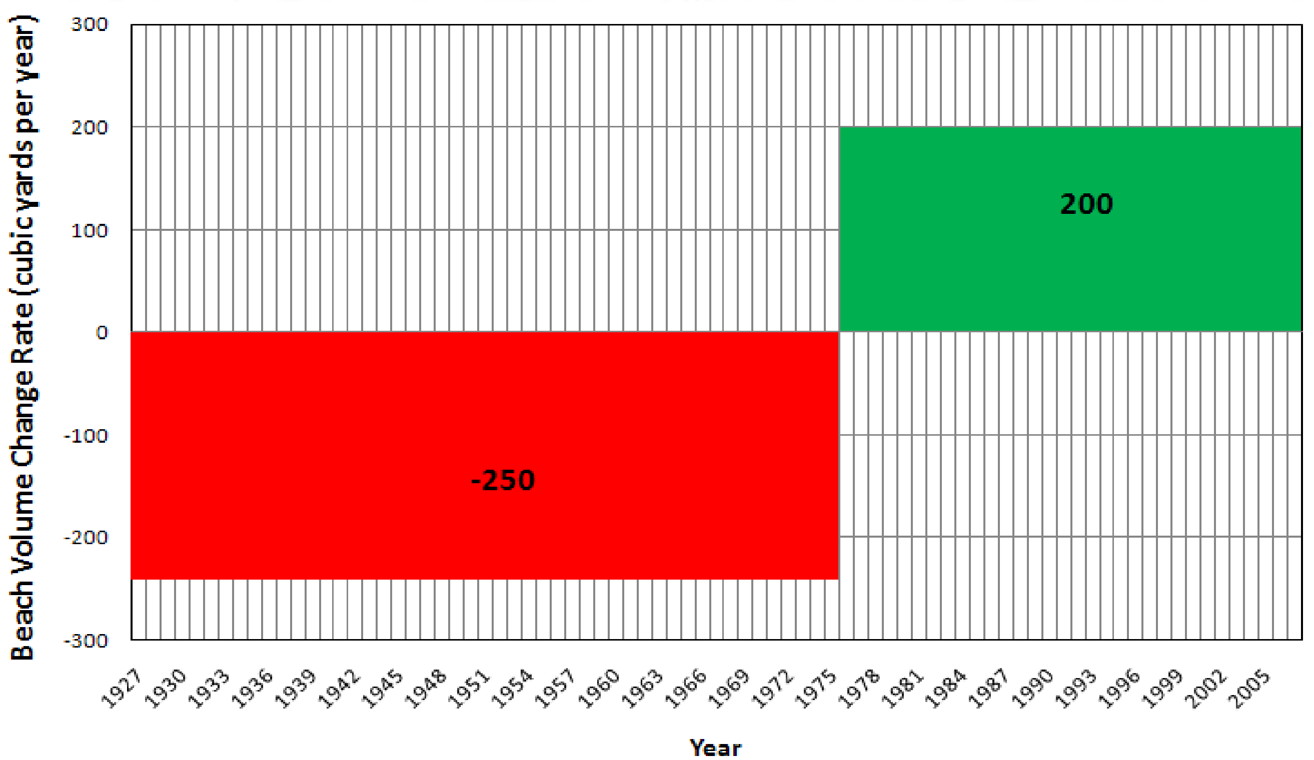


Figure 58. Historical Beach Volumes / Change Rates for Shipwreck Beach Littoral Cell

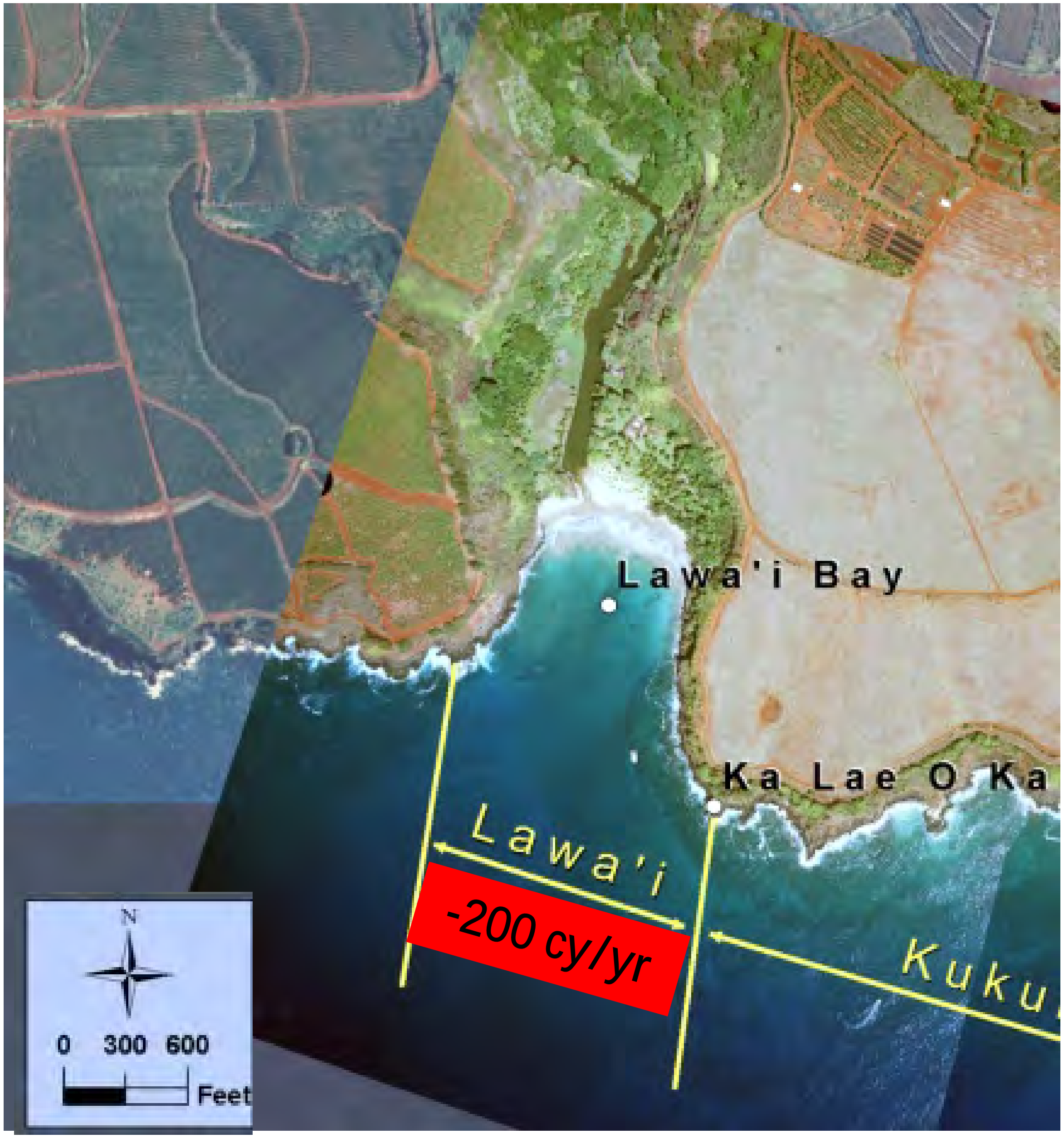


Figure 59. Beach Volume Change Rate for Lawa'i Littoral Cell

Figure 60. Beach Volume Change Rate for Kukui'ula Littoral Cell

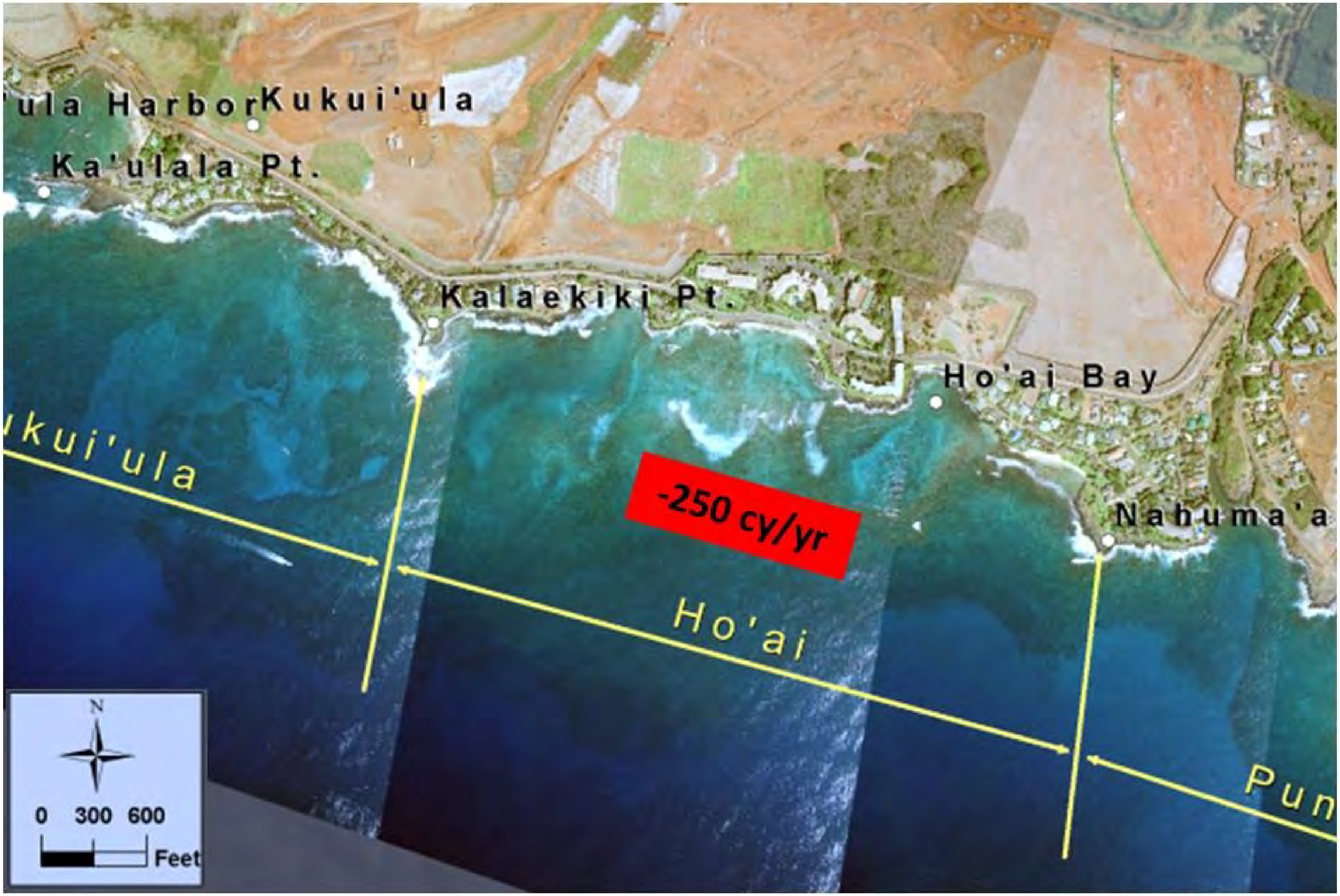


Figure 61. Beach Volume Change Rate for Ho’ai Littoral Cell

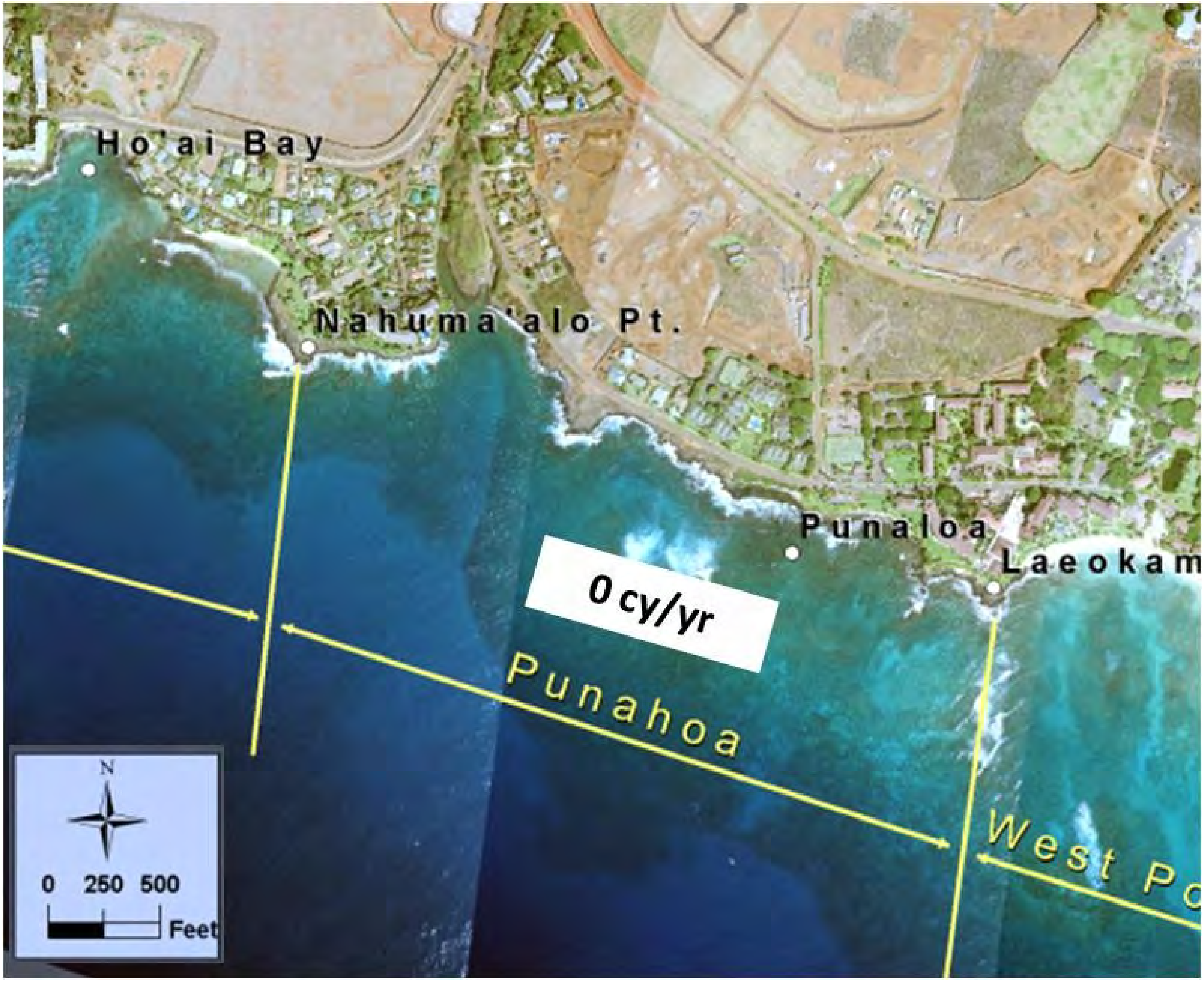


Figure 62. Beach Volume Change Rate for Punahoa Littoral Cell

Figure 63. Beach Volume Change Rate for West Poipu Littoral Cell

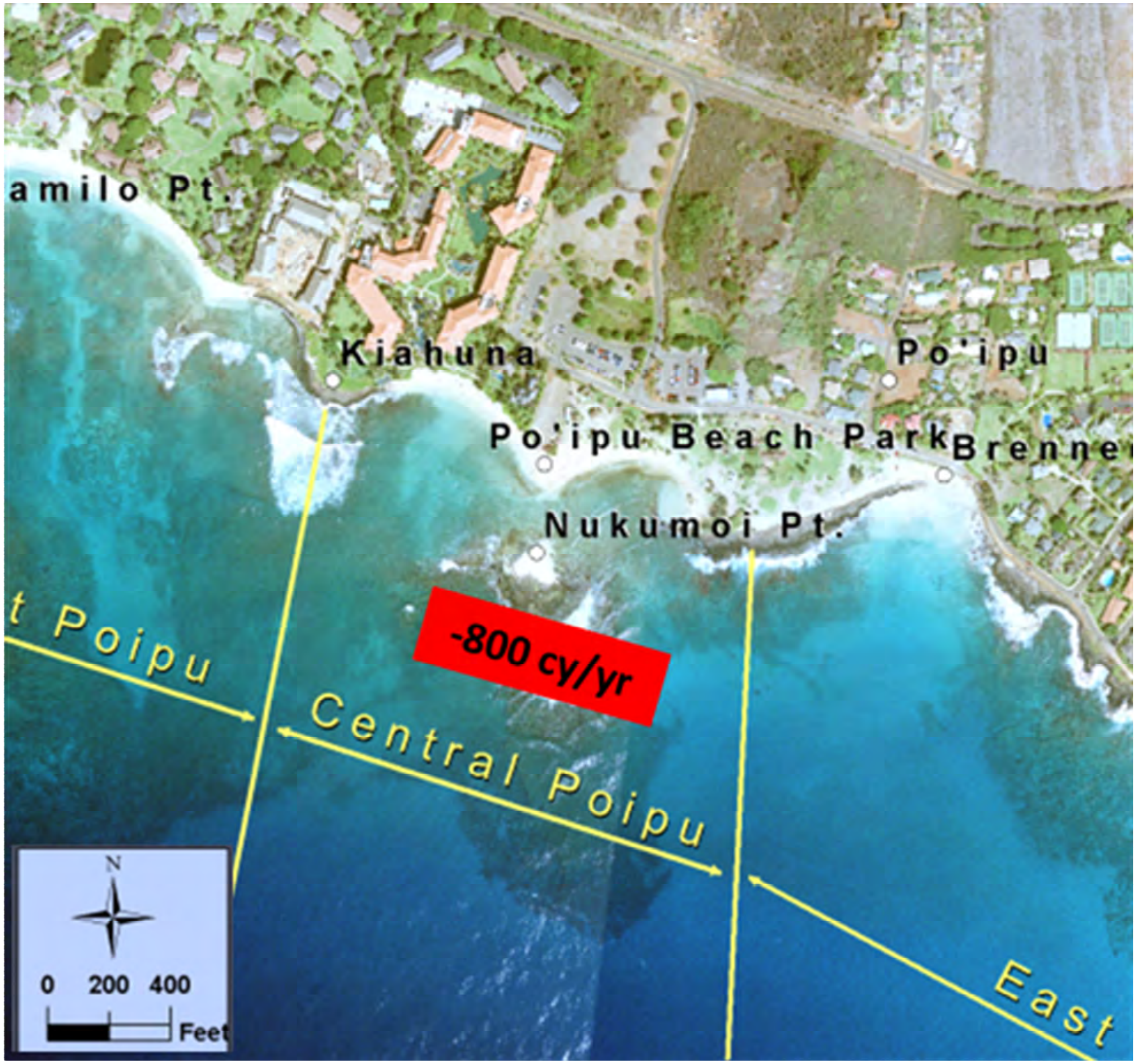


Figure 64. Beach Volume Change Rate for Central Poipu Littoral Cell

Figure 65. Beach Volume Change Rate for East Poipu Littoral Cell

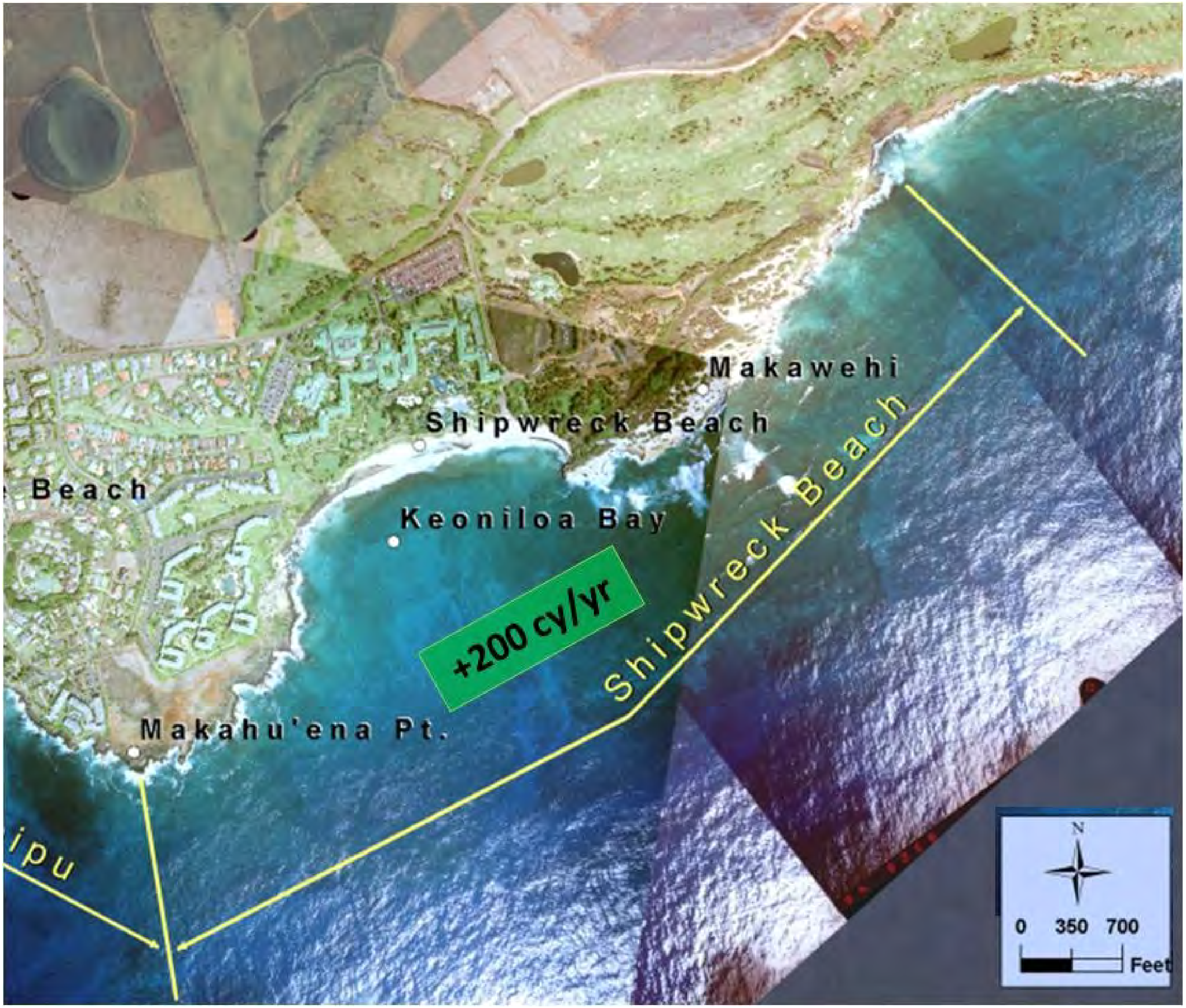


Figure 66. Beach Volume Change Rate for Shipwreck Beach Littoral Cell

For both regions, the beach sediment change rates are complicated by trend (accretion/erosion) reversals, historic shoreline structures, and seasonal effects. However, based on an analysis of the available data, the following is indicated for the Kekaha Region littoral cells (listed from east to west):

- The **Waimea** littoral cell demonstrates a classic reaction to the introduction of a shore-perpendicular structure on the downdrift end of the cell. The dominant transport in this area is from east to west, so when the Kikiaola Light Draft Harbor jetty was built, the cell switched from being erosional to accretional. The cell has been accreting at a relatively significant rate (over 10,000 cy per year) since the construction of the harbor.

  A main source of sediment is likely the Waimea River (estimated yield rate of 5,000 cy per year) which is transported to the west and trapped by the Kikiaola Harbor breakwater. Inman et al (1963) estimates an additional carbonate sand input to this area of 7,000 cy per mile per year, which could equate to an additional 11,000 cubic yards of sand to the Waimea area. The accretion rate based on this RSM analysis is higher than the impoundment rates calculated by previous studies, including a USACE-POH estimate of 4,000 cy per year (Sea Engineering, 2008b). The Sea Engineering report notes though the uncertainties involved, and that the rates could be off by orders of magnitude.

- Dredge records suggest that sediment accumulates within **Kikiaola Harbor** at a rate of 600 to 3,000 cubic yards per year. This compares relatively well to the assumed only source of sediment to the harbor, Kikiaola Harbor Gulch which has an estimated yield of 1,600 cubic yards per year and which discharges directly into the harbor. It is assumed that longshore littoral sediment does not make its way into the harbor. A potential project for future consideration is to reroute the Kikiaola Harbor Gulch to discharge downdrift (to the west) of the harbor and thus minimize the amount of maintenance dredging of the harbor.

- The **Oomano Point** cell has been in a relatively steady erosional state over the last decade. Comparison of the line graphs of the two littoral cells indicate that the Oomano Point and Kekaha Beach cells have separate littoral transport processes.

- The **Kekaha Beach** cell has experienced both erosion and accretion over the study period. In recent geologic history, Kekaha Beach was the southeastern extent of the portion of the Mana Coastal Plain which had been accreting (USACE 1978). Analysis of the volumes generated by this study indicates: a) an erosional trend in the study period prior to 1975, b) a significant accretion period from 1975 to 1992, and then c) back to an erosional trend from 1992, based on a single data point (2006) since that time. The latter "trend" may have been a single event loss during Hurricane Iniki, however the data are insufficient to identify this loss. It is not known what caused the Kekaha Beach erosional pattern to switch to an accretional pattern from the mid 1970's to the end of the 1990s. A USACE (1978) analysis also indicates that Kekaha Beach was eroding during the period of 1950-1976, but cites an accretion period from 1936-1950. The latter is probably related to the 1928 shoreline data and its associated larger beach volume.

- The beaches in this region did not seem to have lasting damage from Hurricane Iwa.

Results for the Poipu Region littoral cells indicate the following:

- In general, the sediment transport rates are extremely small, which is to be expected in a region with pocket beaches separate by headlands and protected by offshore reef.
- The **Kukui'ula, Ho'ai, and Punahoa** littoral cells have very small beach volumes (less than 10,000 cubic yards) and essentially no overall long-term average erosional or accretional trend (change rates of less than 100 cubic yards per year) based on an analysis of the beach volumes. However, the Kukui'ula and Ho'ai cells have experienced trend reversals which could simply be attributed to seasonal variation and the season in which the historical shorelines were measured.
- Although the **Shipwreck Beach** littoral cell went through an erosional period prior to approximately 1975, it has been accreting at almost the same rate since that time. Data points are limited for this cell and the difference in trend could be simply attributed to seasonal variation and the season in which the historical shorelines were measured.
- The **West Poipu** and **Central Poipu** cells have all been eroding over the past century, at similar rates. The **East Poipu** cell though seems to behave differently (see Figure 67 below). Although the East Poipu total average rate over the time period is erosional and similar in order of magnitude to the West and Central Poipu cells, the rate is slightly accretional following 1975. It is not known what caused the accretion and erosion blip in the East Poipu cell, but the overall data shows that the East Poipu beach did not recover from the significant erosion event.
- The **Lawa'i** cell also experienced a significant erosional period from 1966 to 1975, and has been generally eroding over the last century. As the primary sediment source to this cell may be the Lawa'i Stream, it may be that the Lawa'i Stream is no longer producing as much sediment due to urbanization or other upstream controls.
- The effects of Hurricane Iniki (1992) seem to be reflected in all of the Poipu region cells, except for the Lawa'i, East Poipu, and Shipwreck cells, i.e. the cells on the west and east ends of the Poipu region.

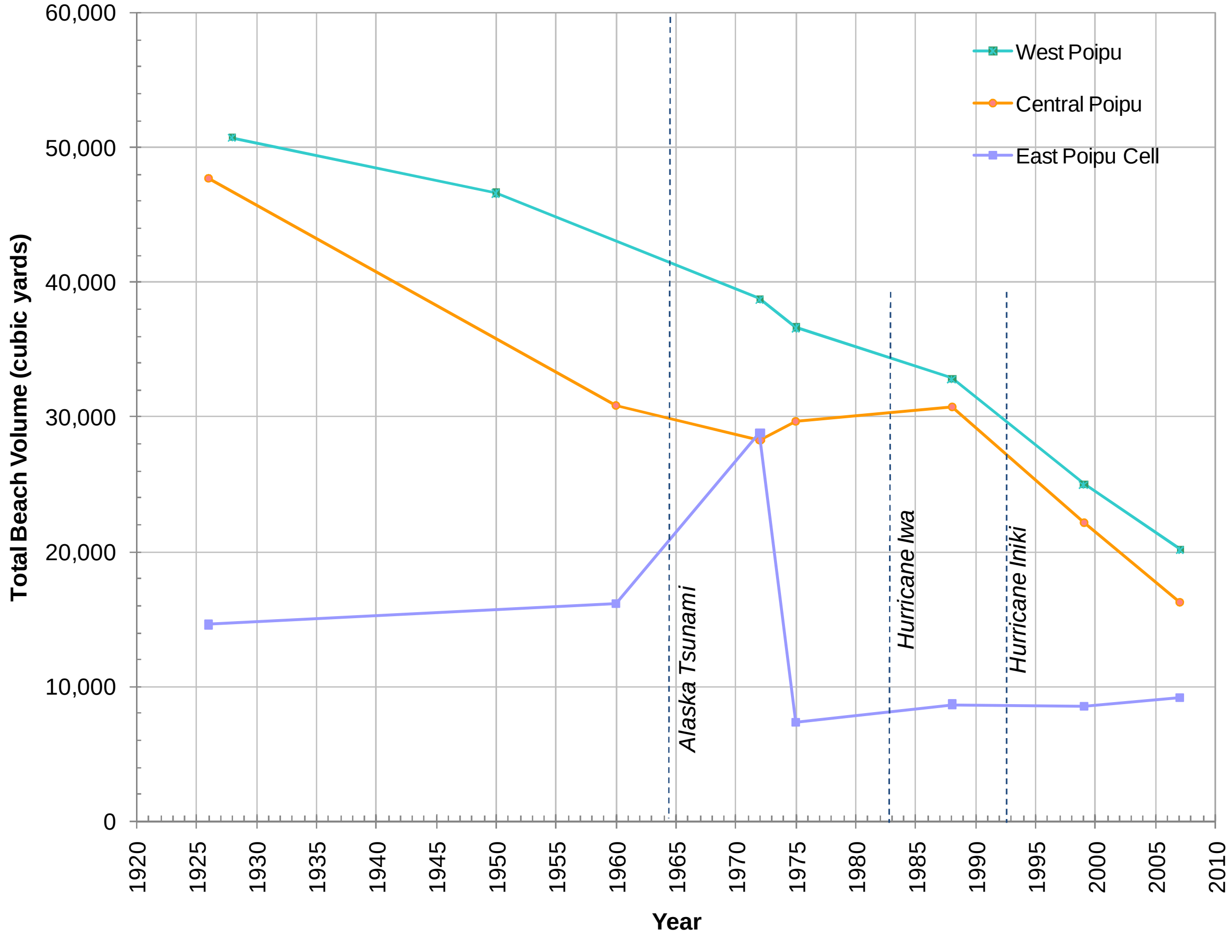


Figure 67. Historical Beach Volumes of West, Central, and East Poipu Cells

With the volume changes established, the sediment transport pathways could be developed based on coastal processes, particularly current modeling, and on general morphological considerations. This may be done in future studies and/or future revisions of this document.

The sediment budgets are further discussed in Appendices F and G.

IX. Ocean Sand Source Inventory

There are believed to be significant sources of sand offshore of the study region, held in low spots and channels on the reef (e.g., Hampton, Blay, and Murray 2004). As part of this RSM study, the University of Hawai‘i, Coastal Geology Group, conducted research to identify stable, shallow water (reef top) sand fields in four locations and determine their surface areas. Changes in the extent of these sand bodies over time help differentiate ephemeral and stable (non-emphemeral) sand volumes that may indicate potential sand resources.

High-resolution orthophotomosaics of the four research targets were selected to examine reef-top sand field extent. The photomosaics were chosen based on their date, the area of coverage, amount of surface glint and cloud cover, water column clarity, and quality of the water surface. The areas of coverage for Kauai included the following:

1. **Kekaha, Kauai** – Waimea to Kekaha Beach Park. For this study region, two mosaics (one of Waimea and one of Kekaha) were used for each year. Photomosaics from 1950 and 1987 were used as historical coverage. Mosaics from 2006 were used as the modern coverage. Several other years of mosaics were available, but were not analyzed due to poor water conditions because of suspended sediment from Waimea River. The mosaics that were chosen for this study had the best seafloor viewing conditions.
2. **Poipu, Kauai** – Shipwreck Beach to Lawa'i Bay. Mosaics from 1999, 1992, 1988, 1982, 1960, 1950, and 1928 were analyzed, but not used for historic coverage because of incomplete coverage and/or poor visibility of the seafloor. A 1975 mosaic was used as historical coverage, and a 2007 mosaic was used as modern coverage.

Two potential sand source areas in Maui and one in Oahu were also studied. These areas are also potential sources even for the Kauai regions, given the proximity of the islands and the high demand for sand. Future RSM projects should consider the use of sand sources on an inter-island basis.

This photo analysis, coupled with ground-truthing, concluded the following:

- 189.4 acres (766,461 m^2) of stable reef-top sand is stored off the coast of Kekaha, Kauai, as shown in Figure 68. The majority of this sand is located in two large sand fields off of Kekaha Beach Park.
- 72.2 acres (292,104 m^2) of stable reef-top sand is stored off the coast of Poipu, Kauai, as shown in Figure 69. The majority of this sand is located in a large sand field off of Brennecke Beach.

The complete study report is provided in Appendix H. Another study of a sand source in Kahului Bay on Maui (Sea Engineering 2008) is provided in Appendix I. This Kahului Bay sand could also be a source even for the Kauai regions, given the proximity of the islands. As discussed above, this potential source should be considered for future RSM projects.

X. Kauai Stream Sediment Management

There are numerous rivers/streams/gulches within the two Kauai regions, but there is no known stream sediment management (sediment removal) within any of these rivers/streams/gulches. On Oahu, a Stream Mouth Map Book was prepared to provide descriptions of the littoral setting, aerial photographs, ground photographs, current management practices, and recommendations for management. This type of document could be useful for Kauai RSM regions and is a potential future RSM task.

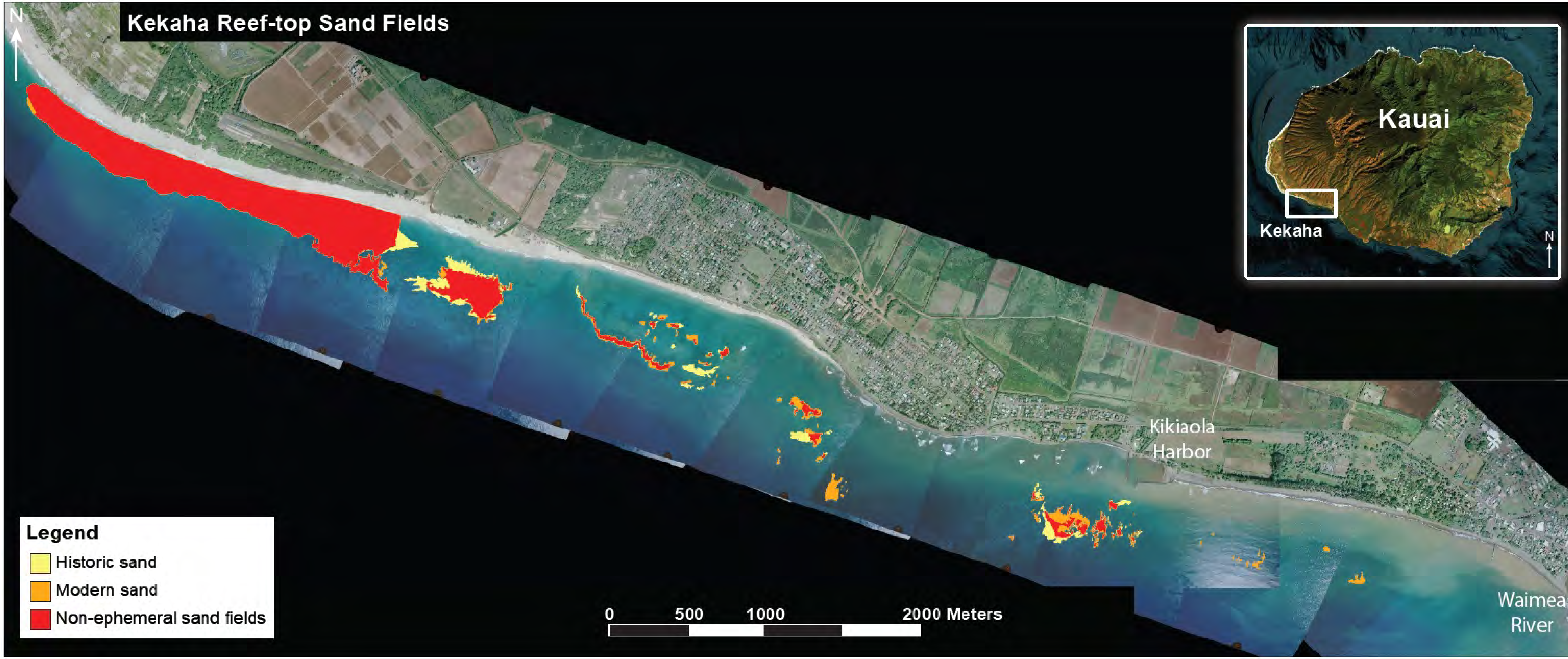


Figure 68. Reef-top Sand Fields Located at Kekaha, Kauai

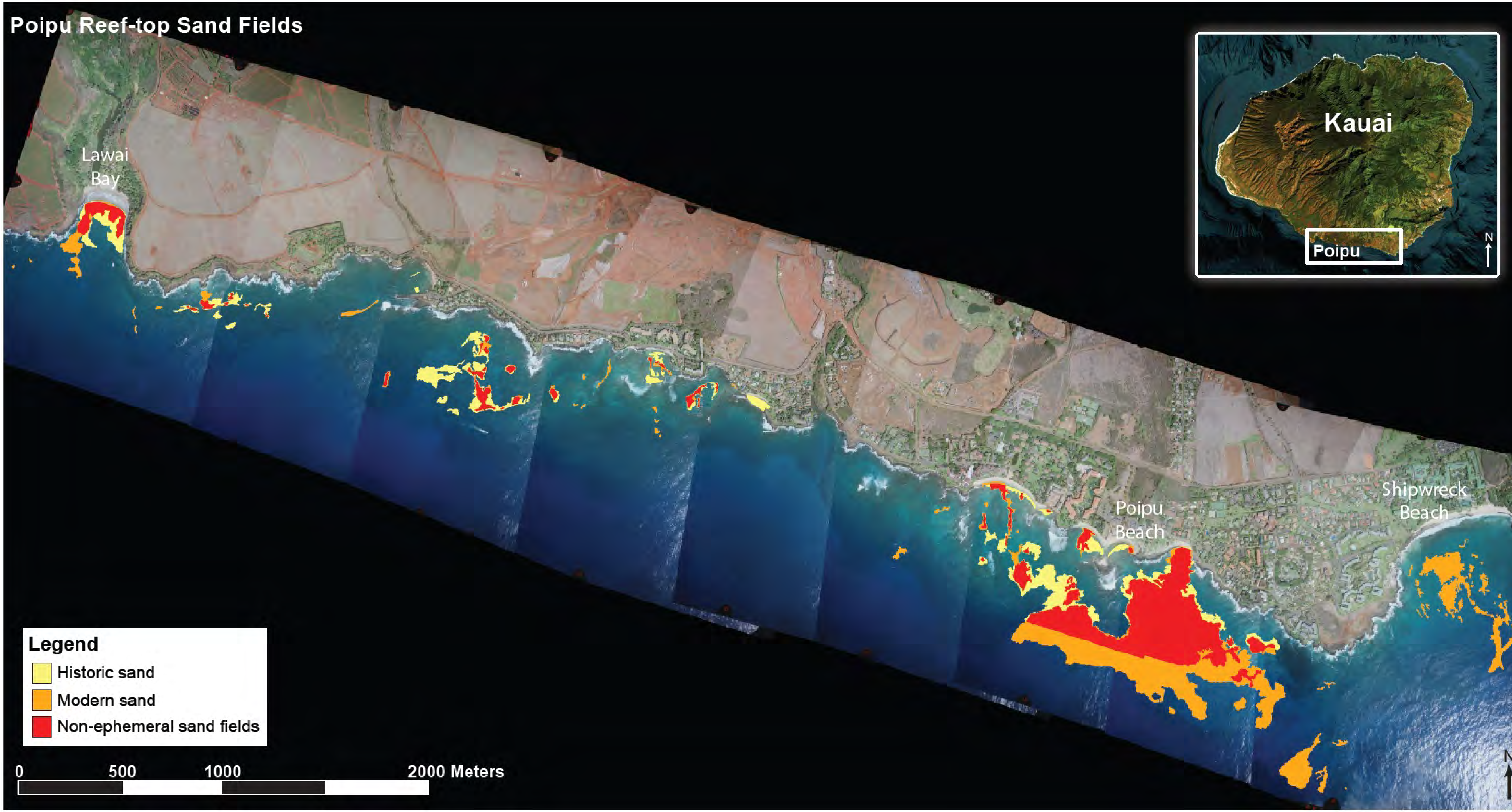


Figure 69. Reef-top Sand Fields Located at Poipu, Kauai

XI. Potential RSM Projects

A. Kikiaola Harbor Sand Bypassing

Bypassing beach sand from the east side of Kikiaola Harbor to the west side has been a topic of discussion for many years. As discussed in Section IX.A, previous studies have shown that the amount of sand impounded on one side of the harbor, and lost to erosion on the other, is on the order of 3,500 to 5,000 cy per year (Sea Engineering 2008b). An annual by-pass effort should be somewhat higher. Based on this impoundment rate and a desired higher annual by-pass effort, the potential project would be on the order of 6,000 cy per year. This would follow an initial bypass effort of 80,000 cubic yards, based on an estimated total sand deficit west of the harbor on the order of 80,000 cy in the 1,500-ft reach between the Harbor and Mamo Road (Sea Engineering 2008b).

Annual placement can be accomplished over a 1,000-ft reach adjacent to and west of the harbor. Placement on the flanked section of the west breakwater root is a priority, however the bulk of the placement should likely be concentrated at the center of the reach where a beach salient occurred prior to construction of the harbor. The sand borrow area will extend approximately 1,200 ft east of the harbor (on Waimea Beach). The placement and borrow sites for the initial bypass effort are shown in Figure 70.

Two viable bypass methods are hydraulic dredging and truck hauling. Truck haul methods have been used previously at Kikiaola Harbor, and are cost effective for smaller one-time projects. Hydraulic dredging requires installation of a pipeline, fluidization in the borrow area, and dewatering in the placement area. Startup costs are high but are amortized for large or repeated projects, especially if the pipeline can remain in place.

B. Poipu Beach Shoreline Restoration

The County of Kauai Department of Parks and Recreation is interested in restoring the popular Poipu Beach Park. An objective is also to eliminate or significantly reduce an existing safety hazard to swimmers at the west end of the park. The potential project is to place 6,000 cubic yards of sand.

The near-term source would be sand presently stored at the Kekaha Landfill. Nearshore and offshore sand deposits off the Poipu shoreline (Figure 69) would be potential sand sources for longer-term renourishment at Poipu Beach Park.

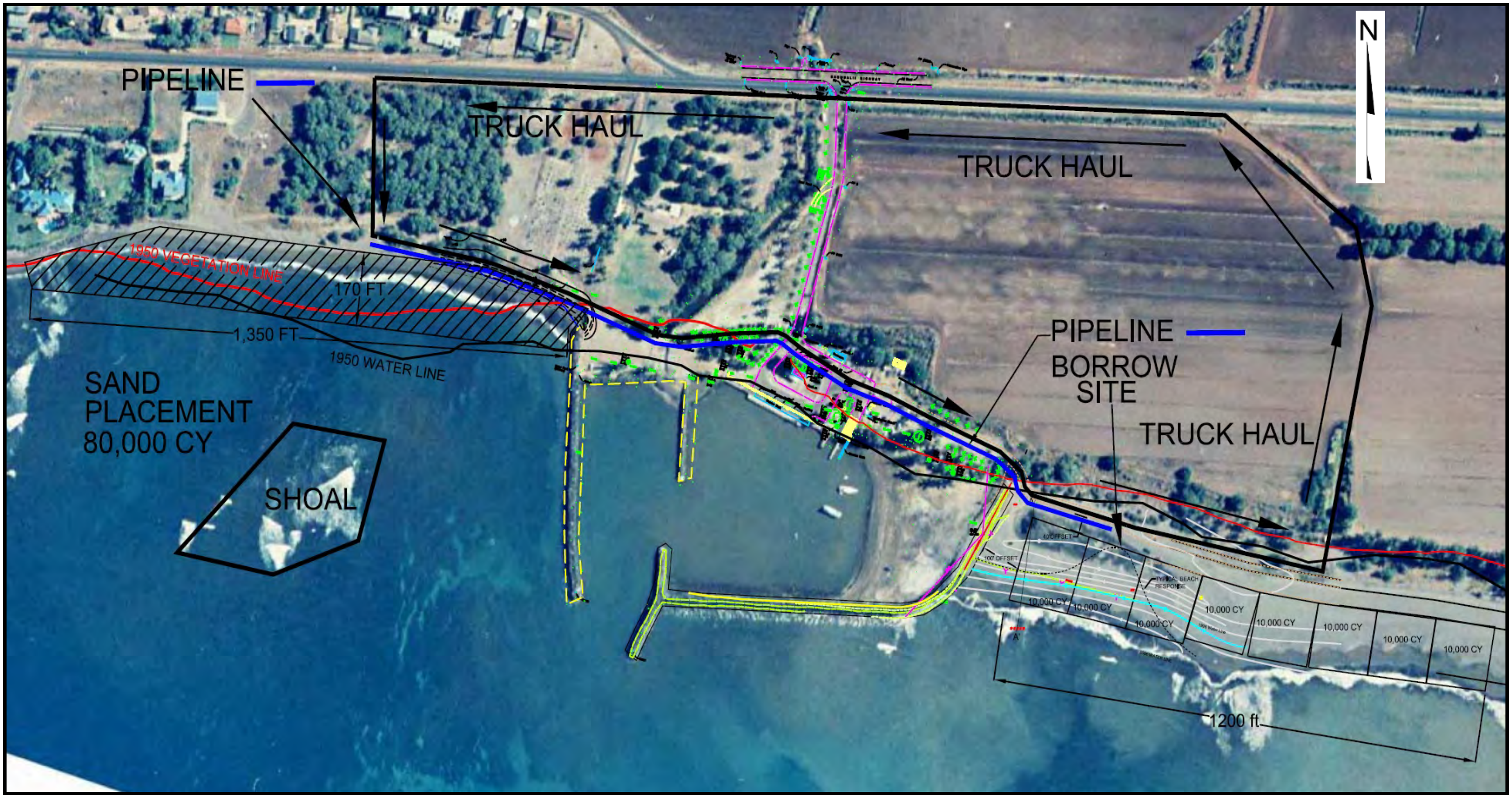


Figure 70. Overview of Kikiaola Harbor Sand Bypass Operation (Sea Engineering, 2008(b))

XII. Conclusions and Recommendations

A. Conclusions

The following initial conclusions result from this Kauai Regional Sediment Management Plan.

Kekaha Region

- In the Kekaha region, the long lengths of sandy beaches result in high volumetric rates within each littoral cell, (in comparison to the rates calculated for the Oahu and Maui RSM studies). The beaches in this region are both erosional and accretional.
- Kikiaola Harbor Sand Bypassing is a potential RSM project. The Kikiaola Harbor jetties and an offshore sand sink appear to prevent longshore sand transport from Waimea Beach to the downcoast beaches, based on accretion upcoast of the harbor and erosion downcoast of it. The potential project would be to remove sand from Waimea Beach and place it on the downcoast Kikiaola Beach. It is recommended that the State of Hawaii implement the sand bypass plan for Kikiaola Harbor as cited in the fully executed project cooperation agreement.
- Another potential RSM project is rerouting of the Kikiaola Harbor Gulch. The gulch discharges directly into Kikiaola Harbor. Rerouting of the gulch to downcoast of the harbor would minimize the amount of maintenance dredging of the harbor and should be considered for future RSM studies.
- The sand sources search resulted in the identification of 189.4 acres (766,461 m^2) of stable reef-top sand stored off the coast of the Kekaha region. The majority of this sand is located in two large sand fields off of Kekaha Beach Park.
- There are presently three existing Federal projects in the Kekaha region.

Poipu Region

- In the Poipu region, the historic erosion rates are relatively small. Thus, only a small amount of beach nourishment would be needed to create stable beaches.
- Poipu Beach Park Restoration is a potential RSM project. The County of Kauai desires restoration of the popular Poipu Beach Park. The potential project is to place 6,000 cubic yards of sand. Therecent erosion rate is 800 cubic yards per year so the proposed beach fill quantity would be expected to remain in the reach for six to eight years.
- The sand sources search resulted in the identification of 72.2 acres (292,104 m^2) of stable reef-top sand is stored off the coast of Poipu, Kauai. The majority of this sand is located in a large sand field off of Brennecke Beach.
- There are presently no existing Federal projects in the Poipu region.

The sediment budget analysis is based on limited available data. The scarcity of historical shoreline data points could be masking the historical physical processes within each region, i.e. rate changes or trend reversals could be occurring during certain periods of time when shoreline data points are not available and thus any changes are not apparent in the historic beach volume graphs. An example of this was seen in the Kekaha region graph (Figure 42) with the effects of the construction of Kikiaola Harbor.

Dune protection does not appear to be a major issue in the Kauai regions and no associated Potential RSM Projects have been identified.

The Honolulu District RSM web site has been updated to include the Kauai regions. Historical aerial photography, digitized shorelines, ground photography, coastal structure inventory, regional sediment budget, reports and other Kauai RSM products are available to the public on the web site. An Internet Map Server provides real-time mapping capabilities to enhance the utility of the information compiled for the regions.

A workshop was conducted in January 2011 concerning the needs, findings and RSM opportunities within the Kekaha and Poipu regions. The workshop provided an overview of the tasks accomplished in the Kauai regions and included detailed discussions on the findings presented in the preliminary Kauai RSM Plan. A summary of the findings from this workshop is provided as Appendix J.

B. Recommendations

It is recommended that the following work be completed in association with future Kauai RSM studies.

- Continue water circulation and wave transformation numerical modeling to refine the Kauai regional sediment budgets. As an example, the analysis could indicate a reversal in transport direction in the Kekaha region, associated with Kona waves.
- Perform field visits and jet probing of reef-top sand sources.
- Perform grain size characterization of potential beach nourishment sites (potential RSM projects) and analyze their compatibility with potential sand source sites.
- Develop further data on the sediment yield (inputs) to the Kauai littoral cells from the streams and rivers to provide a better understanding of the overall sediment budgets. Define sediment source(s) and loads into Kikiaola Harbor.
- Develop a further understanding of seasonal fluctuations of the beaches within each region. This could include development of new shoreline profiles.
- Confirm/refine the 0.40 cubic yards per square foot beach volume conversion factor for applicability to Kauai RSM region beaches.
- Update the preliminary Kauai regional sediment budget and RSM plan based upon the findings of the above.

- Develop a state-wide approach to utilization of sand sources, including the consideration of inter-island sand exchanges given the proximity of the islands and the high demand for sand.
- Re-establish the State Programmatic General Permit for small (<10,000 cy) beach nourishment projects and/or develop a new State (or regional) permit(s)/program for opportunistic sand use for beach nourishment projects.
- Develop details for potential RSM projects identified to improve sediment management strategies in the region. Activities to reduce project costs and increase beneficial use of sediments on a regional scale at Poipu Beach Park and Kikiaola Beach will be investigated and coordinated with various stakeholders.

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