MAUI

HAWAII REGIONAL SEDIMENT MANAGEMENT
KAHULUI AND KIHEI 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

Prepared by

Moffatt & Nichol

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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 Kahului and Kihei regions of Maui has been produced as a part of the Hawaii Regional Sediment Management study. The document compiles available information for the RSM regions, including studies produced directly in support of the 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 Maui 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 Kahului and Kihei 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 Kahului and Kihei RSM regions of Maui.

Kahului Region

- Almost all of the cells within the Kahului region experienced relatively significant erosion during the time period prior to approximately 1987. This is consistent with impacts from the historic sand mining in the area which concluded in the 1960-1975 timeframe. Since 1987, some of the beaches have shown signs of increasing stability.
- The seasonal fluctuations for the Kahului region beaches appear to be significantly higher than the long-term average change rates.
- The Wailuku Kahului Wastewater Reclamation Facility (WWRF) Shore Protection Project is a potential RSM project that could reduce the maintenance

costs of a federal shore protection structure while beneficially using sand from a Federal dredging project (i.e. Kahului Harbor). The permanent removal (historical mining) of sand from the littoral system has resulted in a deficit in the sediment budget and erosion over the length of the area from Baldwin Beach to Kahului Harbor and the rate of shoreline erosion at the WWRF is still significant. Two beach nourishment alternatives have been identified as part of the long-term protection of the WWRF: one for a 3,800-ft long beach replenishment and one for a 2,400-ft long replenishment. The former would require approximately 105,000 cubic yards of initial sand placement and the second alternative would require approximately 65,000 cubic yards.

- Another potential RSM project is Kahului Harbor Dredge Material Beneficial Reuse. Based on sediment sample testing done for the 1999 Kahului Harbor dredging project, the harbor sediment grain size is primarily sand which suggests the potential to reuse dredge material for beach nourishment. A potential RSM project is to place Kahului Harbor dredge material along the Kahului Harbor shoreline, which has a current beach erosion rate of approximately 800 cy per year. The dredge material may also be appropriate and have higher potential benefit for other beach nourishment sites in the region, depending upon the grain size compatibility with the other sites.
- The RSM sand sources search identified 7.8 acres (31,656 m^2) of stable sand stored on the reef flat off of the north shore of Maui, serving as a potential resource for beach replenishment.
- A sand search done as part of a separate project also indicated a very large (~3,500 acres) potential source of beach-quality sand seaward of the Kahului Harbor breakwater
- There are currently six Federal projects in the Kahului region.

Kihei Region

- The Kihei region experiences both wave-driven longshore sediment transport direction that is from south to north and wind-driven sand transport from north to south. A significant contributor to erosion on the beaches is due to the wind blowing sand onshore over eroded dunes and through breaks in the dunes and thus out of the littoral cell.
- While many of the beaches along the west-facing shoreline of the Kihei region have experienced erosional trends prior to 1998, the Kawililipoa littoral cell area has been steadily accreting. This is possibly associated with a unique rubble formation in the nearshore at the north end of the Kawililipoa Beach littoral cell which acts as a groin and interrupts sand transport to the north, causing accretion on its downcoast side.
- The Kihei Beach Hurricane and Storm Damage Reduction Project is a potential RSM project. The potential project area shoreline extends approximately five miles from the northern limit of Kalama Park to northwest of the Kealia Pond. This area includes the North Kihei, Kawiliwilipoa Beach, and part of the Kealia and Kalama littoral cells of this RSM study. The project would include an initial

beach nourishment (approximately 358,000 cubic yards), as well as future renourishment.

- The sand sources search identified 13.8 acres (55,821 m^2) of stable sand stored on the reef flat off the coast of Kihei, Maui, serving as a potential resource for beach replenishment.
- There are currently three Federal projects in the Kihei region, one of which is only in the study phase.

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 potential RSM projects relate to both existing Federal projects and potential future Federal interest. Dredging of beach quality sediment outside the Kahului Harbor entrance (offshore reef-top sand fields) for placement on beaches could minimize dredging cycles at Kahului Harbor (existing Federal project). Beach nourishment at the WWRF would also have the potential effect of minimizing the maintenance cycle on the existing WWRF rock revetment (potential Federal assistance project). The Federal interest in the Kihei Beach project would be associated with National Economic Development benefit from erosion protection including loss of land, structural damage prevention, reduced emergency costs, reduced maintenance of existing structures and incidental benefits, and hurricane and storm damage reduction benefit of reduction of damages to existing structures.

The Honolulu District RSM web site has been updated to include the Maui regions. Historical aerial photography, digitized shorelines, ground photography, coastal structure inventory, regional sediment budget, reports and other Maui 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 Kahului and Kihei regions. The workshop provided an overview of the tasks accomplished in the Maui regions and included detailed discussions on the findings presented in the Maui RSM Plan.

It is recommended that the following work be continued in association with future Maui RSM studies:

- Complete water circulation and wave transformation numerical modeling to refine the Maui regional sediment budgets and define sediment transport directions.
- Perform field visits and jet probing of reef-top sand sources. Also investigate other beach sand sources, such as dredge material from Kahului Harbor and Maalaea Harbor.

- 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 Maui littoral cells from the streams and rivers to provide a better understanding of the overall sediment budgets. Additionally, stream mouth management, relative to dune breaching, could be a significant factor and mitigation measures should be implemented and monitored.
- Identify critical dune areas to be targeted for protection.
- Develop a further understanding of seasonal fluctuations of the beaches within each region and use the information to update the shoreline positions and change rates. 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 Maui RSM region beaches.
- Update the preliminary Maui 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 to improve sediment management strategies in the region and across the state. Activities to reduce project costs, streamline permitting, and increase beneficial use of sediments on a regional scale at Kihei Beach and in the Kahului area should be investigated and coordinated with various stakeholders and agencies.

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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, Honolulu District). 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 Maui: Kahului Region and Kihei 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 the 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 report addresses the two RSM regions on Maui. Figure 1 shows the locations of these two regions.

A. Kahului Region

The Kahului region is located along the north shoreline of the island of Maui, between Iao Stream to the west and extending to Hookipa Beach Park (Kaua) to the east. See Figure 2 for a more detailed view of this region.

Based on USACE site investigations conducted in April 2008, Federal RSM activities may be applicable in this region (USACE, Honolulu District, 2010). The Kahului region includes a Federal navigation project (Kahului Harbor) where the principles of RSM could be employed to increase beneficial use of dredged material. There is also a rock revetment to the east of the harbor that protects a wastewater treatment facility. Maui County is currently considering extension of the revetment and/or beach fill alternatives to address continued erosion of the shoreline in this area.

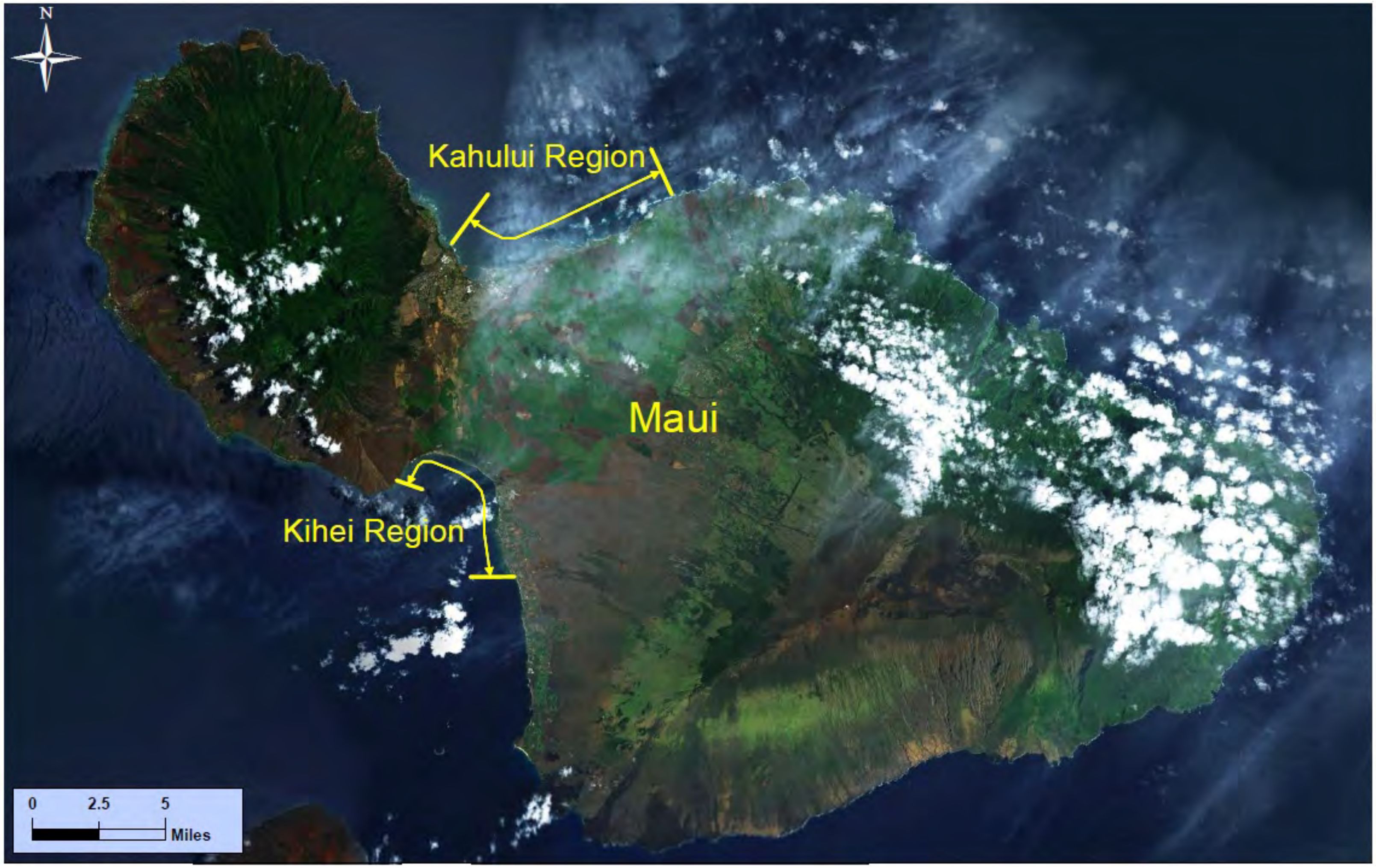


Figure 1. Hawaii RSM Regions of Maui

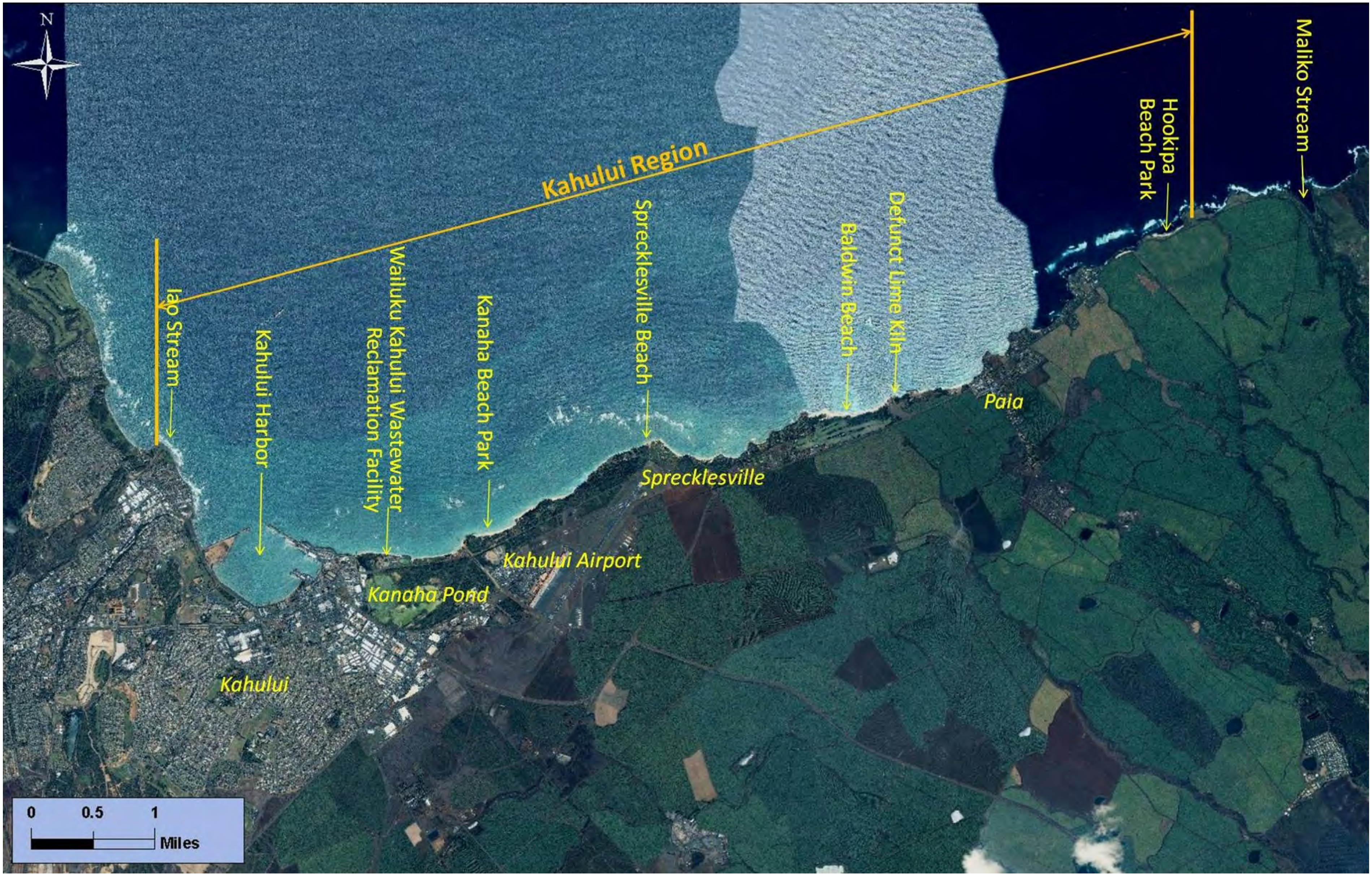


Figure 2. Kahului Region

Figure 3. Kihei Region

B. Kihei Region

This region is located along the south shoreline of the island of Maui, within the hook-shaped Maalaea Bay from/including Maalaea Harbor on its western boundary and extending to Kalama Beach Park on its east boundary. See Figure 3 for a more detailed view of this region.

Based on USACE site investigations conducted in April 2008, Federal RSM activities may be applicable in this region (USACE, Honolulu District, 2010). The Kihei shoreline includes a Federal shore protection project at Kalama Park, and this area is widely used by the public for recreation. Shoreline erosion north of the park in recent years led to initiation of a Section 103 study, which is currently on hold due to lack of non-Federal funds. Another Federal project is ongoing at Maalaea Harbor to attenuate surge within the harbor (currently in the Preconstruction, Engineering, and Design phase). These and other Federal projects are described further in the following section.

II. Federal Projects in the Maui RSM Regions

A. Overview

There are several Federally-authorized projects on the island of Maui, six of which are within the Kahului region and three of which are within the Kihei region. The project locations in the Kahului and Kihei regions are shown in Figures 4 and 5, respectively. The other Maui Federal projects are in West Maui (Kahoma Stream Flood Control, Launiupoko Highway Shore Protection, Mokuhinia.Mokuula Ecosystem Restoration, and West Maui Watershed projects).

This section presents only the projects within the Maui RSM regions, 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.

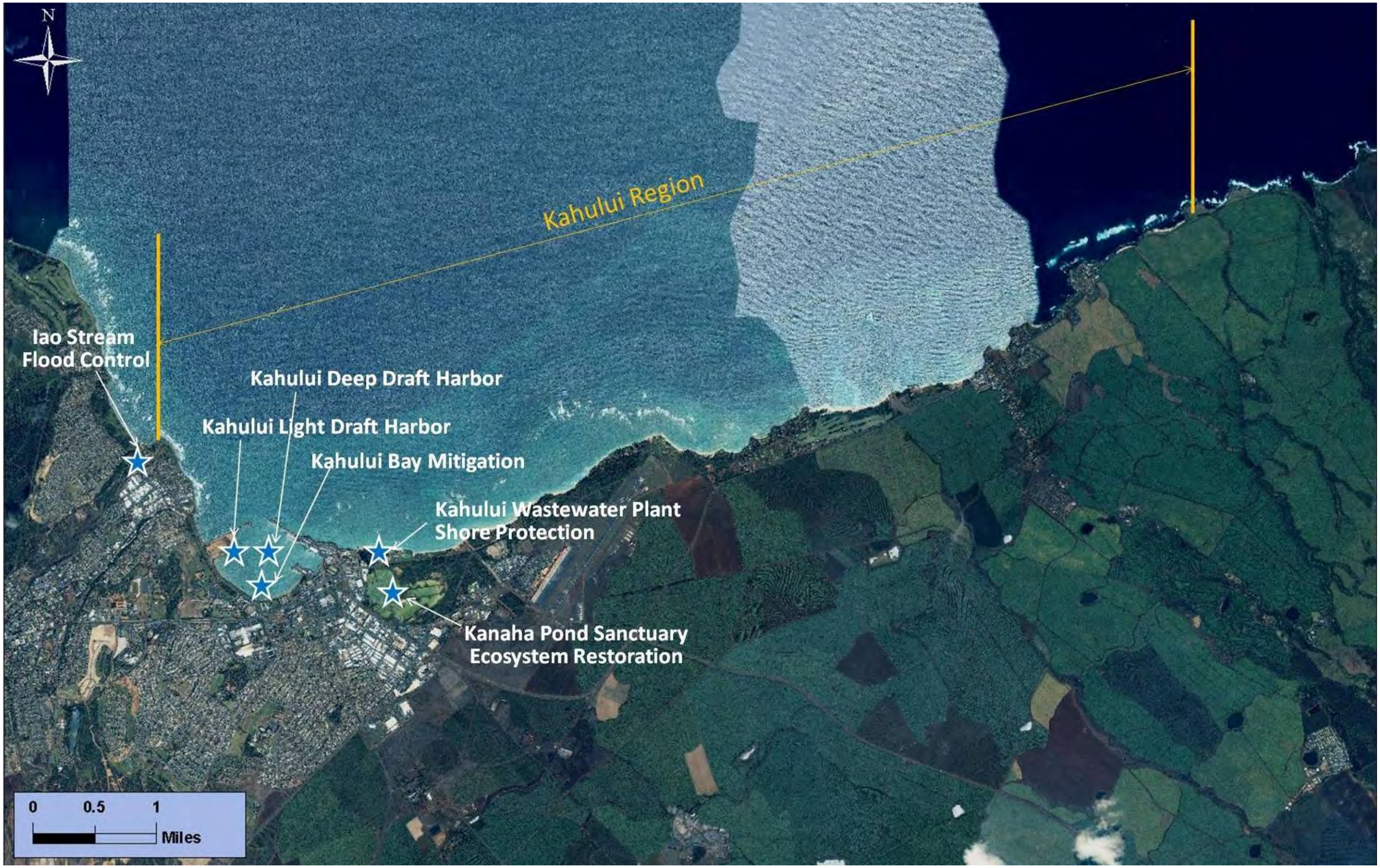


Figure 4. Federal Projects in the Kahului Region

Figure 5. Federal Projects in the Kihei Region

B. Federal Navigation Projects

Kahului Deep Draft Harbor (Kahului Region): The Kahului Deep Draft Harbor (DDH) is a commercial port located on Maui's northern coast. The harbor was constructed in 1931 and consists of: rubble mound breakwaters on the east and west sides of the harbor, approximately 2,800 and 2,300 feet in length, respectively; an entrance channel 600 feet wide between the breakwaters; and a harbor basin 2,050 feet wide, 2,400 feet long and 35 feet deep. The plan view of the harbor and cross-sections of the breakwaters are shown in Figure 6.

Since initial construction, the following rehabilitation and repair to the harbor has taken place:

- Removal of a rocky shoal area in the northeast edge of the basin in 1966;
- Rehabilitation of the breakwaters in 1969, 1973, and 1977;
- Major rehabilitation of the east and west breakwaters in January 1984; and
- Repair of 1,200 feet of revetment that is attached to the Kahului Harbor east breakwater structure in 2002.

Kahului DDH was last maintenance dredged in February 1999. A total of 91,000 cubic yards of dredged sediment was removed from the harbor and disposed of three miles offshore at a U.S. Environmental Protection Agency designated ocean disposal site. Previous dredging cycles occurred in 1990 and 1977. A condition survey was completed in June 2007 that indicated shoaling within the entrance channel and turning basin areas. The next maintenance dredging of the harbor is scheduled for FY12. The non-Federal project sponsor is the State of Hawaii, Department of Transportation (DOT), Harbors Division.

In 2008, the State DOT Harbors Division requested assistance with modifications to Kahului Harbor that would allow commercial activities at the west coral stockpile area to support container, ferry, and cruise ship activities. This is evidenced by the overcrowding at the existing terminals. This new area will require dredging of a new basin to support commercial vessels and possibly breakwater improvements.

Kahului Light Draft Harbor (Kahului Region): The Kahului Light Draft Harbor site is located within Kahului Deep Draft Harbor (Figure 7) on the northern coast of the island of Maui. The navigation improvement project consists of removing an existing rock groin; constructing a 130-foot-long rubblemound breakwater structure with a crest elevation of +9.0 feet above mean lower low water; dredging an entrance channel 1,030 feet long, 50 feet wide, and 9.5 feet deep; and dredging a turning basin 100 feet long, 100 feet wide, and 8.5 feet deep.

The project also included a State (non-Federal sponsor) option, which included replacing an existing single-lane boat launch ramp and dock with a new three-lane boat launch ramp and concrete loading dock with lighting. The project was completed in April 2006. A June 2007 condition survey indicates that there is adequate depth within the entrance channel. The project breakwater structure was last inspected in July 2008 and was determined to be in good condition.

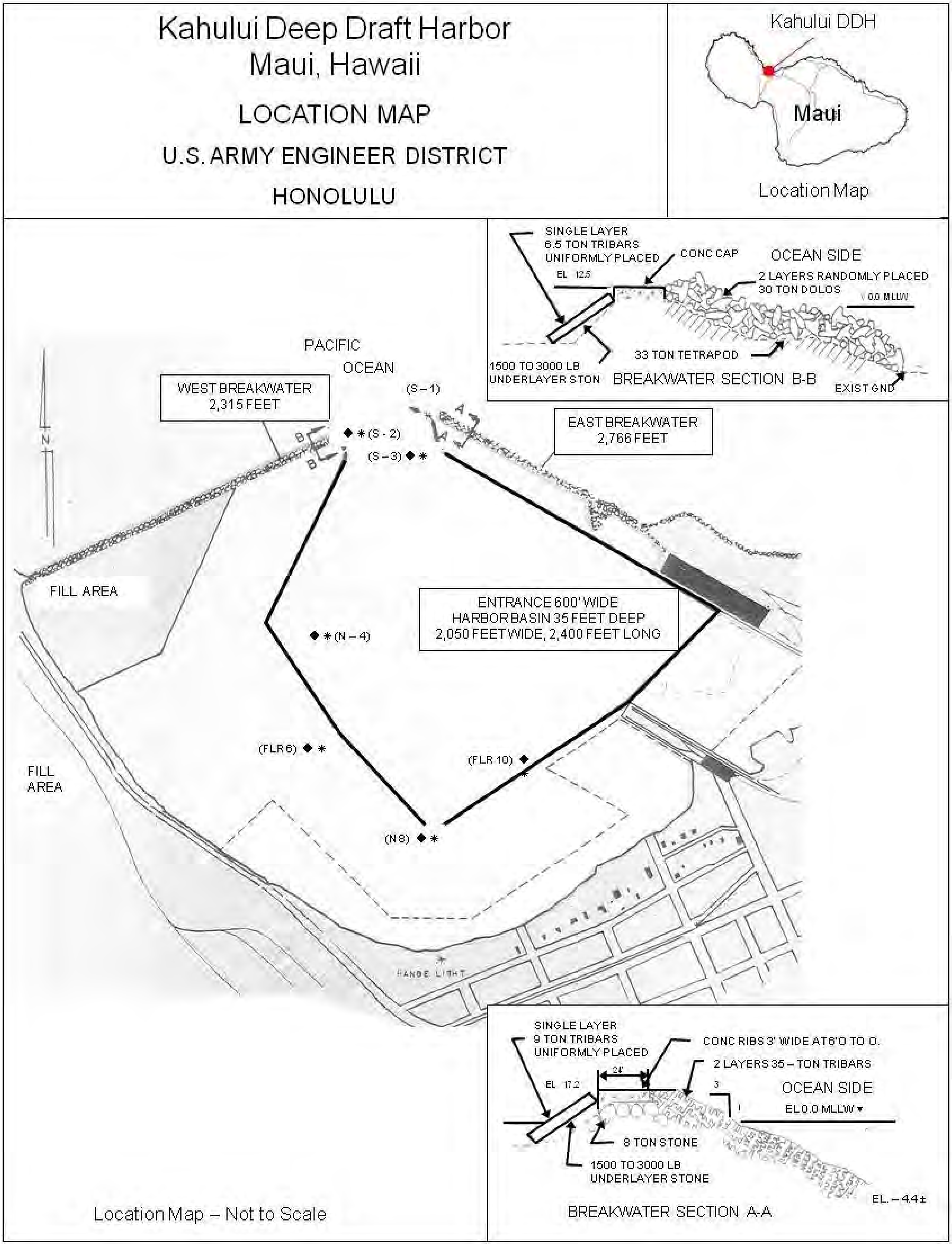


Figure 6. Kahului Deep Draft Harbor Improvements Project Map

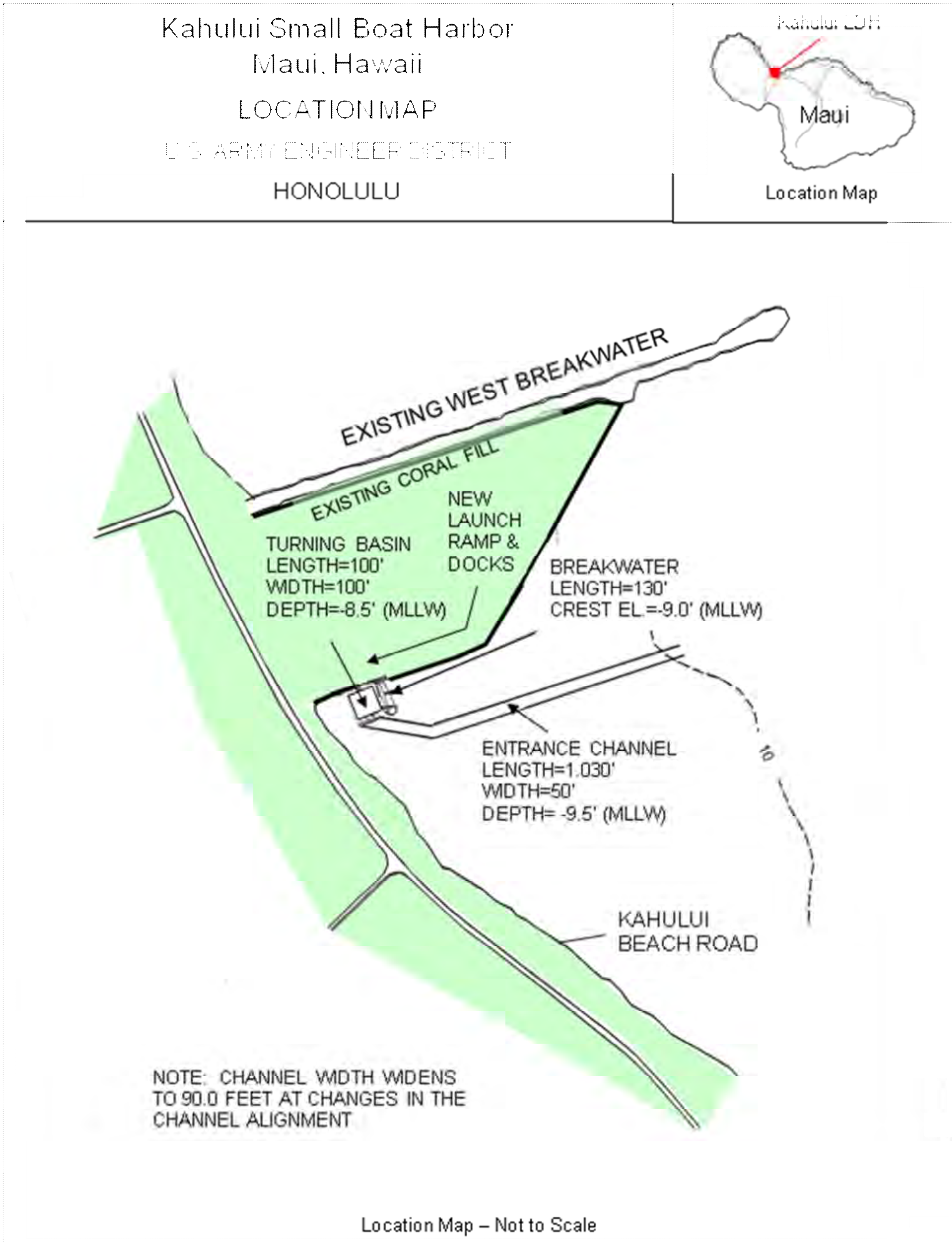


Figure 7. Kahului Light Draft Harbor Improvements Project Map

Maalaea Harbor (Kihei Region): The Maalaea Harbor (Figure 8) is situated on the southwest coast of Maui. The harbor was first developed by the Territory of Hawai'i in 1952 and later modified by the Territory and State of Hawai'i in 1955, 1959, and 1979. The project objective is to improve navigational access by realigning the entrance channel and modifying/extending the breakwater to attenuate surge within the harbor thus eliminating damage to vessels. These improvements will also allow the non-Federal sponsor to safely develop the interior of the harbor basin and double the existing berthing capacity, which is currently at 93 vessels, to potentially 220 vessels.

The community and environmental groups raised concerns in 1982 and 1998 that the proposed project design may potentially destroy the "Maalaea Pipeline" surf break, and may adversely impact coral resources, humpback whales, sea turtles and other protected marine species. Construction of the project was delayed as a result. Since 1998, the Corps has been evaluating measures to reconfigure the project features and minimize impacts to environmental and recreation resources.

The completion of the design is contingent on the acceptance of the third Supplemental Environmental Impact Study (SEIS) and the preparation of a Limited Reevaluation Report (LRR) scheduled for completion in FY11. The non-Federal sponsor is the State of Hawai'i, Department of Land and Natural Resources, Division of Boating and Ocean Recreation (DBOR).

Figure 8. Maalaea Harbor Improvements Project

C. Federal Flood Control Projects

Iao Stream (Kahului Region): The Iao Stream is located in northern Maui and discharges to the Pacific Ocean in the town of Waiehu. The stream has a drainage basin of approximately 10 square miles. The Iao Stream Flood Control Project (Figure 9) was constructed in 1981 and included a debris basin, diversion levees, and channel improvements along the lower 2.5 miles portion of the Iao Stream. The project was constructed to protect the town of Wailuku, Maui, from destructive floods by channelizing high velocity floodwaters into the Pacific Ocean. The original project did not fully line the stream due to limited project funding and inadequate economic benefits as mandated by Federal laws.

The Corps is currently conducting an investigation to correct the existing levee system to enable the Project to function in the manner as it was originally intended. The ongoing Project is in the Pre-construction, Engineering and Design phase, and the non-Federal sponsor is the County of Maui, Department of Public Works. Preparation of an Engineering Documentation Report (EDR) and Environmental Assessment (EA) are underway, with the EA being scheduled for public release in Spring 2009. Construction is scheduled for the fall of 2011 and to be completed by 2013.

D. Shore Protection Projects

Kahului Wastewater Plant (Kahului Region): The Wailuku-Kahului Wastewater Reclamation Facility (WWRF) is located on the north shore of the island of Maui, along the shoreline between Kahului Harbor and Kaa Point. In February 1979, the USACE constructed 450 linear feet of rock revetment in the vicinity of the WWRF. The non-Federal sponsor is the County of Maui, Department of Public Works.

Damages to the revetment and erosion on the eastern and western shorelines of the structure have resulted in the County of Maui, Department of Environmental Management (DEM) requesting Corps assistance with the erosion problem in the vicinity of the WWRF in 1994. Protection of approximately 900 feet of shoreline is the County's primary concern. Corps assistance under either the Continuing Authorities Program or Planning Assistance to States Program is being investigated.

The County of Maui is also pursuing an extension of this revetment to protect and stabilize the eroding shoreline over the remainder of the Waste Treatment plant site. The project is presently in the conceptual development and initial regulatory phase.

Kahului Bay Prevention and Mitigation of Shore Damages (Kahului Region): The project is located within Kahului Bay, along the north-facing shoreline. As shown in Figure 10, the project provided for: (a) 890 feet long stone revetment along Kahului Beach Road; (b) beach replenishment of 6,550 cubic yards of sand; (c) a 100-foot long breakwater; and (d) a west groin, 280 feet long, and e) an east groin, 300 feet long. The project was completed in 1976 by the Corps with no non-Federal sponsor. The project was last inspected in September 2009 and although the 100-foot long breakwater has been in disrepair for some time, the backlying shoreline appears to have stabilized over the years.

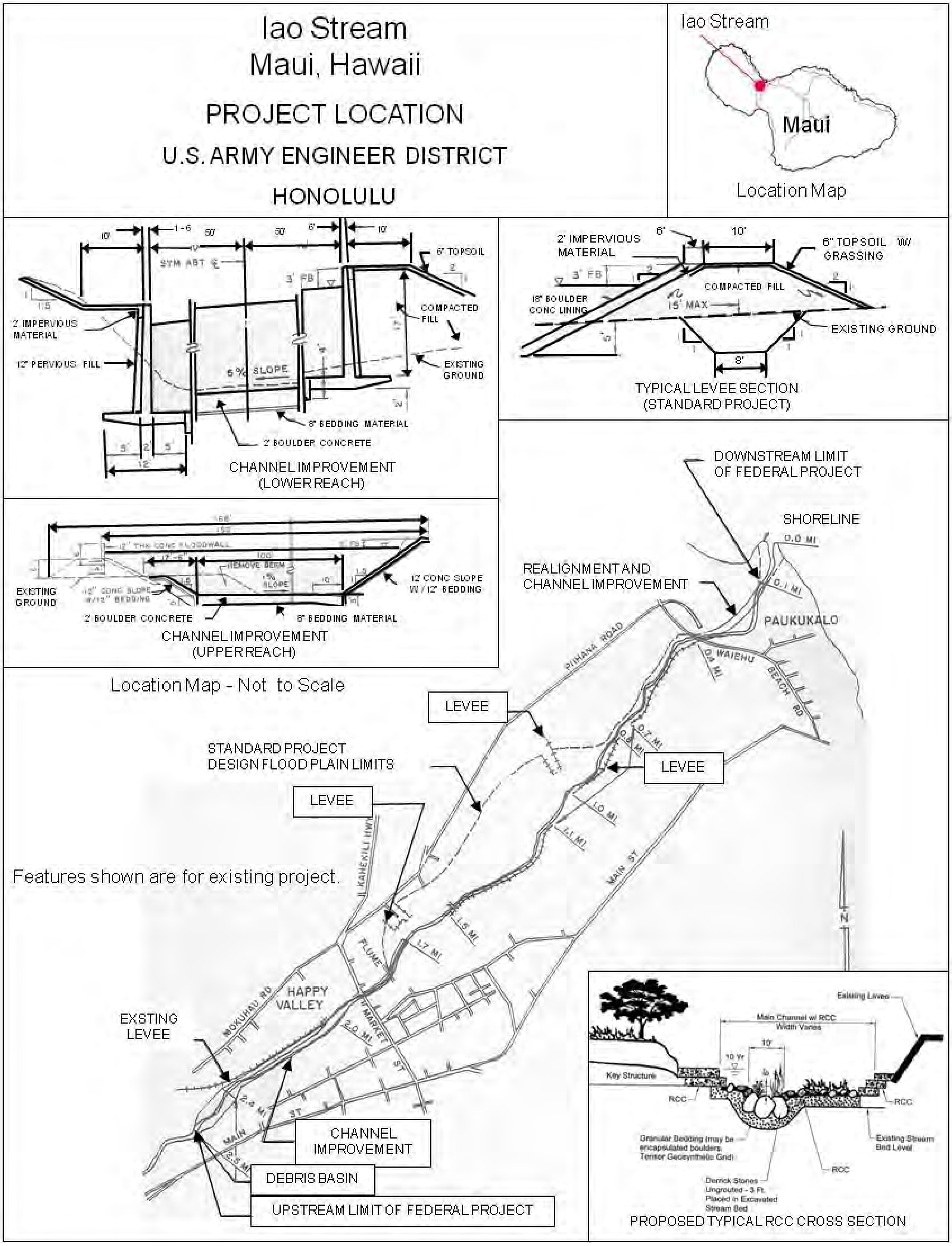


Figure 9. Iao Stream Project Map

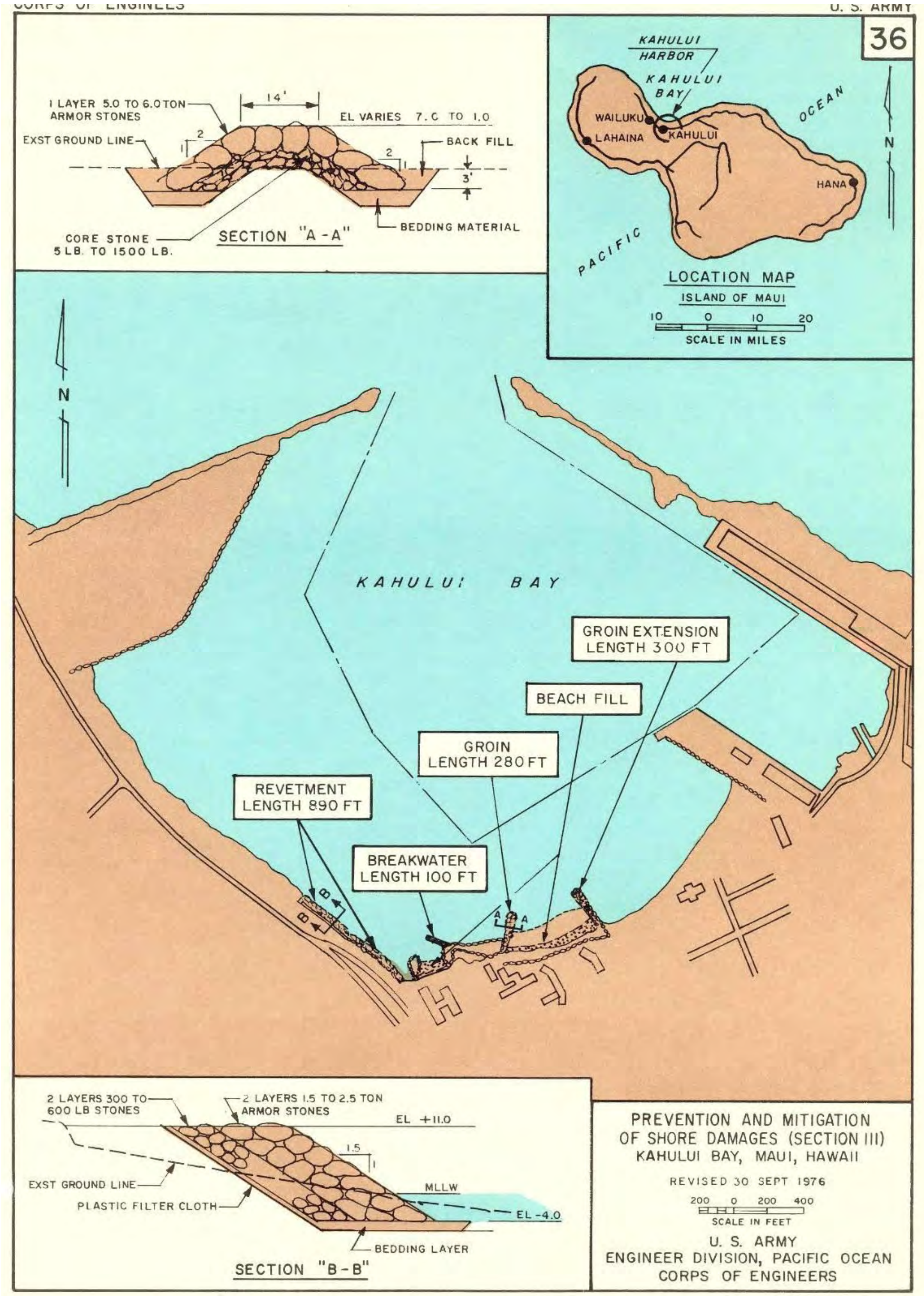


Figure 10. Kahului Bay Mitigation

Kihei Beach Shore Protection Project (Kihei Region): Kihei Beach is located on the southwest coast of Maui and extends from the Kihei Pier to the north to Keawaakapa to the south. The project location is shown in Figure 11.

In response to erosion in vicinity of Kalama Park, the USACE constructed a 2,610-foot long protective stone revetment with a crest elevation of 8.0 feet MLLW; a recreational beach berm approximately 20 feet wide, and 2,610 feet long in June 1971. The seaward slope of the revetment is armored with 1,000-pound stone placed on a slope of 1:3 (vertical: horizontal). The revetment toe is placed on the underlying coral strata excavated to a depth of -4.5 feet below MLLW. The Kihei Beach Shore Protection was last inspected in September 2006. The project's condition rating is listed "acceptable," meaning the project is in good condition and functional.

Kihei Area Erosion (Kihei Region): The Kihei Beach is a long coastal reach approximately seven miles long on the southeast coast of Maalaea Bay from Kihei Park in the north to Keawakapu Point in the south.

The project is in response to concerns by the County of Maui and the public about erosion that was occurring in the vicinity of the Kalama Park revetment. The Kalama Park revetment was built by the Corps in 1971. The Honolulu District received a study request on 6 February 2001 from the County of Maui and the project is currently in the reconnaissance phase. The non-Federal sponsor is the County of Maui, Department of Public Works.

E. Ecosystem Restoration Projects

Kanaha Pond Wildlife Sanctuary Restoration (Kahului Region): The Kanaha Pond Wildlife Sanctuary (KPWS) is located shoreside of the Kahului commercial/industrial area and near the international airport, as shown in Figure 12. KPWS is home to two endangered endemic birds, the Hawaiian Stilt (Ae'o) and the Hawaiian coot, and a number of other migratory species. Most of KPWS is also designated as critical habitat for the endangered Blackburn's sphinx moth.

The objectives of the KPWS Restoration project are to improve the habitat through providing more water and water circulation throughout the pond. The Preliminary Restoration Plan (reconnaissance report) was completed in June 2003 and found that Federal interest is warranted to proceed with detailed investigations. Kanaha Pond project investigations are being conducted under the Continuing Authorities Program and funding was received in FY08 to complete the feasibility phase investigations. Field investigations were initiated in November 2008 and completion of the feasibility study is scheduled for December 2010. The non-Federal sponsor is the State of Hawaii, Department of Land and Natural Resources Department of Forestry and Wildlife.

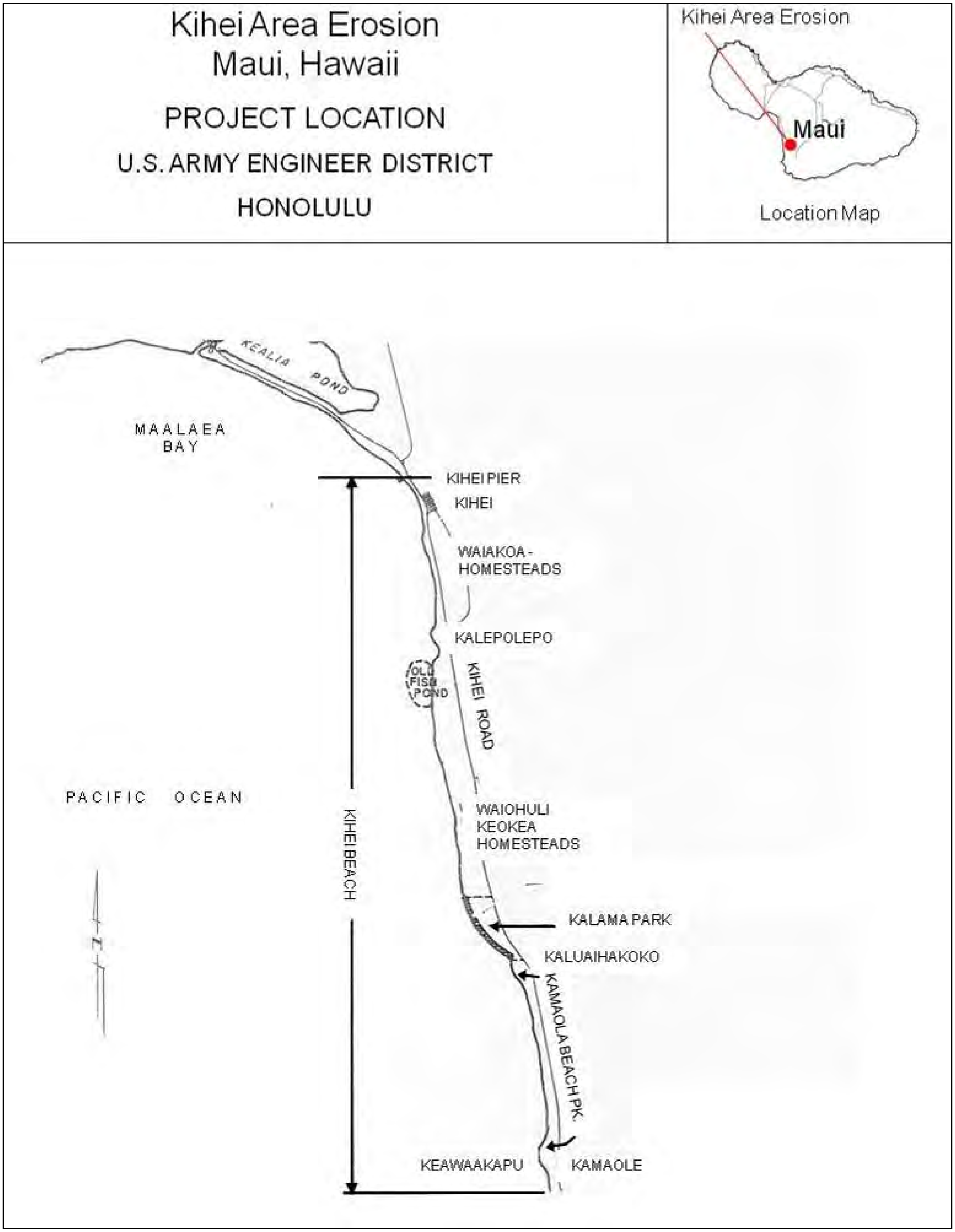


Figure 11. Kihei Beach Erosion Project Map

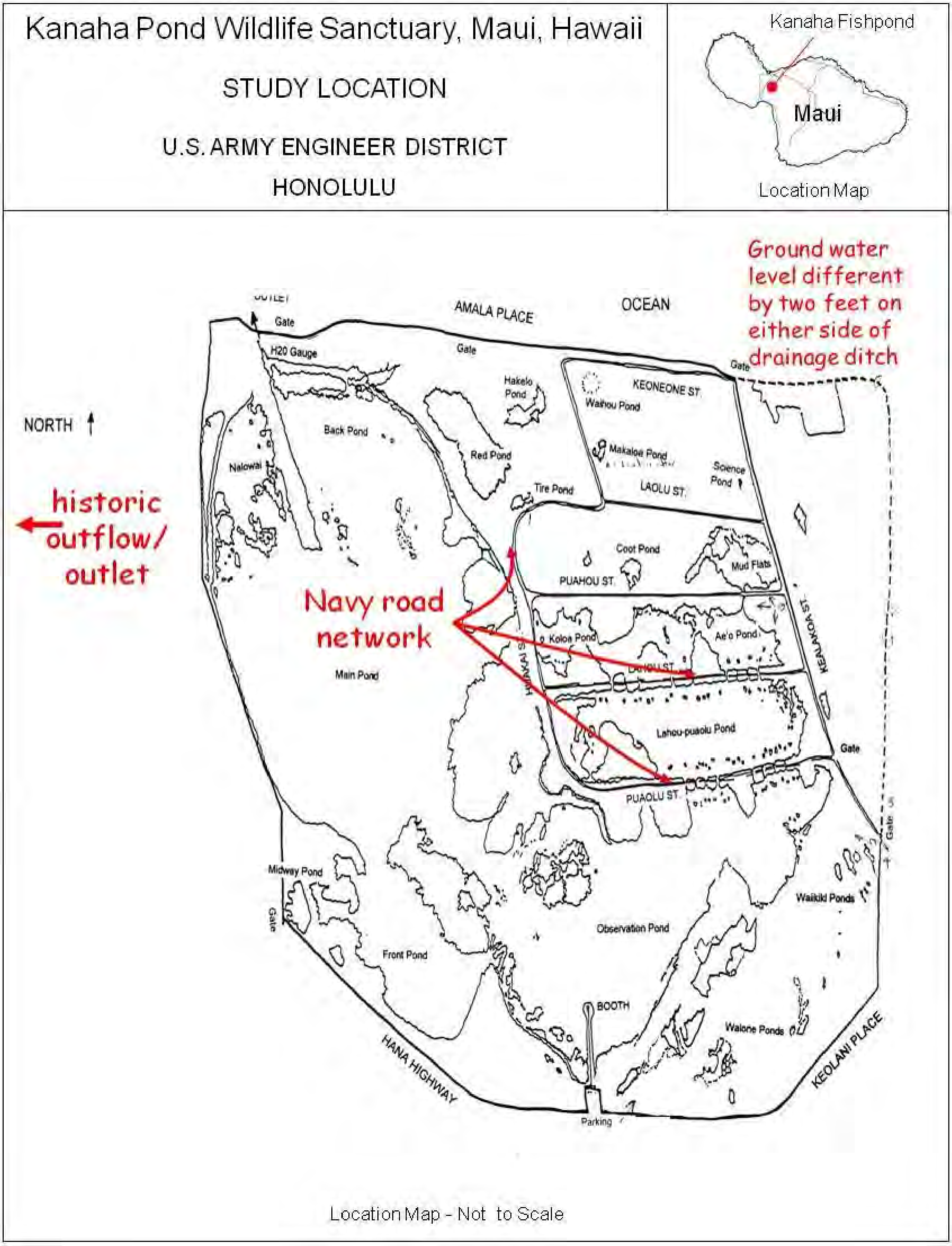


Figure 12. Kanaha Pond Wildlife Sanctuary Restoration Project Map

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 would require substantial economic resources (University of Hawai‘i 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 regions. The beach volume erosion rates (Section X and Appendices F and G), and the shoreline erosion hazard maps prepared by the University of Hawaii (Section IX.B and Appendices D and E), identify erosional areas. On Maui, there are several areas where infrastructure is threatened by shoreline erosion, e.g. the Wailuku-Kahului Wastewater Reclamation Facility. 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 regions. 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.

Some condominium associations and neighborhood boards already act as *de facto* beach management districts. For example, the Spreckelsville Beach Restoration Foundation, a group of beachfront owners, has already completed at least one beach nourishment project. On Oahu, the hotel industry and the Hawaiʻi Tourism Authority coordinated with the State of Hawaiʻi in the 2006 nourishment of Kuhio Beach; the economic importance of this tourist beach has driven cooperation in the area.

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 Hawaiʻi. The results of this assessment are described in Section XI. Beach nourishment projects that could be potential RSM projects are described in Section XIII. Beach nourishment, sand bypassing and sand backpassing along eroding beaches within the Maui 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 regions that may be suitable for protection, either through engineering and/or bioengineering methods (dune stabilization) or through regulatory means. Given the importance of the dune systems on Maui beaches, all dunes should be considered for protection. 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 regions 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

The Hawaii Coastal Zone Management Act gives Maui County regulatory control of shoreline setbacks and all development within the Shoreline Setback Area (SSA). The SSA is defined as the area between the shoreline and the shoreline setback line. In support of this work, the University of Hawaiʻi is under contract to the County to quantify shoreline erosion hazards. One work product from this program is a set of draft erosion hazard maps, available at <http://www.soest.hawaii.edu/coasts/erosion/maui/index.php> and provided as Appendices D and E for the two Maui 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 Maui 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 public has access along the beach seaward of the certified shoreline and the County of Maui provides an inventory of shoreline access points.

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 Hawaiʻi Department of Health Section 401 Water Quality Certification;
- Hawaiʻi Coastal Zone Management Federal Consistency Review;
- DLNR Conservation District Use Permit.

A goal of the USACE and the State of Hawaiʻi 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 Maui RSM regions. This objective is met through the production of this document, associated workshops, and the USACE RSM website.

Currently, the State of Hawaiʻi 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.

Also, the West Maui Watershed Project has recently been initiated and may provide opportunities to partner with RSM to address sediment related issues, including stream sediment management, on a system-wide scale (USACE, Honolulu District, 2010).

J. Structures and Activities within the Shoreline Area

Some of the shoreline within the Kahului and Kihei study regions has been modified with the construction of structures, including harbors, rock revetment, and groins. The specific structures within each region are discussed in Section IX.A. Additional details about these structures and graphics showing the locations of these structures are provided in Appendices F and G. Additionally, sand mining has had a significant impact to the Kahului region and breaching of dunes to drain makua streams (for flood control) has affected the Kihei shoreline.

The County of Maui allows only minor structures and/or minor activities within the Shoreline Setback Area. Minor structures are defined as those that do not impede the natural movement of the shoreline, do not alter the existing grade of the shoreline area, and cost less than $125,000. Given this definition, there is no RSM study objective related to minor structures.

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 Maui may encourage coordination between the County of Maui, 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

Kihei and Kahului (especially Baldwin Park) area beaches have been identified as “eroding beaches” in the public’s eye and potential RSM projects may be of interest in these areas. The objectives of the present project in relation to public awareness are to inform the public of ongoing studies and plans in the regions 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 can also be met through a combination of public workshops, community college courses, and the Maui RSM website. This process will be continued through the ongoing development of this Hawaii RSMP.

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. Maui is towards the southeast of the chain, i.e. it is one of the more recent geologic formations.

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.

The island of Maui is composed of two large volcanoes, separated by a low-lying isthmus. The isthmus was created during the shield building stage of the Haleakala volcano as lava flowed into the West Maui volcano. The Haleakala volcano is dormant, but not inactive.

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.

Both Kahului and Kihei regions have broad fringing reefs offshore. 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 former two items have the effect of reducing along-shore sediment transport. 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.

A large fringe reef located just offshore extends for several miles along the Kahului region coastline. It is characterized by a wide crest (one-half to one mile in width), extending from a shallow nearshore toe out to depths ranging from 10 to 30 feet (Cox 1954). Closer to Kahului Harbor, the reef is narrow or absent (Cox 1954). The reef has complex potential sediment pathways.

In the Kihei region, a large fringe reef exists offshore from approximately Kalama Beach Park in the south to Kihei Pier in the north.

C. Study Regions

There are two study regions on the island of Maui. The Kahului region is on the windward (north) side of Maui and includes the towns of Kahului and Paia (as shown in the previous Figure 2). The Kihei region is on the leeward side of Maui and includes the towns of Maalaea and Kihei (as shown in the previous Figure 3). The shoreline within this reach faces both due south in the vicinity of Maalaea Bay Beach and west in the Kihei area. Each region is described below.

Kahului Region. The Kahului RSM region is approximately nine miles long and is defined as the coastline between Iao Stream to the west and extending to Hookipa Beach

Park (Kaua) to the east. It is generally positioned in the low-lying isthmus area between the island's two volcanoes.

The region includes Kahului Harbor, formed by rubble mound shore-perpendicular breakwaters on its west and east sides. To the east of the harbor, much of the region's shoreline consists of pocket beaches formed by natural lava and beachrock points and manmade groins.   The beaches are backed by large sand dunes. To the west of the harbor is a relatively straight stretch of cobble beach shoreline extending to Iao Stream.

The natural and anthropogenic processes affecting this region's shoreline are unusually varied and complex. Long-term changes in sediment supply and littoral transport must be analyzed in the context of seasonal fluctuations and man-made changes. Human impacts to the region include historical sand mining, construction of Kahului Harbor, construction of revetments and groins along the shoreline, and damage to the coastal dune system.

Kihei Region. The Kihei RSM region is approximately 7.5 miles long and lies within the hook-shaped Maalaea Bay. The region is defined as the coastline from just southwest of the Maalaea Harbor on its western boundary and extending to the Kalama Beach Park on its eastern boundary.

The region includes Maalaea Harbor, formed by rubble mound shore-perpendicular breakwaters on its south and north sides. To the southwest of the harbor, the east-facing shoreline includes one small pocket beach.   Immediately to the northeast of the harbor is a south facing shoreline lined with beach-front residences fronted by seawalls and/or rock revetments. Further west is the low-lying Maalaea Bay Beach and Kealia Pond area. Along the west-facing shoreline of the Kihei region are beaches backed by vegetated dunes.

Although no major rivers or streams discharge into the Kihei region, there are multiple gulches and drainage channels originating from adjacent hillsides that discharge along the coastline.

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

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 made larger volumes of sand.

The sediment in the Kahului region beaches is poorly sorted calcareous sand, ranging in size from medium-sized grains to cobbles (M&N 2008). There are also areas of beachrock. The beaches in the Kihei region are mostly fine sand (M&N 2000). The beaches in the southeastern part of the Kihei region were found to be composed almost exclusively of calcareous sand, whereas farther north in the region (towards the Kihei pier), the sand was found to be composed of almost equal amounts of volcanic and calcareous sediments (M&N 2000).

Sand can be lost to the beach system in a number of ways.

- 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 its ongoing formation.
- 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 the beaches within the Kahului region for use in producing lime for the sugar industry. Large-scale sand mining is now prohibited: the few exceptions include clearing sand from stream mouths.

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 Maui RSM 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 Maui. Macroalgae covers over fifty percent of the benthic habitat in the reef system. Listed species that may occur in or near the study regions include: the Hawaiian monk seal, humpback whale, green sea turtle (possibly nesting sites), spinner dolphin, white tern, and others.

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 encompasses areas around the islands of Maui, Lanai, and Molokai, and parts of Oahu, Kauai and Hawaii. The sanctuary extends seaward from the shoreline to the 100-fathom isobath (NMS 2009 and NOAA 2010c) The Kihei RSM region lies within the sanctuary's boundaries. The Kahului region is not within the sanctuary's boundaries.

Kahului Harbor is designated as a Fishery Management Area. There are three Marine Life Conservation Districts in Maui County (DLNR 2010), but none within or near the two Maui RSM regions.

VI. Coastal Processes

A. Water Levels

Hawaii shorelines are microtidal, with ranges much smaller than those observed over the west coast of the continental United States. The Maui tide station is at Kahului Harbor. The water level datums, measured by NOAA at this station and reported on the NOAA web site, are given in Table 1 (NOAA 2010a).

Table 1. Tidal Datums at Kahului Harbor (1983-2001 Epoch)

Datum	Water Level (feet, MLLW)
Highest Observed Water Level (12/20/1968)	3.49
Mean Higher High Water (MHHW)	2.26
Mean High Water (MHW)	1.90
Mean Sea Level (MSL)	1.12
Mean Tide Level (MTL)	1.11
Mean Low Water (MLW)	0.33
Mean Lower Low Water (MLLW)	0.00
Lowest Observed Water Level (6/19/1955)	-1.61

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 regions, 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

In addition to normal short-term periodic fluctuations of the sea surface, there is also a progressive change in sea level. Relative sea level changes on the Hawaiian Islands are caused by rising sea levels, which may be accelerated by global warming and land subduction (the latter caused by the plate movements of the islands).

Globally, the mean sea level has risen by 10 to 30 cm (4 to 12 inches) over the last century. In the Hawaiian Islands, land subduction increases the rate of relative sea level rise. The rate of land subduction decreases from the island of Hawaii to the northwest (D. Jeon 1995). Therefore, the island of Maui subsides faster than Oahu and Kauai, since it is located closer to Hawaii.

Tide gauge data from Kahului Harbor presented by NOAA (2010b) shows an historic relative sea level rise of 2.32 ± 0.53 mm per year (9.1 ± 2.1 inches per century) between 1947 and 2006.

The recent rate of global sea level rise appears to be accelerating in response to anthropomorphic climate change (Intergovernmental Panel on Climate Change 2007). Several studies indicate future sea level rise may increase considerably (Fletcher 1992 and Fletcher et al. 2002).

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 9.1 inches per century (4.5 inches over the next 50 years) for Maui. 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 Maui would be 1.4 feet and 2.0 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 and Wind 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. In Kihei, the northeast trade winds become northerly to northwesterly as they are funneled between the mountains of East and West Maui as shown in Figure 13. Trade wind speeds often reach 25 knots (30 mph) in Kihei.

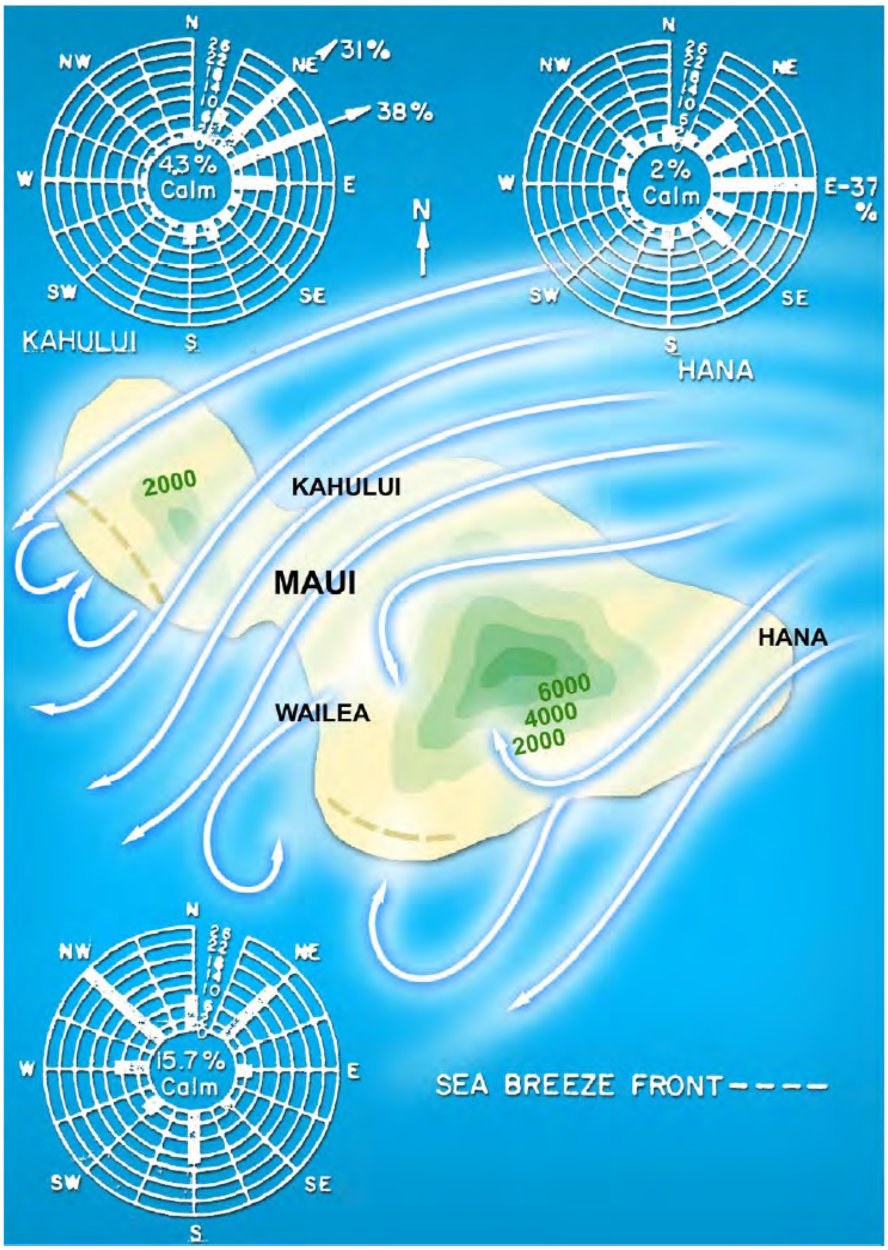


Figure 13. Typical Trade Wind Pattern on Maui (M&N 2000)

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 14. The Kihei region, on the leeward shore of Maui, is exposed to Kona storm waves and southern hemisphere swell. Kona waves can approach Kihei either from the south or west; Kahoolawe Island provides shelter from southwesterly Konas, which can be the highest Kona waves (Moberly and

Chamberlain, 1964). Southern hemisphere swell approaches Kihei from the south. The Kihei region is sheltered from the predominant northeast tradewind-generated waves as well as from the winter North Pacific swell. Thus, wave activity at the shore is relatively mild except during the summer months, when the southern swell can produce moderately high surf conditions, and during Kona storm events.

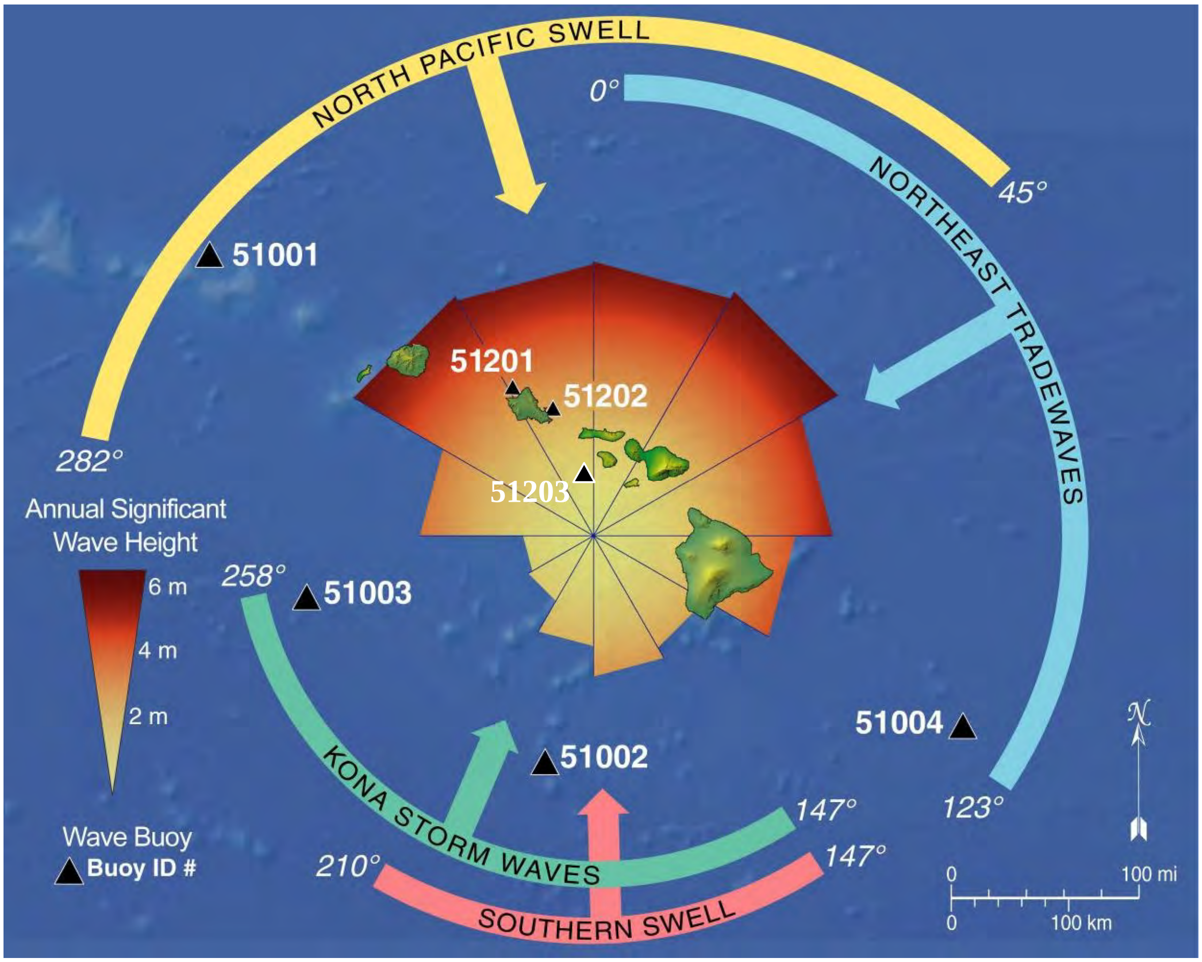


Figure 14. Dominant Wave Directions, Swell Wave Rose, and Monitoring Buoy Locations (Vitousek and Fletcher 2008)

The Kahului region, on the windward shore of Maui, is exposed to predominant northeast tradewaves and winter North Pacific swell. As seen in Figure 14, the waves on this side of Maui (Kahului region) are significantly higher than on in the south side.

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 regions.

D. Numerical Modeling of Wave Transformation

The nearshore wave climate in the study regions 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 are 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 Maui 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).

Kahului Region

Kahului is on the north shore of the Maui with exposure to waves arriving from approximately 300 to 90 deg. The closest Wave Information Studies (WIS) save point is Station 102 located at 21.5 deg North and 156 deg West in a depth of 4,974 meters (16,320 feet). Station 102 is shown in Figure 15 with a yellow circle. WIS Station 101 is also near the site of interest. Stations 101 and 102 have very similar wave height, period, and direction distributions, but Station 101 has slightly higher peak wave heights due to more exposure to the northwest. Station 102 was selected because it is closer to the site of interest and the exposure is more representative.

A wave rose for Station 102 for 1981-2004 is given in Figure 16. The wave rose shows distribution of wave height with wave direction. Large wave heights are prevalent out of all directions from northwest to east.

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). Appendix B (Figures B-3,-4, and -5) provides graphs of the compressed time series of the years 1984, 1992 and 1994 at Station 102.

Figure 15. WIS Station Location – Kahului Region

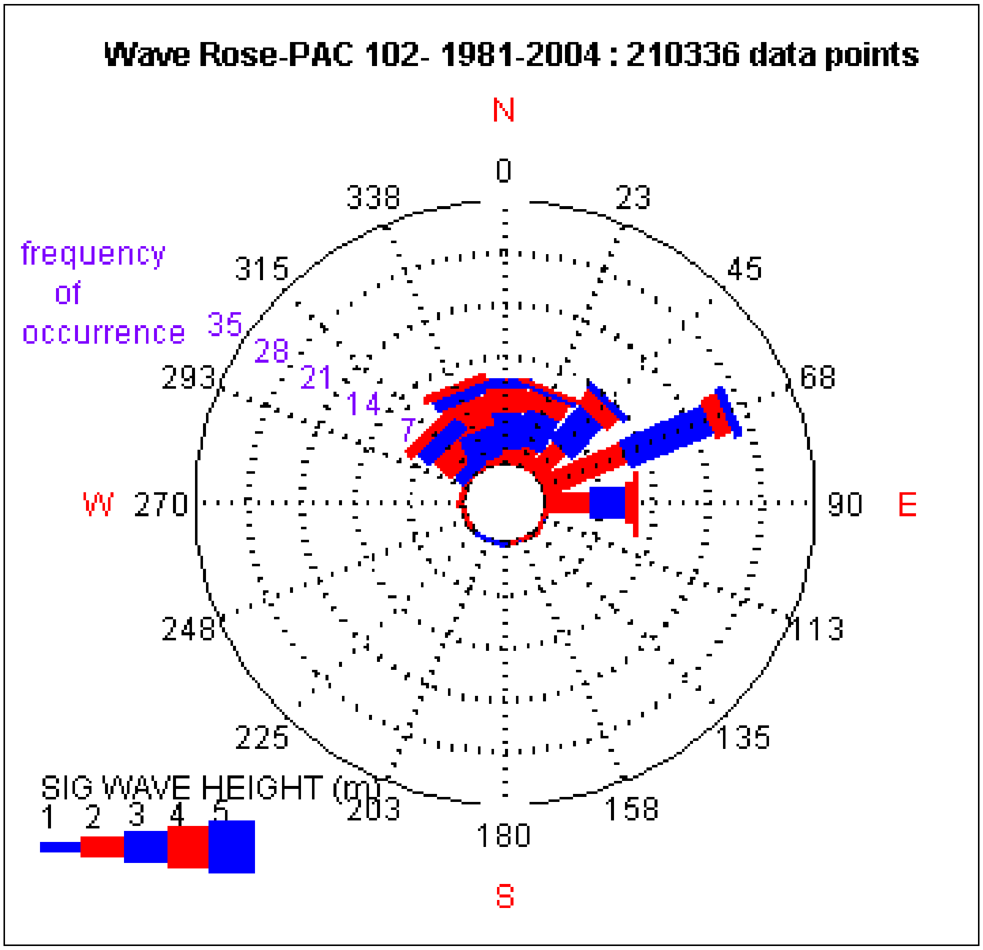


Figure 16. Wave Rose for 1981-2004 for WIS Station 102.

Since the WIS save points are in deep water and away from Maui, the wave heights include energy from both waves moving toward and away from the island. To eliminate energy moving away from Kahului, the WIS spectra for these three years were truncated to include only energy from 272.5 to 87.5 deg (0 deg +/-87.5 deg). Then, the truncated spectra were used to recalculate wave height, peak wave period, and mean wave direction. These wave parameters were then transformed to the 100 m depth (approximate nearshore grid boundary) with linear shoaling and refraction (assuming bottom contours are approximately aligned east to west).

These transformed 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 17 for 1984, Figure 18 for 1992, and Figure 19 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 north, +45 deg is 315 deg, and -45 deg is 45 deg). The plots are useful for assessing wave height, period, and direction combinations to be run for the nearshore wave transformation analysis.

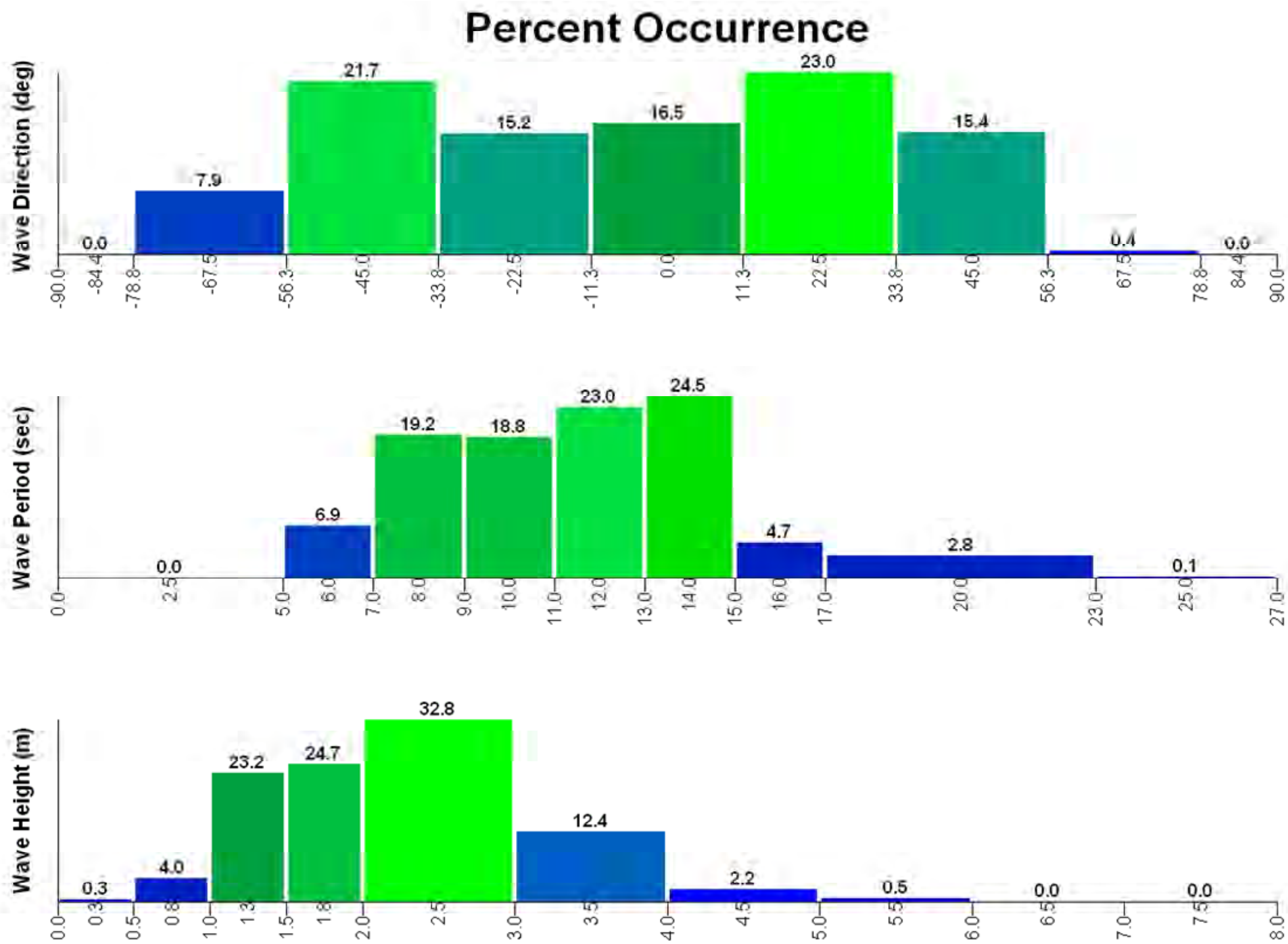


Figure 17. 1984 Percent Occurrences for Wave Height, Peak Period, and Mean Direction for WIS Station 102

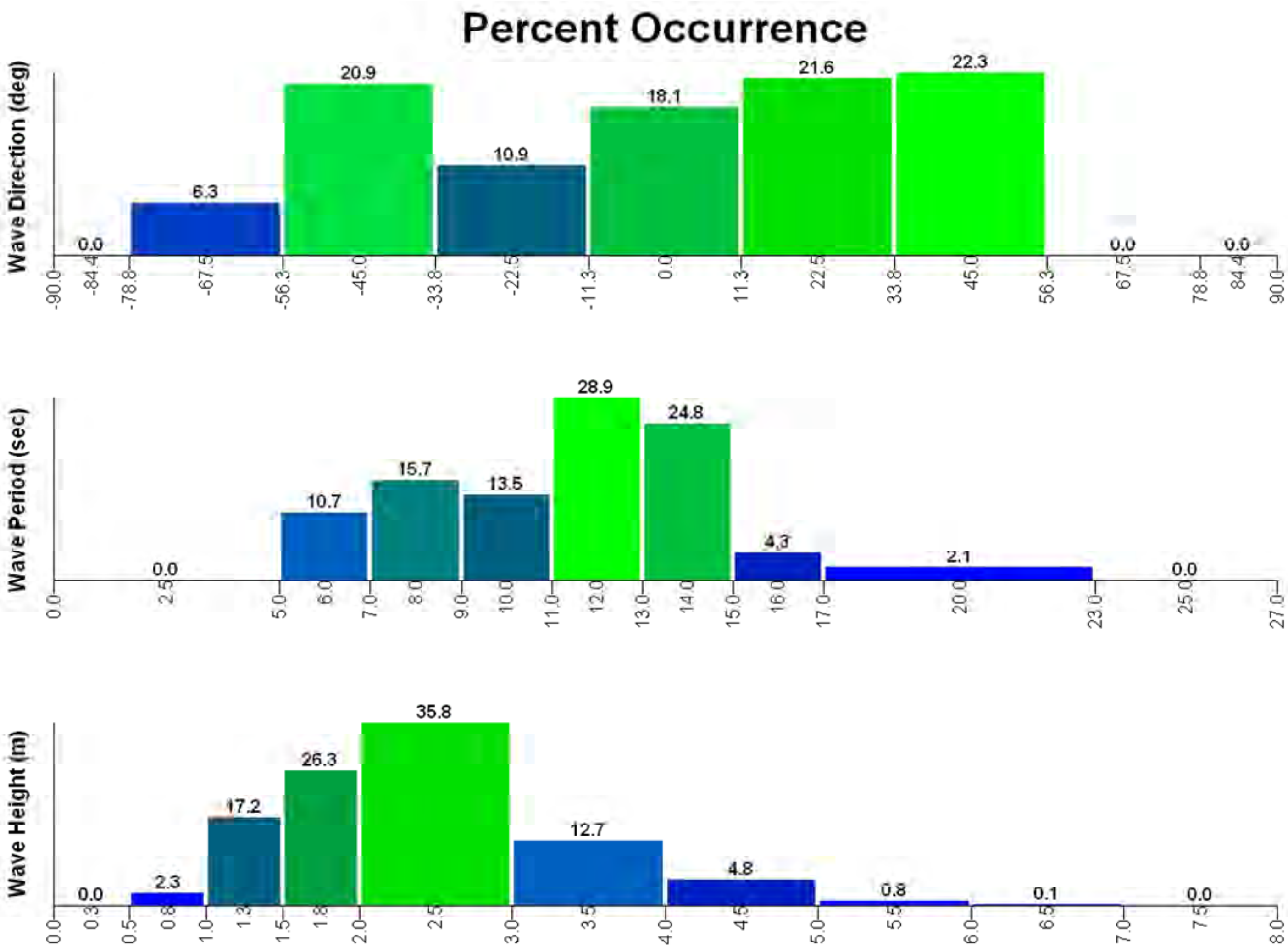


Figure 18. 1992 Percent Occurrences for Wave Height, Peak Period, and Mean Direction for WIS Station 102

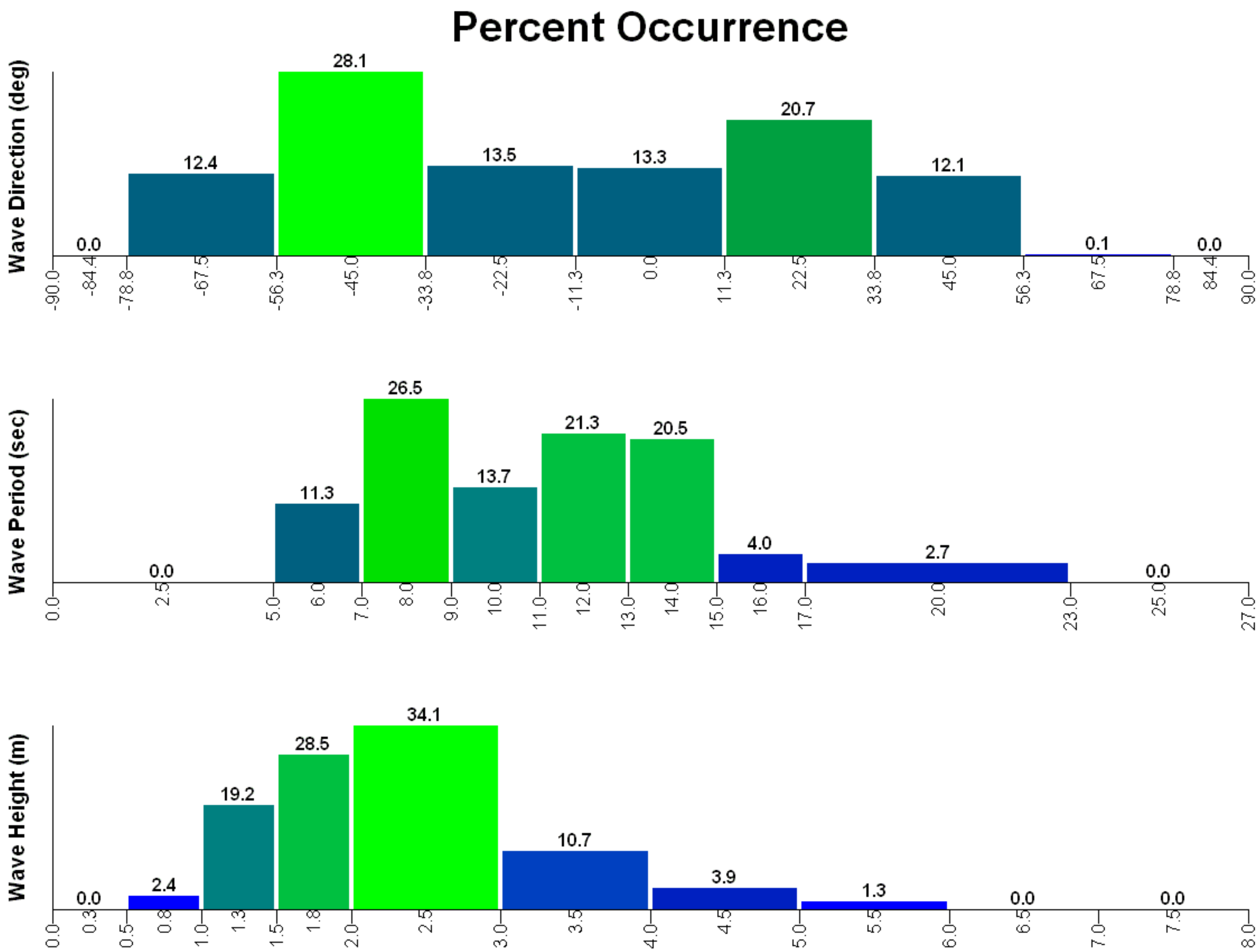


Figure 19. 1994 Percent Occurrences for Wave Height, Peak Period, and Mean Direction for WIS Station 102

Table 2 provides a summary of the mean and maximum wave statistics for the years 1984, 1992, and 1994. Tables 3 and 4 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 – Kahului Region Waves			
	1984	1992	1994
Mean Wave Height (m)	2.1	2.3	2.2
Mean Peak Period (s)	11.3	11.3	10.8
Largest Wave Height (m)	5.8	6.4	5.9
Peak of Largest Height (s)	16.3	16.3	11.2
Direction Bin of Largest Height (deg)	337.5	315	45

Table 3. Typical Conditions – Kahului 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 67.5 deg
1.0 (2)	8 (2)	-45 (2)	from 45 deg
1.5 (3)	10 (3)	-22.5 (3)	from 22.5 deg
2.0 (4)	12 (4)	0 (4)	from 0 deg
2.5 (5)	14 (5)	22.5 (5)	from 337.5 deg
3.0 (6)	16 (6)	45 (6)	From 315 deg
4.0 (7)	20 (7)	67.5 (7)	from 292.5 deg (sheltered)
5.0 (8)			

Table 4. Extreme Conditions - Kahului Region Waves (30 conditions)			
Significant Wave height, m	Wave Period, sec	Wave Direction, deg from STWAVE axis	Wave Direction, deg met convention
6 (9)	10 (3)	-45 (2)	from 45 deg
7 (10)	12 (4)	-22.5 (3)	from 337.5 deg
	14 (5)	45 (6)	from 315 deg
	16 (6)		
	20 (7)		

Nearshore STWAVE grids were generated for the Kahului and Kihei 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 Kahului RSM region, as shown in Figure 20 below, with a grid resolution of 50m.

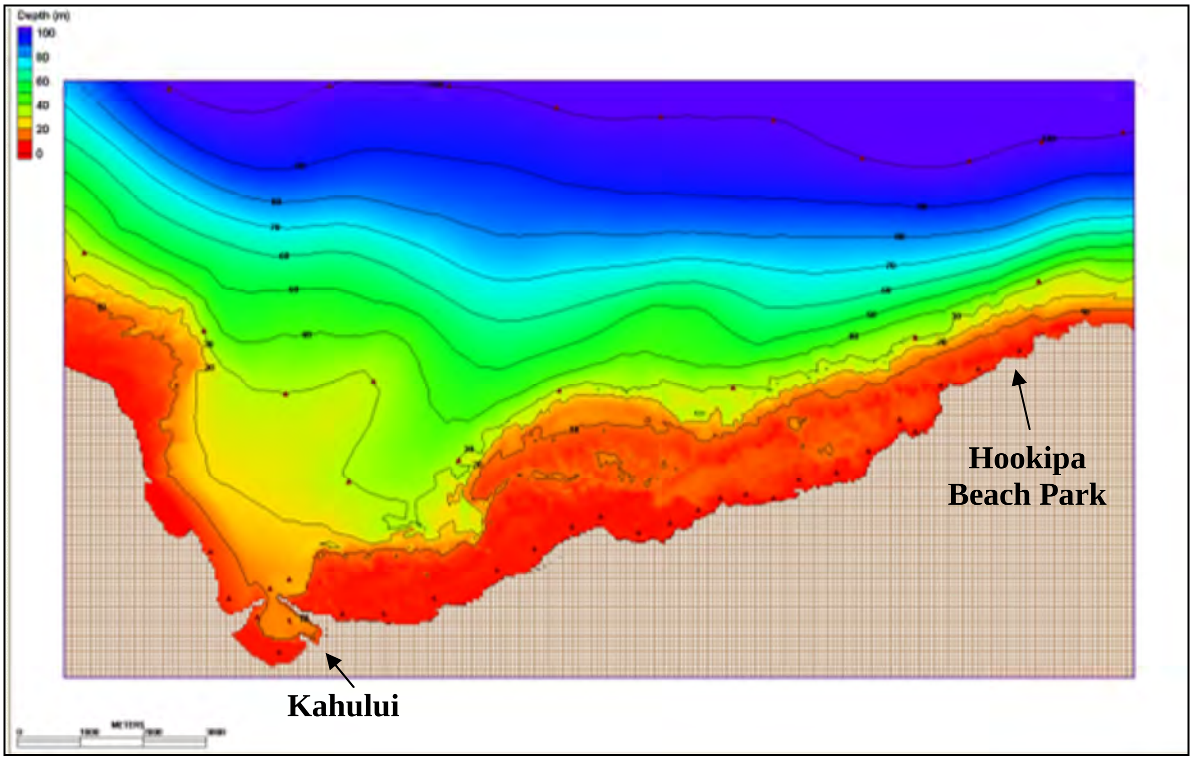


Figure 20. STWAVE Grid Extents for Kahului Region (10-meter contours shown)

The Kahului region grid is oriented such that its offshore boundary (at approximately 100m depth) faces directly north at 0 degrees True North (TN). The bathymetry along the nearshore areas includes the well-resolved features of the reef and other features such as channels and headlands. Figure 20 shows the features of Kahului Bay including Waihee Reef to the northwest of the harbor. A detailed view of the STWAVE grids in the nearshore areas adjacent to Kahului Harbor is shown in Figure 21.

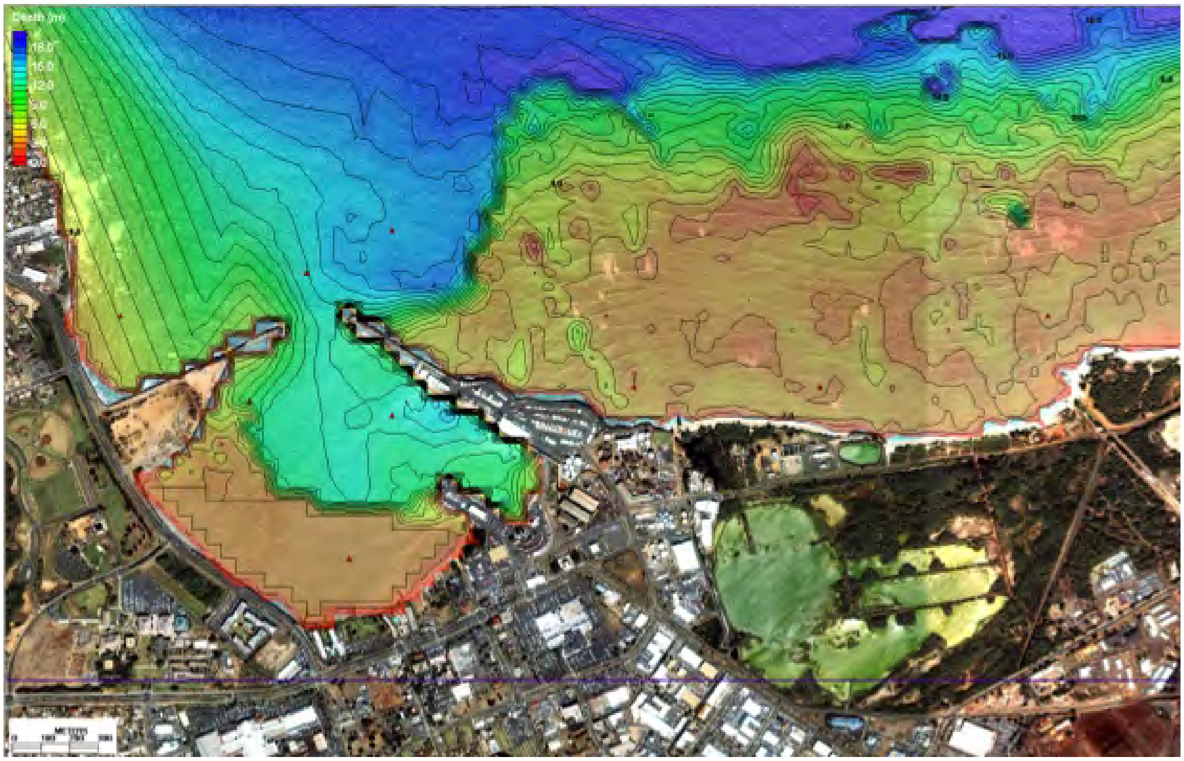


Figure 21. STWAVE Grid Adjacent to Kahului Harbor in Kahului Region
(1-meter contours shown)

Wave parameters from Tables 3 and 4 were used to generate wave input spectra for the Kahului 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 Kahului grid is shown in Figure 22. 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 22 as black squares). Wave parameters for these selected locations were saved in a separate file for use in the next step of the process.

A database (or "lookup table") of wave parameters that correlates the most frequent offshore wave conditions at the WIS station (from Table 3 and 4) 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.

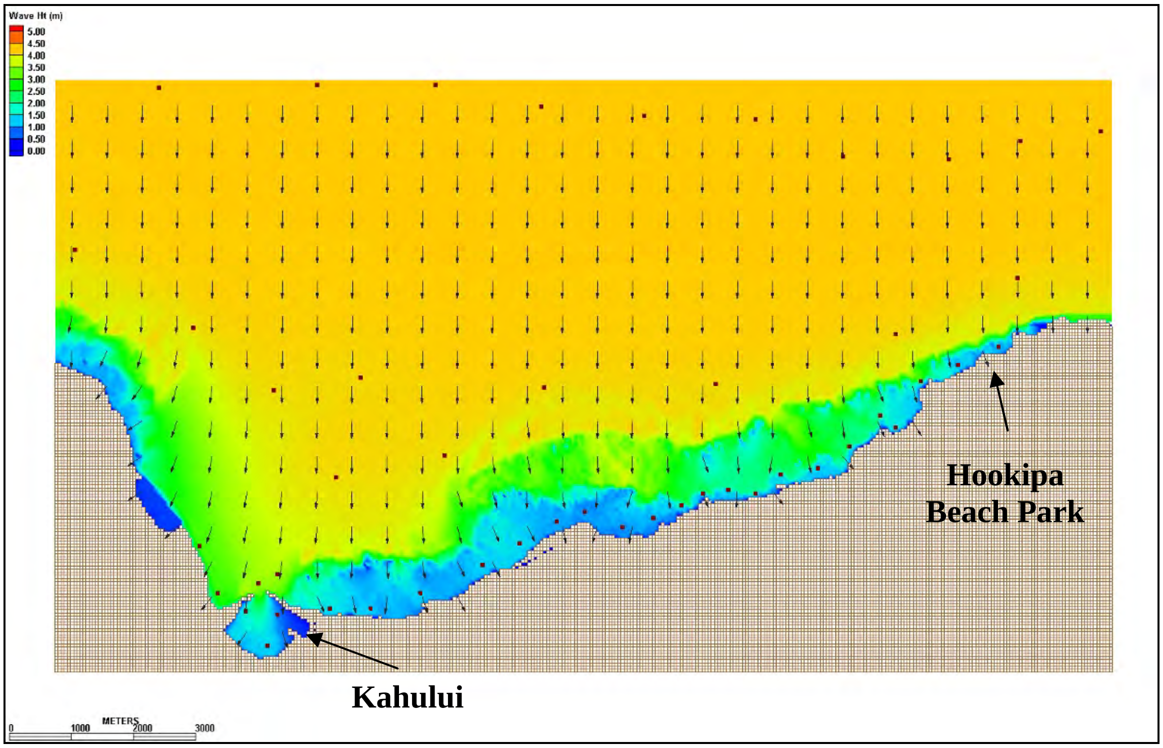


Figure 22. Resulting wave height (color scale) and Wave Direction (arrows) in Kahului Region for Case 724 (Ho = 4m, T= 8s, Dir=0 TN) and Location of Observation Points (black squares).

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 the Kahului grid. A portion of an output file resulting from the application of the FORTRAN program is shown in Figure 23 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   0.942    10.0   -10.0   346.0
   1984010101   0.948    10.0     0.0   336.0
   1984010102   0.959    10.0     0.0   336.0
   1984010103   0.974    10.0     0.0   336.0
   1984010104   0.996    10.0     0.0   336.0
   1984010105   1.024    10.0     0.0   336.0
   1984010106   1.061    12.5    -3.0   339.0
   1984010107   1.106    12.5    -3.0   339.0
   1984010108   0.868    12.5    -2.0   338.0
   1984010109   0.911    12.5    -2.0   338.0
   1984010110   0.957    12.5    -2.0   338.0
   1984010111   0.985    12.5   -10.0   346.0
   1984010112   1.030    12.5   -10.0   346.0
   1984010113   1.075    12.5   -10.0   346.0
   1984010114   0.898    12.5    -9.0   345.0
   1984010115   0.934    12.5    -9.0   345.0
   1984010116   0.966    12.5    -9.0   345.0
   1984010117   0.997    12.5    -9.0   345.0
   1984010118   1.025    12.5    -9.0   345.0
   1984010119   1.050    12.5    -9.0   345.0
   1984010120   0.894    12.5    -9.0   345.0
   1984010121   0.910    12.5    -9.0   345.0
   1984010122   0.924    12.5    -9.0   345.0
   1984010123   0.937    12.5    -9.0   345.0
   1984010200   0.950    12.5    -9.0   345.0
   1984010201   0.941    14.3   -11.0   347.0
   1984010202   0.959    14.3   -11.0   347.0
   1984010203   0.982    14.3   -11.0   347.0
   1984010204   1.009    14.3   -11.0   347.0
   1984010205   1.041    14.3   -11.0   347.0
   1984010206   1.042    14.3   -11.0   347.0
   1984010207   1.079    14.3   -11.0   347.0
   1984010208   0.840    14.3   -11.0   347.0
   1984010209   0.842    16.7   -12.0   348.0
   1984010210   0.870    16.7   -12.0   348.0
   1984010211   0.896    16.7   -12.0   348.0
```

Figure 23. 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 the Kahului Wastewater Plant is shown in Figure 24. This figure shows that 21% of waves during the 3 selected years approached from 350-360 degrees TN, and that the wave heights at this location were in the 0.5 to 1.0m and 1.0 to 1.5 m ranges. Similarly, 64% of waves approached from 0 – 10 degrees TN, also within the 0.5 to 1.0m and 1.0 to 1.5 m ranges. Finally, 15% of waves approached from 10-20 degrees TN, however the wave heights from this direction were lower in the 0 to 0.5m and 0.5 to 1.0m ranges. Another histogram of an observation point outside the entrance to Kahului Harbor is shown in Figure 25, and indicates a larger variability in significant wave height and direction. This would be expected due to the greater depth and exposure of the observation point outside the harbor.

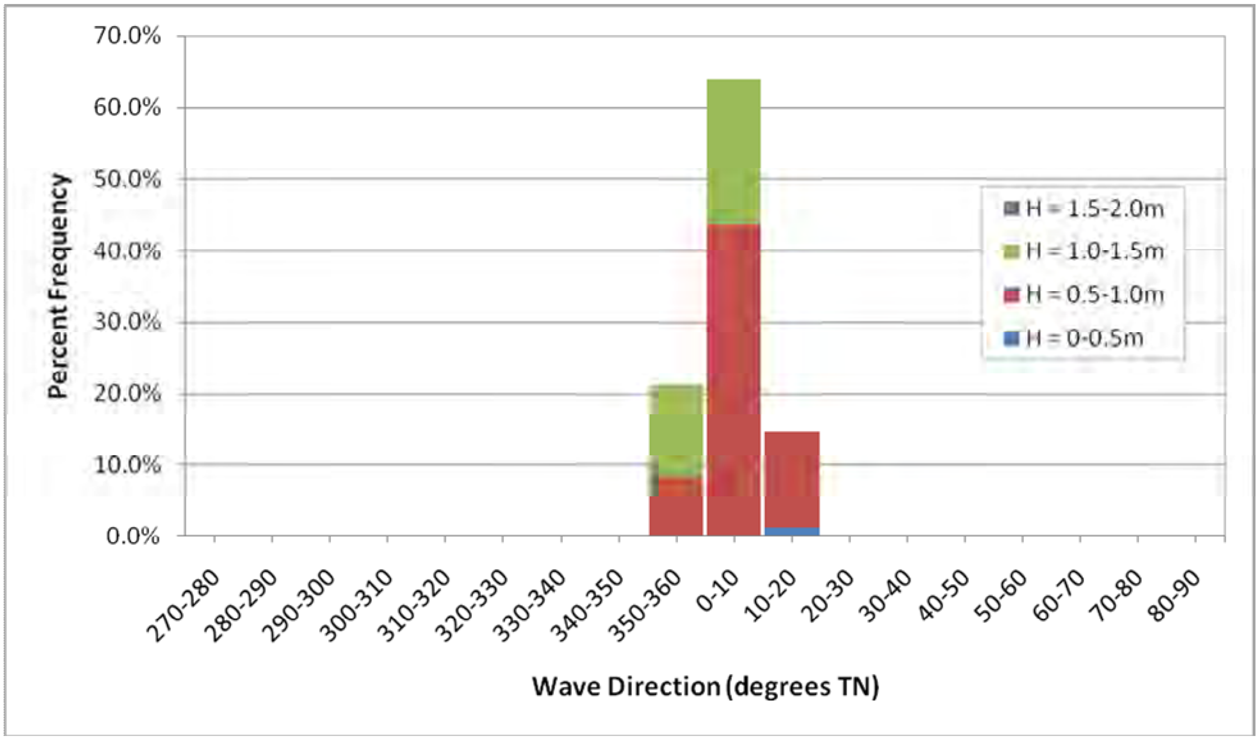


Figure 24. Histogram of Wave Height and Direction at Nearshore Observation Point Close to Kahului Wastewater Plant (Shore normal = 7 degrees TN)

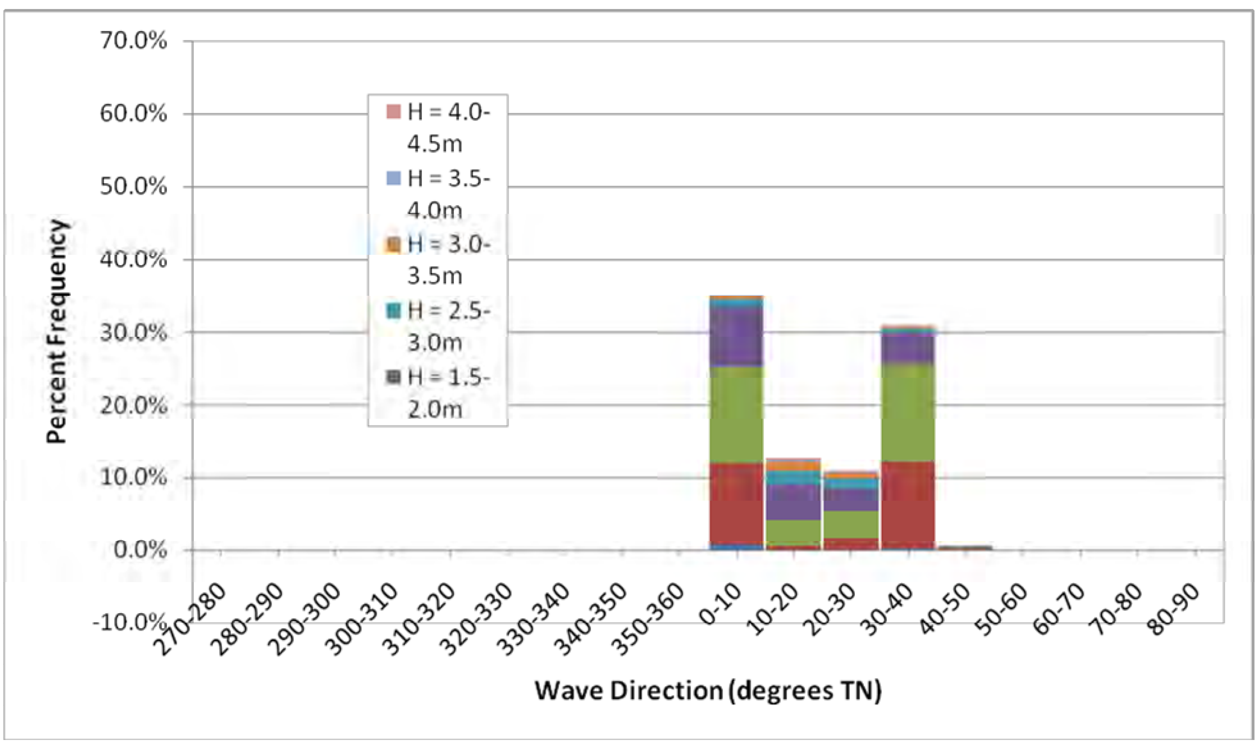


Figure 25. Histogram of Wave Height and Direction at Nearshore Observation Point at Entrance to Kahului Harbor (Shore normal = 55 degrees TN)

Kihei Region

Kihei is on the south shore of the Maui with exposure to waves arriving from approximately 160 to 270 deg. The closest Wave Information Studies (WIS) save point is Station 113 located at 20 deg North and 156.5 deg West in a depth of 3,659 meters (12,000 feet). Station 113 is shown in Figure 26 with a yellow circle. Station 113 was selected because it is the closest to the site of interest and has a similar wave exposure.

A wave rose for Station 113 for 1981-2004 is given in Figure 27. The wave rose shows distribution of wave height with wave direction. Large wave heights are prevalent from northwest and northeast at this WIS station, but the waves are sheltered by southern part of Maui, Kahoolawe, Lanai and Molokai for the Kihei region.

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). Appendix C (Figures C-3, -4 and -5) provides graphs of the compressed time series of the years 1984, 1992 and 1994 at Station 113.

Since the WIS save point is in deep water and away from Maui, the wave heights include energy from both waves moving toward and away from the island. To eliminate energy moving away from Kihei, the WIS spectra for these three years were truncated to include only energy from 92.5 to 277.5 deg (180 deg +/-87.5 deg). Because Kihei is strongly sheltered by Kahoolawe, a one-dimensional transformation from deep water to 100-m depth near Kihei would not be meaningful. Thus, an STWAVE grid was constructed with an origin at UTM x = 804,000 m and y = 2,213,434 m and an orientation of 90 deg (offshore boundary on the south side). The grid covers a region of 90 km north-south and 115 km east-west with a grid resolution of 500 m.

A summary of the percent and number of occurrence plots are shown in Figure 28 for 1984, Figure 29 for 1992, and Figure 30 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 south, +45 deg is 135 deg, and -45 deg is 225 deg). The plots are useful in assessing wave height, period, and direction combinations to be run for the nearshore wave transformation analysis.

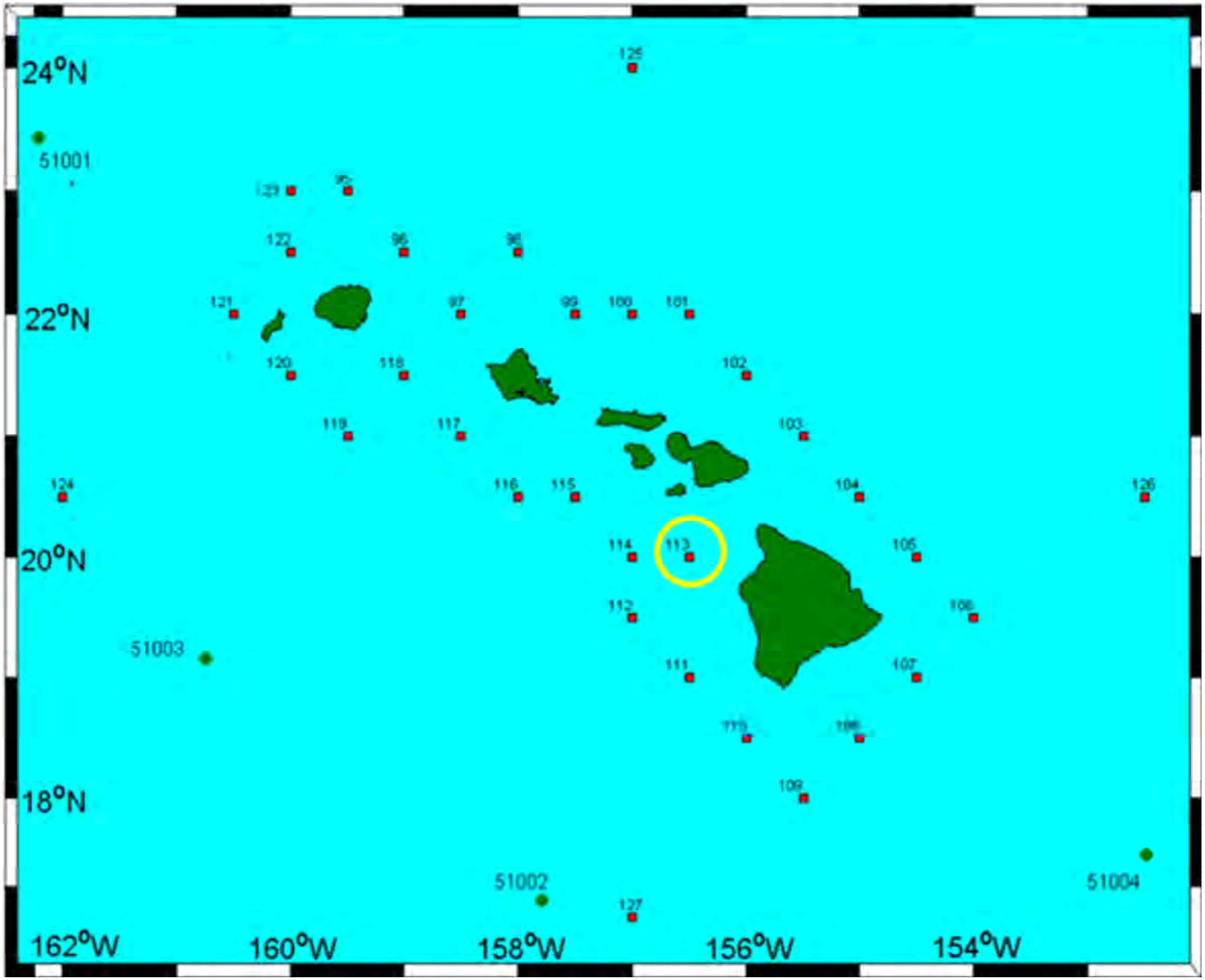


Figure 26. WIS Station Location – Kihei Region

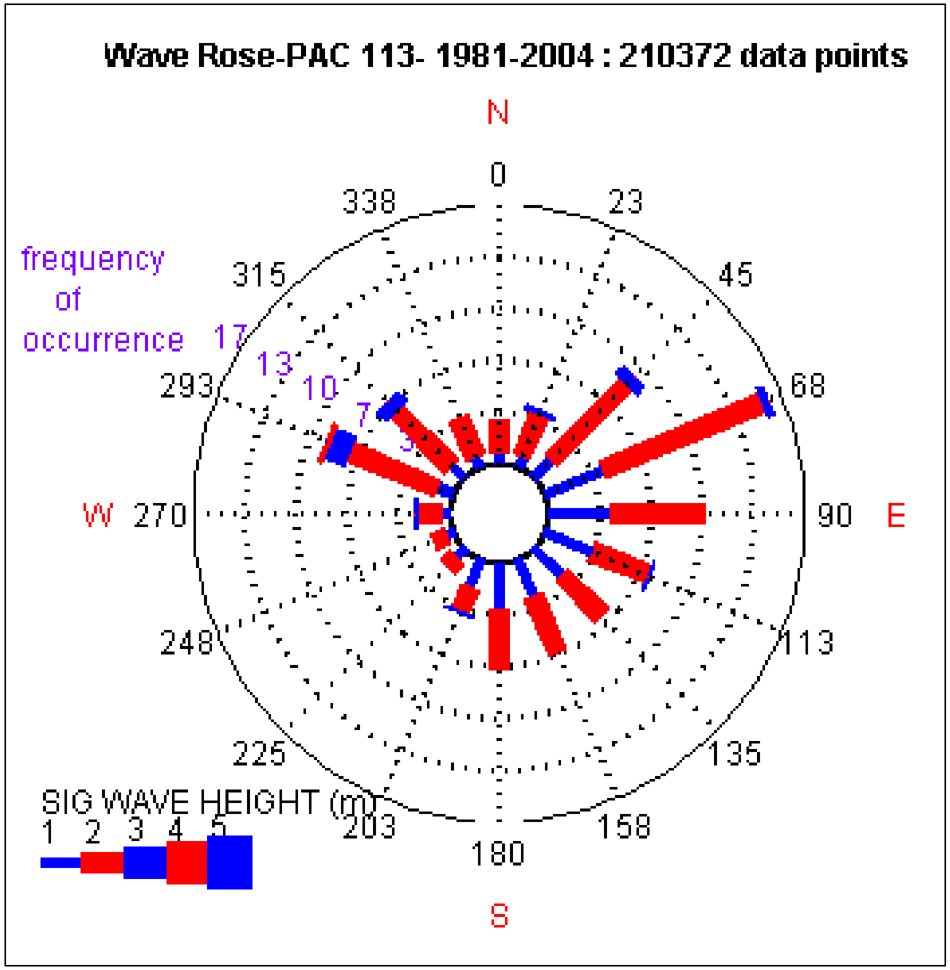


Figure 27. Wave Rose for 1981-2004 for WIS Station 113.

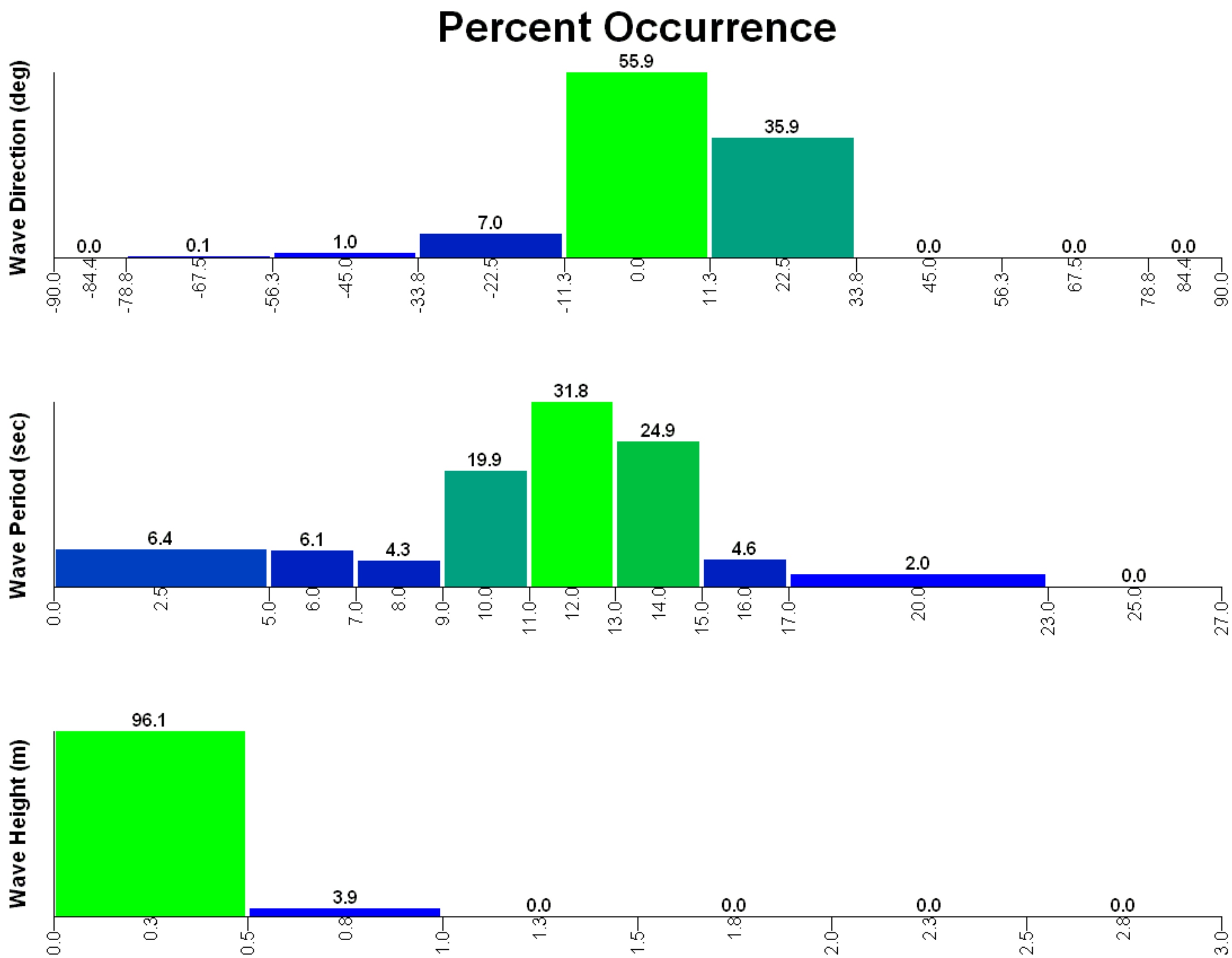


Figure 28. 1984 Percent Occurrences for Wave Height, Peak Period, and Mean Direction for WIS Station 113.

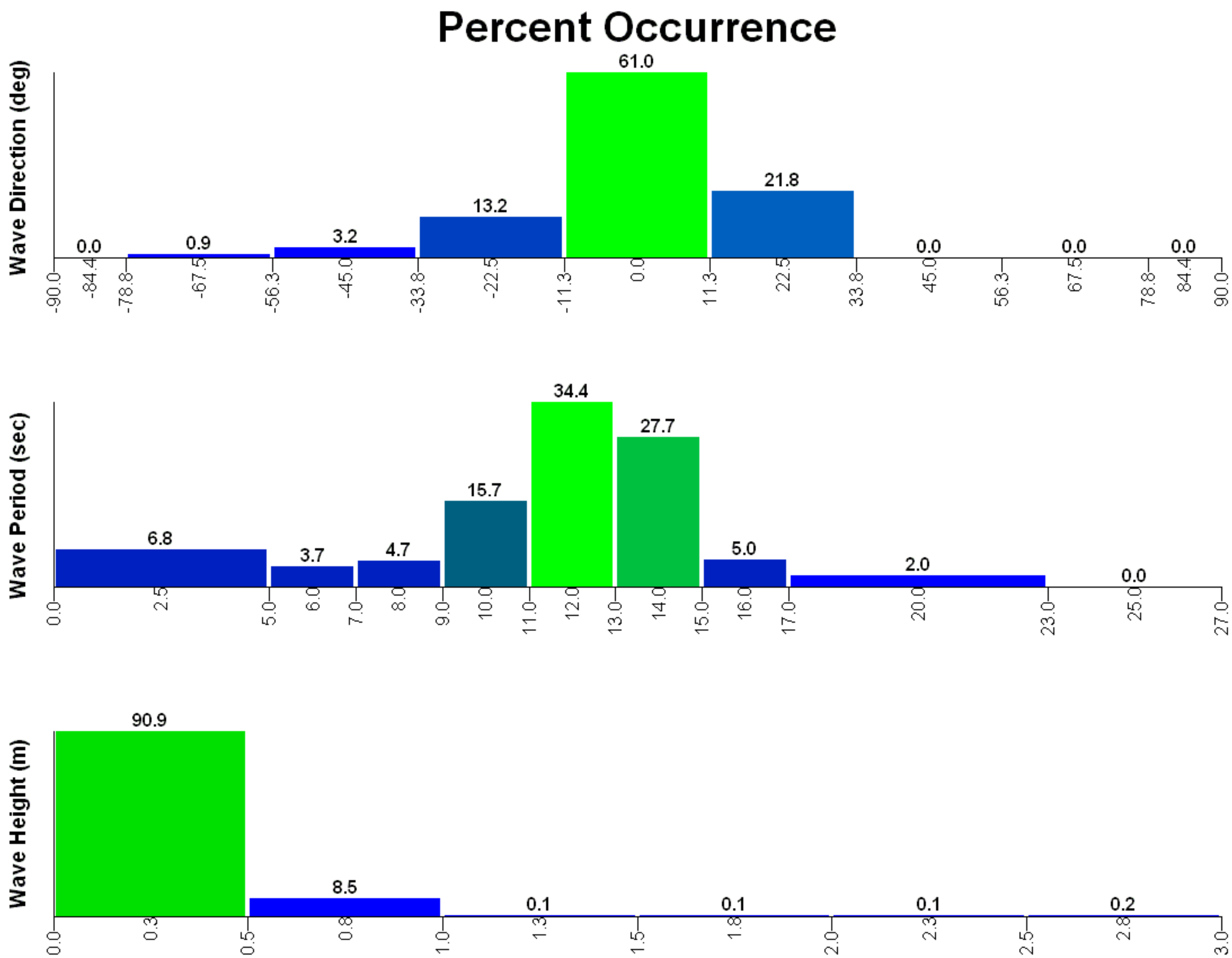


Figure 29. 1992 Percent Occurrences for Wave Height, Peak Period, and Mean Direction for WIS Station 113.

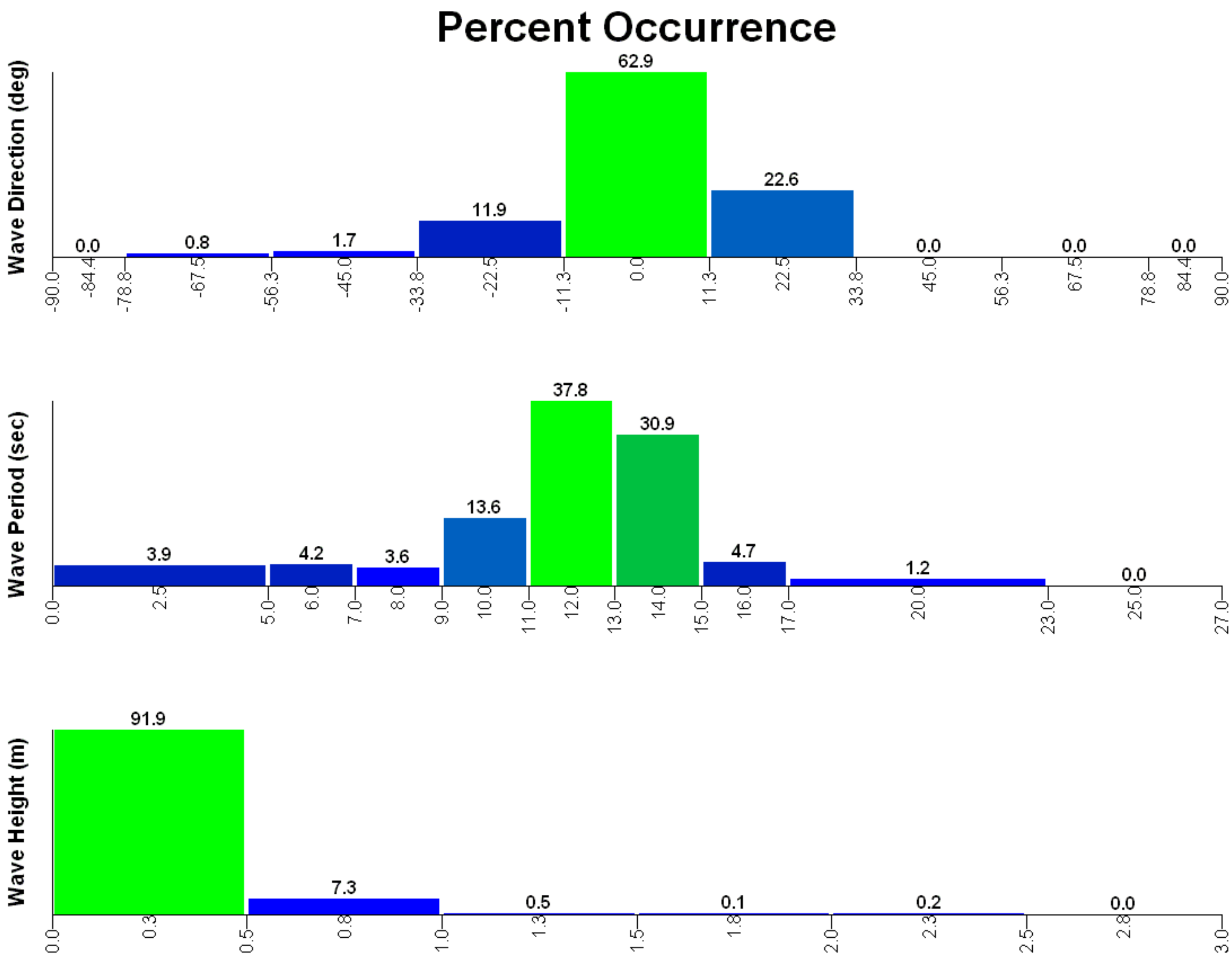


Figure 30. 1994 Percent Occurrences for Wave Height, Peak Period, and Mean Direction for WIS Station 113.

Table 5 provides a summary of the mean and maximum wave statistics for the years 1984, 1992, and 1994. Tables 6 and 7 provide wave parameters used to complete nearshore wave model runs and to build a lookup table to be used in simulating nearshore wave climatology. There are a total of 118 runs (i.e.118 conditions) in the two tables. Wave conditions at this site cover a much smaller range of wave heights than other sites due to sheltering and transformation to 100-m depth.

Table 5. Mean and Maximum Statistics - Kihei Region Waves

	1984	1992	1994
Mean Wave Height (m)	0.3	0.3	0.3
Mean Peak Period (s)	11.3	11.6	11.9
Largest Wave Height (m)	0.8	2.9	2.4
Peak of Largest Height (s)	4.7	10.2	11.2
Direction Bin of Largest Height (deg)	157.5	180	157.5

Table 6. Typical Conditions - Kihei Region Waves (70 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
	10 (3)	-22.5 (3)	from 202.5 deg
	12 (4)	0 (4)	from 180 deg
	14 (5)	22.5 (5)	from 157.5 deg
	16 (6)		
	20 (7)		

Table 7. Extreme Conditions - Kihei Region Waves (48 conditions)

Significant Wave height, m	Wave Period, sec	Wave Direction, deg from STWAVE axis	Wave Direction, deg met convention
1.5 (3)	8 (2)	-45 (2)	from 225 deg
2 (4)	10 (3)	-22.5 (3)	from 202.5 deg
3 (5)	12 (4)	0 (4)	from 180 deg
	14 (5)	22.5 (5)	from 157.5 deg

The STWAVE grid encompasses the entire Kihei RSM region, as shown in 27b below, with a grid resolution of 50m. The Kihei grid is oriented such that its offshore boundary (at approximately 100 m depth) faces southwest at 225 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 31 shows the shallow contours of the Maalaea Bay area. A detailed view of the STWAVE grids in the nearshore areas adjacent to Maalaea Harbor is shown in Figure 32.

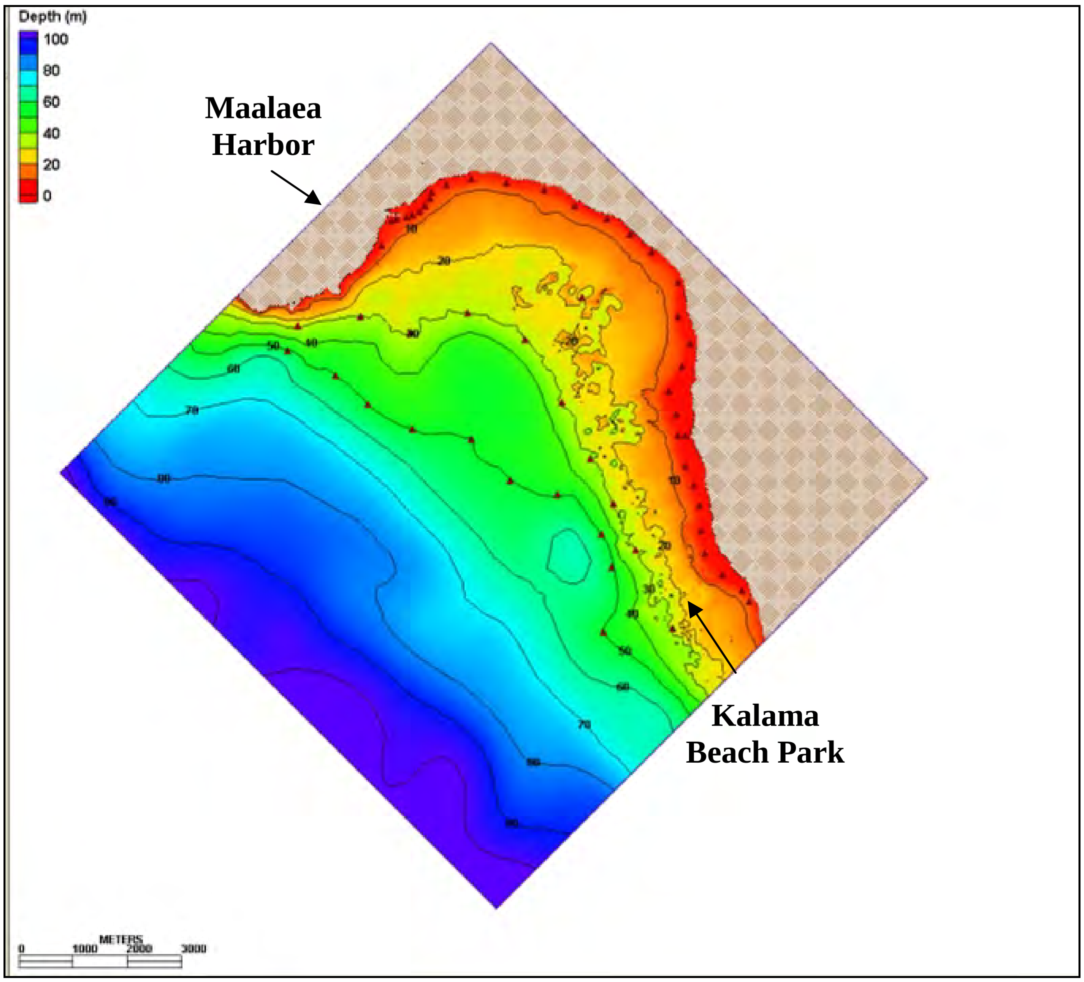


Figure 31. STWAVE Grid Extents for Kihei Region (10-meter contours shown)

Wave parameters from Tables 6 and 7 were used to generate wave input spectra for the Kihei grid. An example of the resulting wave height information (in color) and wave direction (arrows) for the Kihei grid is shown in Figure 33. 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 33 as black squares). Wave parameters for these selected locations were saved in a separate file for use in the next step of the process.

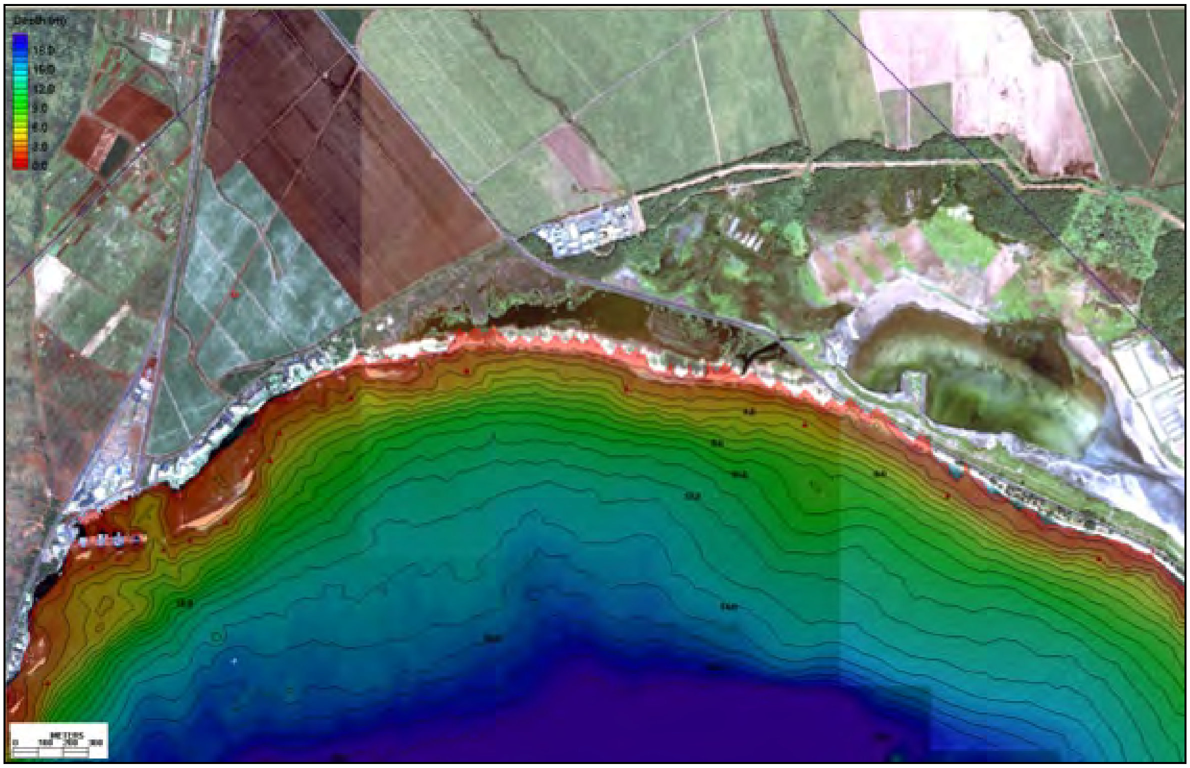


Figure 32. STWAVE Grid Adjacent to Maalaea Harbor in Kihei Region (1-meter contours shown)

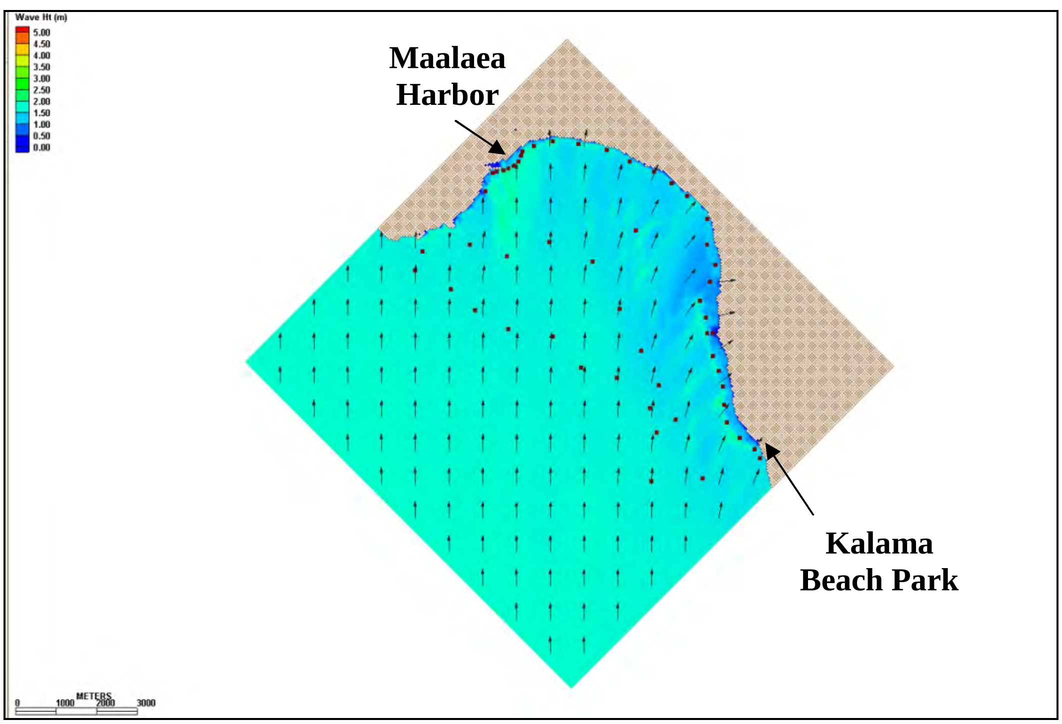


Figure 33. Resulting Wave Height (color scale) and Wave Direction (arrows) in Kihei Region for Case 356 (Ho = 1.5m, To= 14s, Dir=180) and Location of Observation Points (black squares)

A database (or "lookup table") of wave parameters that correlates the most frequent offshore wave conditions at the WIS station (from Tables 6 and 7 for Kihei) 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 Kihei 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 Kihei region, near Maalaea Harbor and Kalama Beach Park, are shown in Figures 34 and 35, respectively.

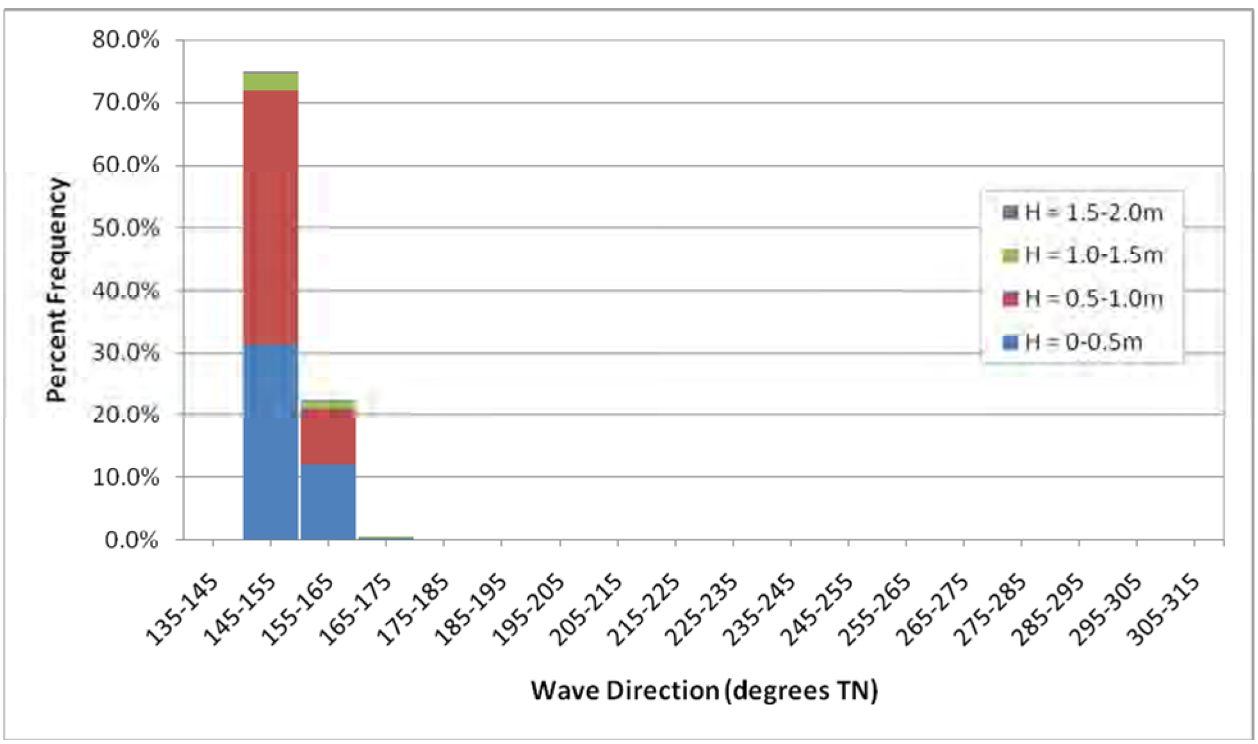


Figure 34. Histogram of Wave Height and Direction at Nearshore Observation Point Near Entrance to Maalaea Harbor (Shore normal = 130 degrees TN)

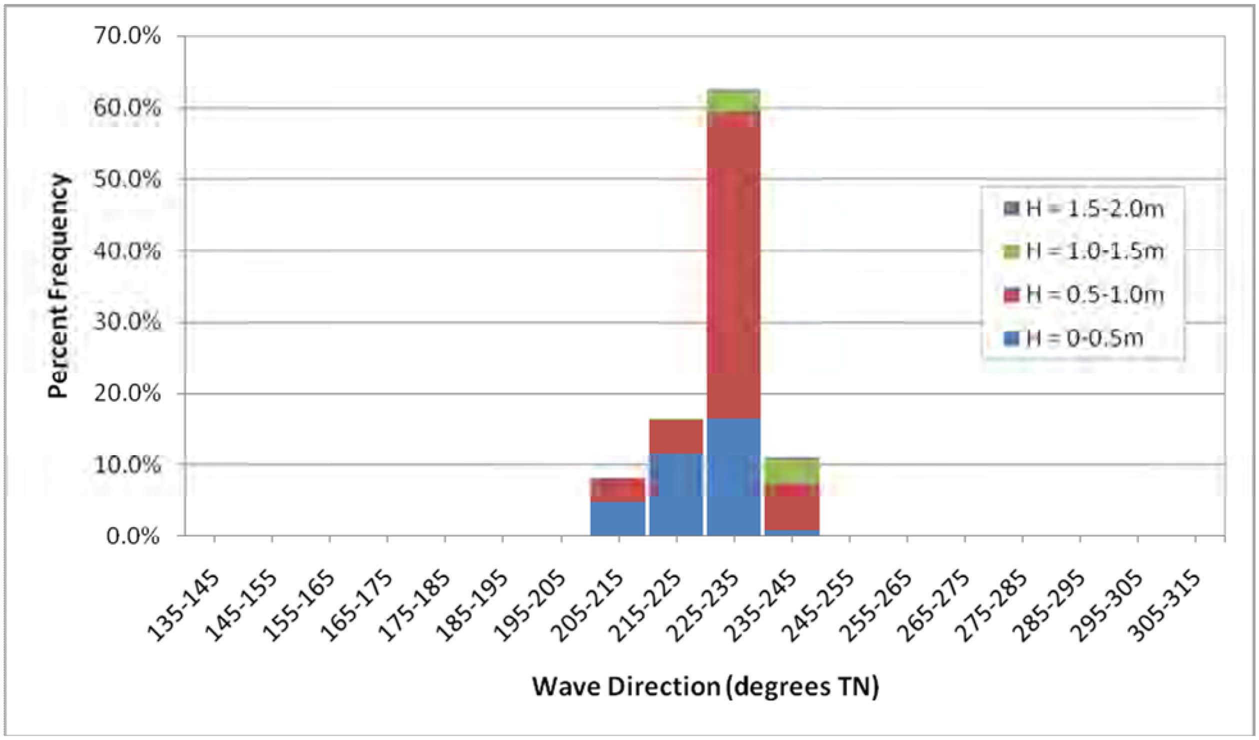


Figure 35. Histogram of Wave Height and Direction at Nearshore Observation Point Near Kalama Beach Park (Shore normal = 252 degrees TN)

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 35 indicates that while the onshore normal direction at this observation point (Kalama Beach Park) is approximately 252 degrees TN, all of the nearshore waves are approaching from an angle of 245 degrees TN or less. This would seem to indicate that sediment transport at this location is from south to north, because of the obliquity of the incoming waves with the shoreline. Comparisons with shoreline aerials of this location support this indication.

This correlation of nearshore wave height and direction to sediment transport direction was not completed for all locations within the Maui 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 the dredged areas within Kahului and Maalaea Harbors. Structures along the shoreline, such as groins, also affect the beach dynamics and associated sand transport. The beach dynamics of each region are described below.

Kahului Region. A significant human impact to the Kahului region was mining for lime production by the sugar company and later mining by others for cement manufacturing and aggregate. This mining began around 1900 and ended sometime between 1960 and 1975. In 1954, it was estimated that approximately 12,000 cubic yards per year of sand had been mined from the beach area to the east of the Kahului Wastewater Facility. Levin (1970) states the dredging during sand mining efforts offshore of the lime kilns changed the bathymetry of the nearshore area, creating “new deep water areas”; it may also have caused turbidity which could have affected the adjacent reef systems.

M&N (2008) provides an analysis which strongly suggests that the WWRF and Kite beach areas (just east of the Kahului Harbor) decrease during the summer months, i.e. that there is a seasonal fluctuation at these beaches. The analysis also suggests that the revetment fronting the Wastewater Facility is now extending far enough into the surf zone to have some of the characteristics of a groin and has the tendency to cause accretion on the upcoast (east) side and erosion on the downcoast (west) side.

Coastal dunes are important to beach dynamics along much of the north shore of Maui. The large sand dunes (some as high as 40 feet) create an obstacle to the landward movement of windblown sand. Vegetation on dunes can further provide stability to the beach by reducing wind velocity on the dune surface causing sand grains to accumulate and by stabilizing the dunes with their root systems. The beaches on the north shore of Maui lose dune sand from wind erosion through man-made gaps in the dunes and as a result of foot-traffic on the dune. Anecdotal evidence suggests that these dunes have become significantly lower/flatter since the rise in wind surfing popularity (and thus increased foot traffic) in the early 1970s. Photographs of some the current (2011) dunes within the Kahului region are shown in Figure 36.

36a. Large Dune Along West End of Baldwin Beach – “Mother’s Beach”

36b. Eroded Dune Along Baldwin Beach Park

Figure 36. Shoreline Dunes in the Kahului Region (2011 Condition)

Photographs of some of the structures within the Kahului region are shown in Figure 37. The shoreline structures within the Kahului region include the Kahului Harbor formed by two breakwaters (photos 37a and 37b), groin fields to the east of the harbor (photo 37c), and several stretches of coastline armored by rock revetment (photo 37d). Additional details about these structures and graphics showing the locations of these structures are provided in Appendix F.

37a. Kahului Harbor

37b. Kahului Harbor – East Breakwater

37c. Groin Field

37d. Wastewater Treatment Facility Revetment

Figure 37. Shoreline Structures in the Kahului Region

Kihei Region. In general, the Kihei region is protected from open ocean waves via the nature of its location within Maalaea Bay. The waves that do penetrate into the bay have their energy spread out via diffraction, resulting in generally less wave energy per length of shoreline than would be found outside of the bay.

The Kihei region is exposed to wave action primarily from the south - Kona waves during the winter and southern hemisphere swell during the summer. This results in a wave-driven longshore sediment transport direction that is from south to north.

Conversely, the frequent and energetic trade winds transport a significant amount of sand across the top of the dry beach face to the south. Thus, there is a wind-driven sand transport from north to south.

As in the Kahului region, coastal dunes are important to beach dynamics in much of the Kihei region. Previous Kihei area studies (M&N 2000) indicate that the practice of breaching dunes to drain mauka streams causes irregularity of the shoreline alignment and allows for significant loss of beach sand inland due to persistent trade winds. Normally, as the sand is transported southerly via trade winds along the dry beach face, it is generally contained on the beach by the dune. However, with breaches in the dune, the southerly moving sand is vented inland and is thus no longer available to be transported south to re-nourish those beaches. M&N (2000) estimates that erosion along the 4-mile Kihei shoreline is on the order of one foot per year due to the dune breaching. Photographs of some the current (2011) dunes within the Kihei region are shown in Figure 38.

38a. Dune Along Kawililipoa Beach

38b. Dune Just South of Hawaiian Islands Humpback Whale National Marine Sanctuary Learning Center

Figure 38. Shoreline Dunes in the Kihei Region (2011 Condition)

This loss of wind-blown sand could have also caused destabilization of the sand and coral rubble-reef-type formations in the Kihei area. The deprivation of sand to the reef system would have allowed the coral rubble to become mobile during significant wave events, with a net coral rubble transport to the north. Since there is insufficient wave energy to move this material back to the south, this is a one-way effect of moving coral rubble to the north and leaves the southern beaches further exposed to wave action and erosion.

Photographs of some of the structures along the Kihei region shoreline are shown in Figure 39. The Kihei region has been affected by the construction of the Maalaea Harbor formed by two breakwaters (photo 39a), Kihei pier (photo 39b), groins (photo 39c), historic fish ponds, and several stretches of coastline armored by rock revetment (photo 39d) and/or seawall.   There is also a unique rubble formation (most likely an ancient fish pond) at the north end of the Kawililipoa Beach cell (photo 39e). Additional details about these structures and graphics showing the locations of these structures are provided in Appendix G.   These shoreline discontinuities complicate the cobble, as well as sand, transport.

39a. Maalaea Harbor

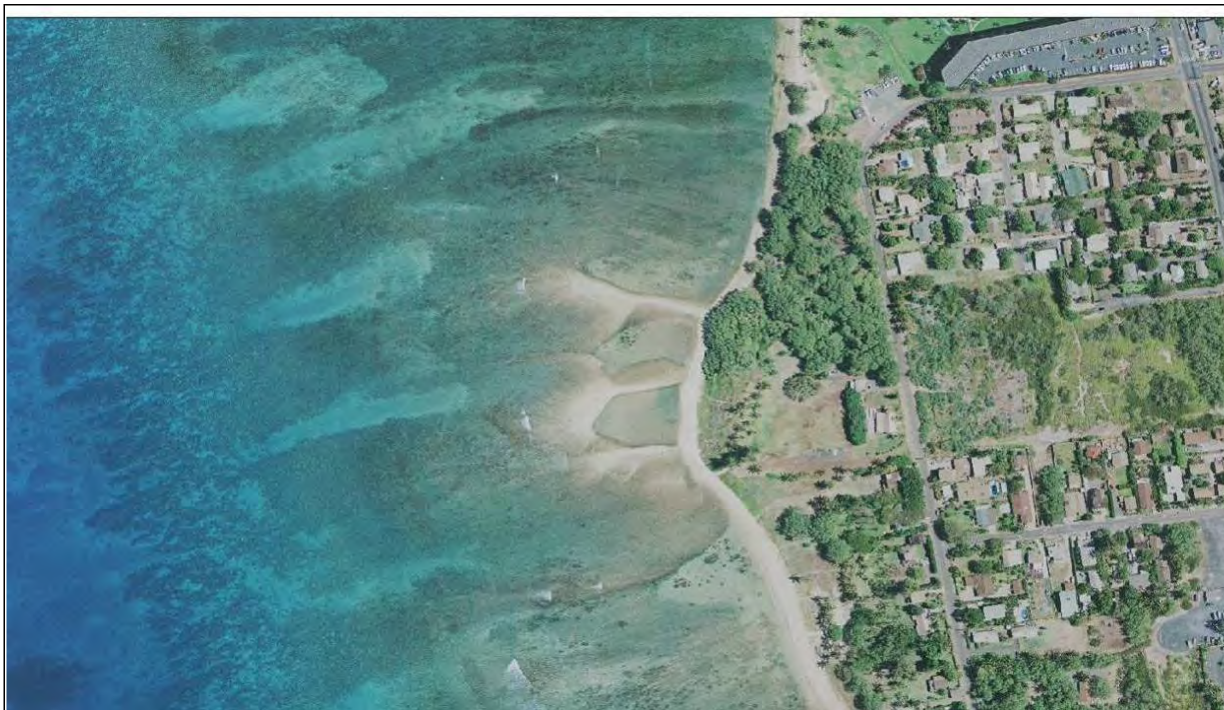
39b. Kihei Pier (Remnant Wharf)

Figure 39. Shoreline Structures in the Kihei Region

39c. St. Theresa's / Halama Street Groin

39d. Kalama Park Revetment

Figure 39. Shoreline Structures in the Kihei Region (cont.)



39e. Unique Rubble Formation at North End of Kawililipoa Beach Cell

Figure 39. Shoreline Structures in the Kihei Region (cont.)

Previous studies (M&N 2000) indicate bi-directional sediment transport along the west-facing shoreline of the Kihei region: northward littoral transport by Kona storm waves and southern hemisphere swell, and returning southerly transport via trade winds blowing over portions of the dry beach and via trade wind-driven waves. This study indicates that net direction appears to be to the north.

The primary sediment source to most of the beaches within the Kihei and Kahului regions is from biological production, i.e. from dead foraminifers and other small marine organisms transported onshore from the reef edge. However, it has been speculated (Sea Engineering 1991 and Guild 1999) that the reefs may not be as productive as they have been in the past, particularly in the Kahului region, and thus there would be a decrease in coralline sand washed onshore. Reasons for loss of reef productivity include: ocean warming, historic mining activities and stream flooding causing turbidity of the ocean, and WWII training exercises which blew up portions of Maui's reefs. Also, it is not known whether this type of beach sediment was produced recently, or whether the majority of the sediment was produced in the early to mid Holocene – from about 5,000 years before present (b.p.) to 2,000 years b.p. The rate of modern sediment production is a major unknown in the sediment budget for the Hawaii RSM regions.

In both regions, some of the sediment on the beach has been imported via small beach nourishment projects. Some of the sediments within the regions are from terrigenous sources such as streams and rivers.

B. Shoreline Position Changes

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 Hawaiʻi as part of their Coastal Hazard Mapping program. The erosion maps (Coastal Geology Group, 2010) are provided in Appendices D and E. The UH maps were compiled for each region to provide a top-level view of the long-term historical erosion rates in each region. These are provided as Figures 40 and 41.

Generally, the calculated historical shoreline position change rates indicate the following in the Kahului Region.

- The entire shoreline is erosional.
- The most significant erosion rates are east of Kahului Harbor, particularly near Kaa and the Wastewater Reclamation Facility, Spreckelsville, and Baldwin Beach.
- In the eastern portion of the region (Paia and Father Jules Papa area) and within Kahului Harbor, the shoreline erosion rates are relatively smaller because the shoreline has generally eroded to the location of existing seawalls.
- A significant landward shift (erosion) of the shoreline occurred between 1960 and 1975 along the beach to the east of Kahului Harbor and west of Kaa. There has been a relatively stable period since then.
- A significant shoreward shift (accretion) of the shoreline occurred between 1960 and 1975 along the beach to the east of the groin at Kanaha Beach Park. This shoreward shift has continued, until at least 2002 (the last recorded shoreline).

Generally, the calculated historical shoreline change rates indicate the following in the Kihei Region.

- Most of the region's shoreline is currently erosional. The exceptions are: small reaches to the south of Kihei Pier, south of Ko'ie'ie Fishpond, along Kawililipoa, and south of the Halama Street groin.
- The most significant erosion rates are in the southern part of the Kihei region near Kalama Beach Park and just northeast of Maalaea Harbor.
- The erosion rates are relatively uniform along the entire length of Maalaea Bay Beach (northwest of Kihei Pier); the current erosion rates based on the 2007 shoreline are lower than those for the period ending in 1997.
- Along the east-facing coastline, longshore sediment transport from south to north is suggested by the erosional area just upcoast (northeast) of Maalaea Harbor.
- Along the west-facing stretch of coastline, longshore sediment transport from south to north is suggested by accretional areas just downcoast (south) of Kihei Pier, Ko'ie'ie Fishpond and Halama Street groin.
- There is a significant accretional area (somewhat like a tombolo) found at Kawililipoa. (This feature could be the result of coral rubble deposits to the area).

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 budgets.

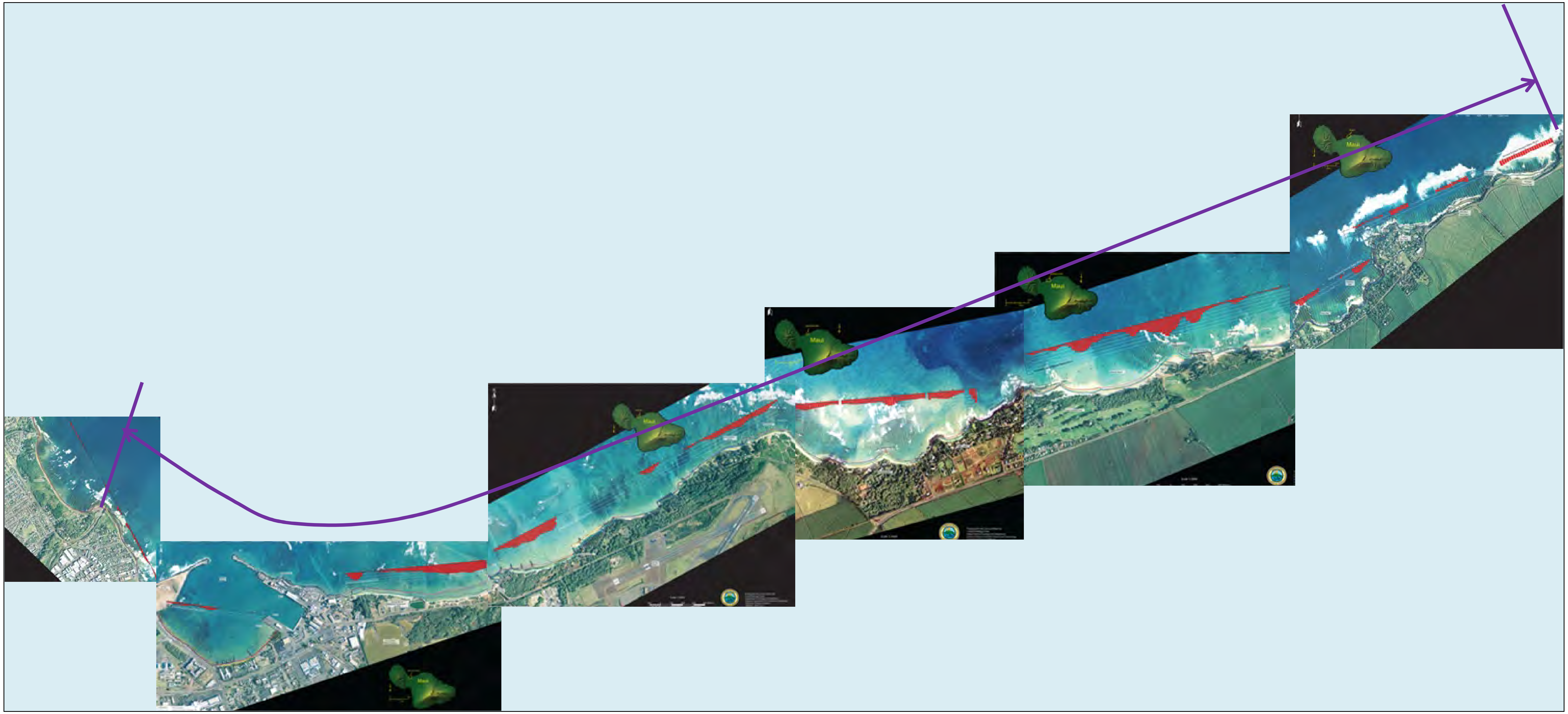


Figure 40. Shoreline Erosion Maps of Kahului Region

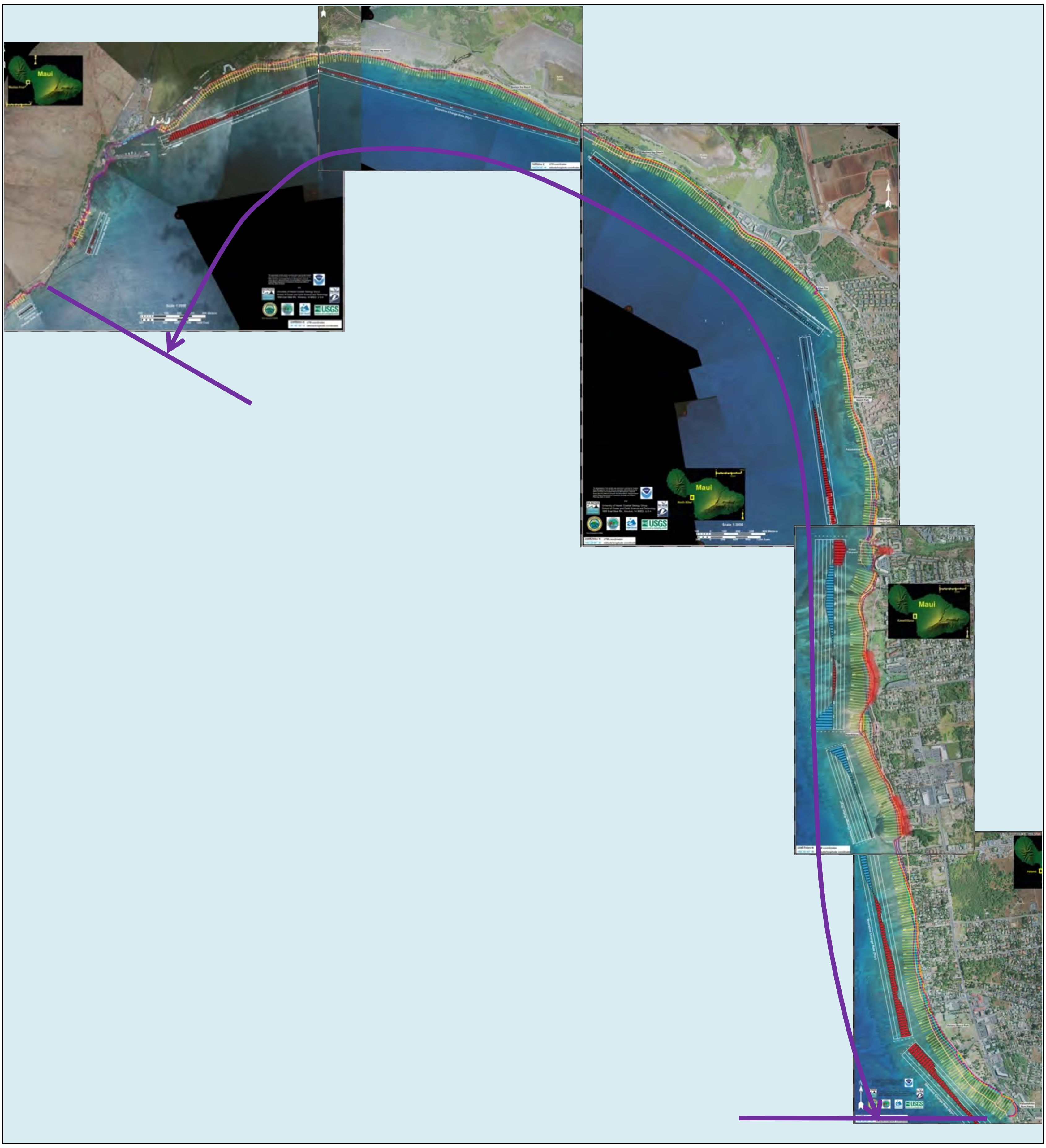


Figure 41. Shoreline Erosion Maps of Kihei Region

VIII. Regional Sediment Budget

The sediment budgets are based on available information regarding shoreline accretion and erosion. 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, 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.

Seven littoral cells were defined for the Kahului region and seven littoral cells were defined for the Kihei region, as shown in Figures 42 and 43, respectively. Each of these littoral cells is described in more detail in Appendices F and G, for the Kahului and Kihei regions, respectively.

The general approach to 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 Maui 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 Kahului and Kihei regions are shown in Figures 44 and 59, respectively. These graphs also show historical events which had the potential for impacting 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 Kahului region and Kihei 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 45 – 51 for the Kahului region and Figures 60 - 65 for the Kihei region. The most recent beach volume change rates (sediment budgets) are shown in Figures 52 – 58 for the Kahului region and in Figures 66 – 71 for the Kihei region.

- The rates take into account historical beach nourishment. The most significant ongoing beach nourishment within the Kahului region has been at Sugar Cove in the Sprecklesville area (M&N 2008). Sand was also placed within Kahului Harbor in 1969 (USACE 1973) and a small beach nourishment project occurred near Mama's Fish House (Hookipa littoral cell) in 2006 (DLNR 2010). In the Kihei region, nourishment projects have occurred on beaches fronting the Maui Lu hotel, a private residence within the North Kihei cell (DLNR 2010), and condominiums just east of Maalaea Harbor (USACE 2004).

Table 8. Kahului Region Beach Sand Volume Change Rates

Littoral Cell	**Accretion(+) / Erosion(-) Rate Over <u>Entire Time Period</u> of Record, cubic yards per year**	**Accretion(+) / Erosion(-) Rate Over <u>Recent</u> Period, cubic yards per year**
Paukukalo	**-1,200**	**0**
Kahului Harbor	**-1,100**	**-800**
Kanaha Beach - Total	**-6,500**	**-10,550**
Spreckelsville	**-2,300**	**-2,400**
Baldwin Park	**-4,800**	**-400**
Paia East	**-500**	**-500**
Hookipa	**0**	**0**

Table 9. Kihei Region Beach Sand Volume Change Rates

Littoral Cell	**Accretion(+) / Erosion(-) Rate Over <u>Entire Time Period</u> of Record, cubic yards per year**	**Accretion(+) / Erosion(-) Rate Over <u>Recent</u> Period, cubic yards per year**
West Maalaea	**-100**	**+50**
Maalaea Harbor	**0**	**0**
Maalaea Bay Beach	**-1,300**	**-800**
Kealia	**-2,300**	**-2,800**
North Kihei	**-800**	**+8,800**
Kawililipoa Beach	**+1,400**	**+1,200**
Kalama	**-1,400**	**-1,600**

It should be noted that the number of available historical shorelines is limited and the graph lines 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.

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

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.

A further discussion of the preliminary sediment budgets for the Kahului and Kihei region littoral cells are provided in Appendices F and G, respectively.

Figure 42. Kahului Region Littoral Cells

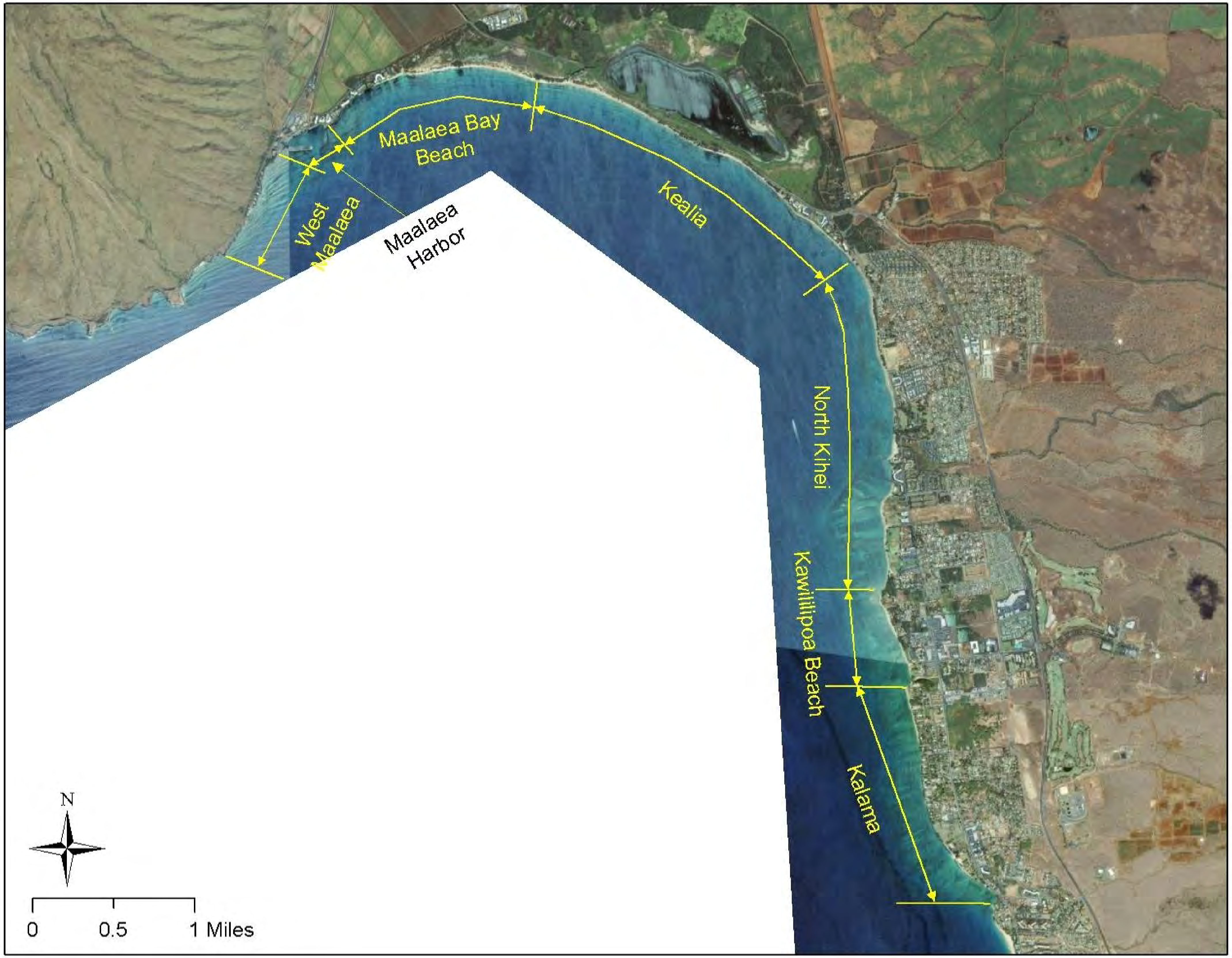


Figure 43. Kihei Region Littoral Cells

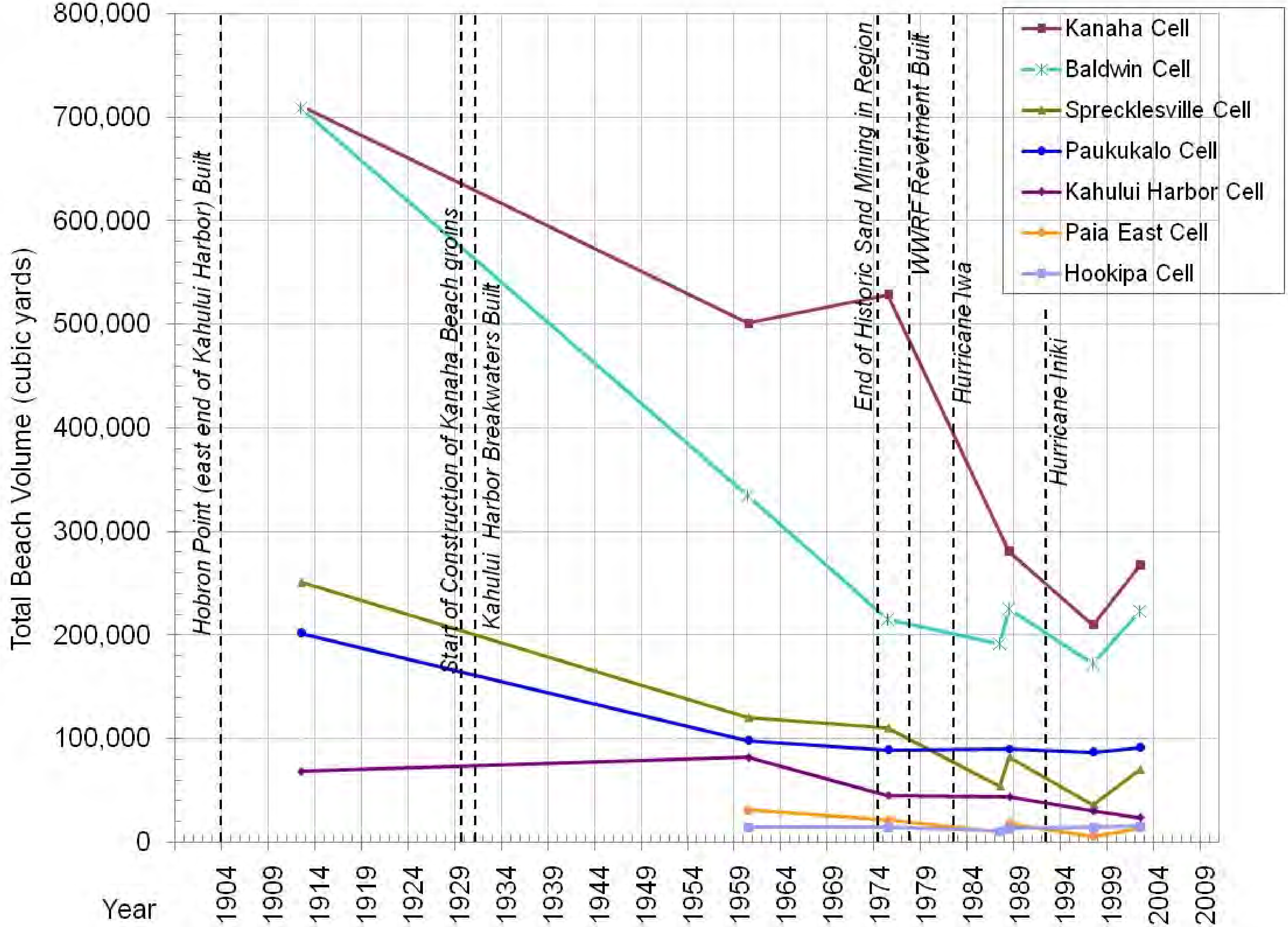


Figure 44. Historical Beach Volumes of Kahului Region Littoral Cells

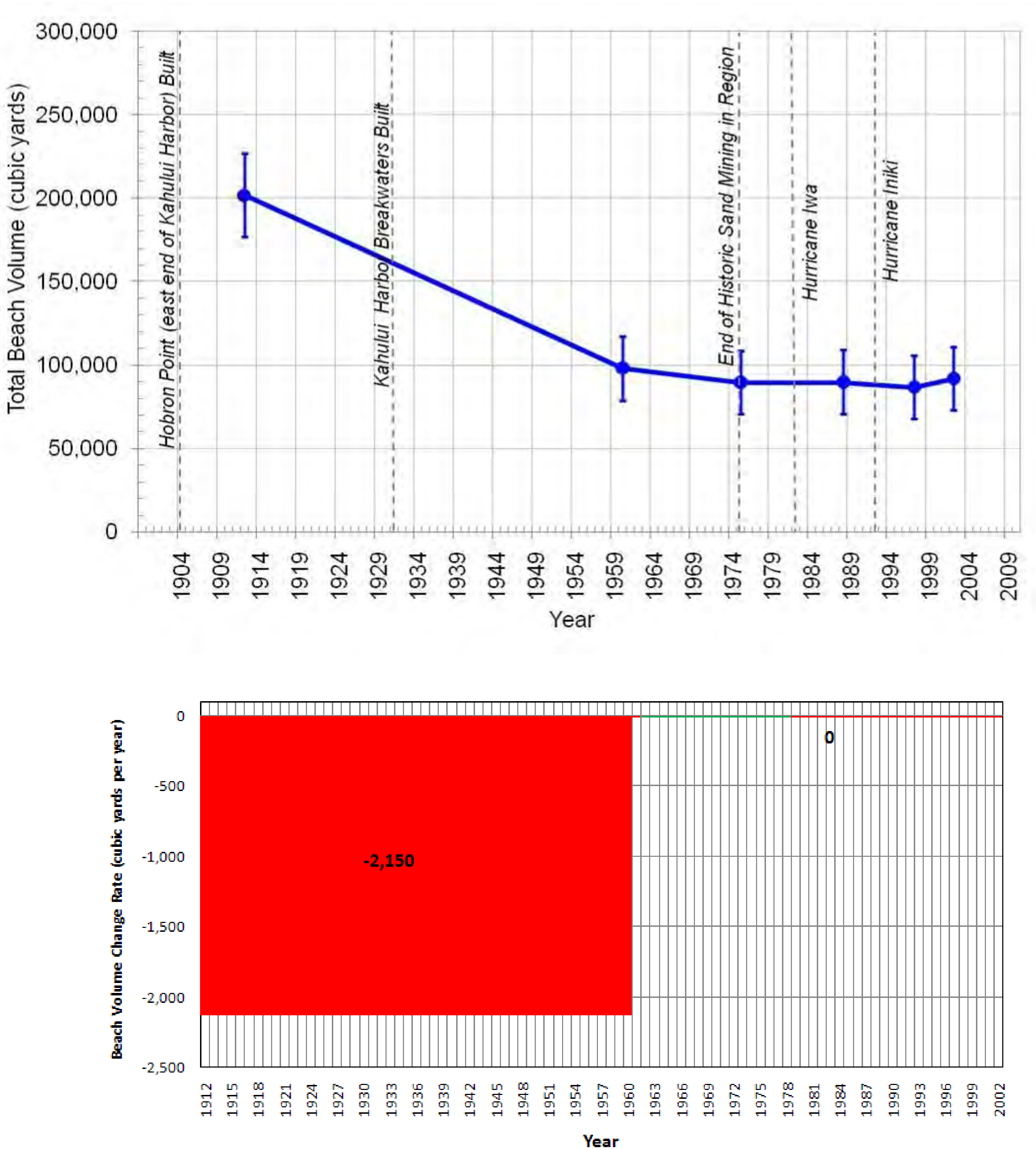


Figure 45. Historical Beach Volumes / Change Rates for Paukukalo Littoral Cell

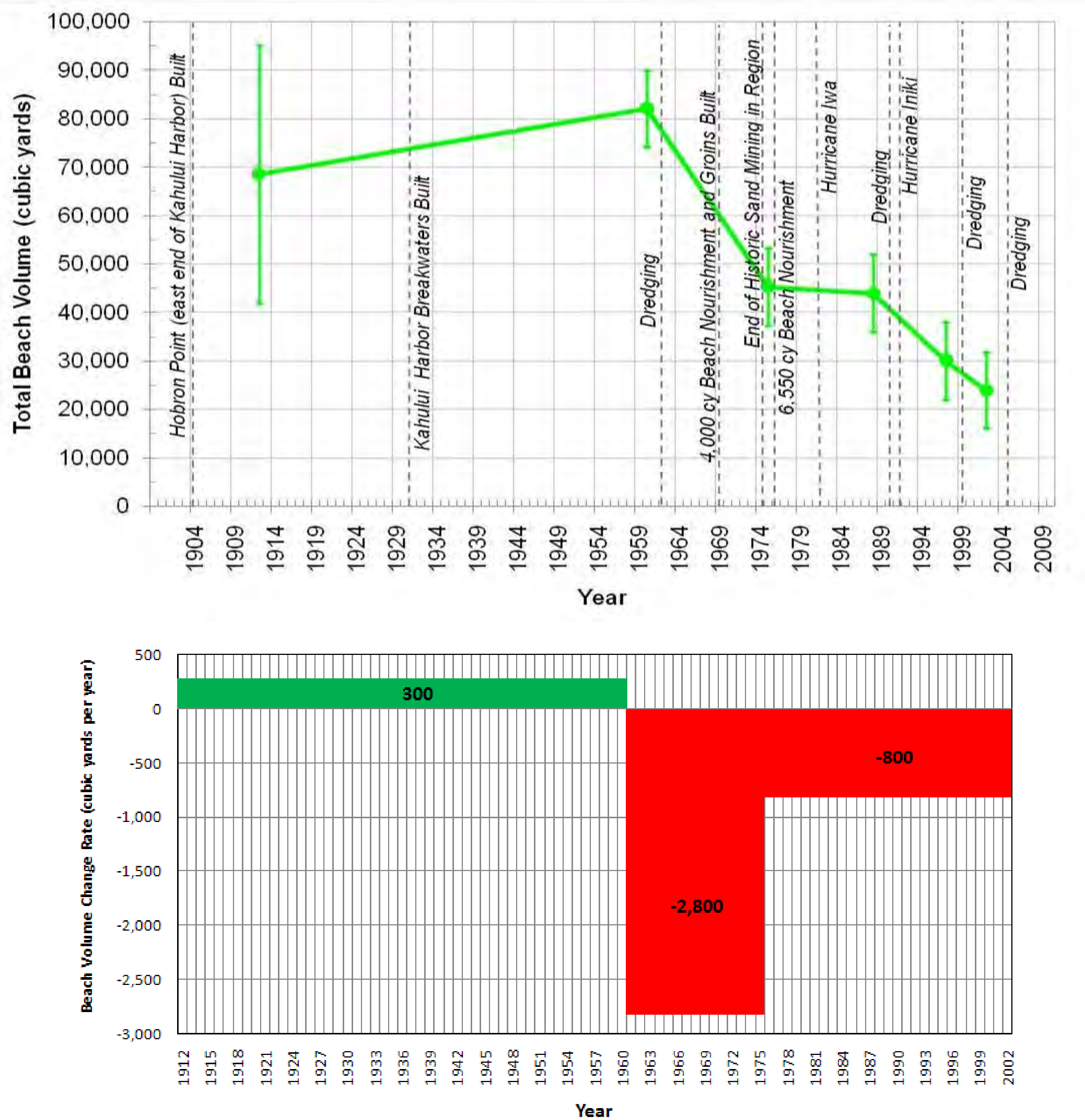
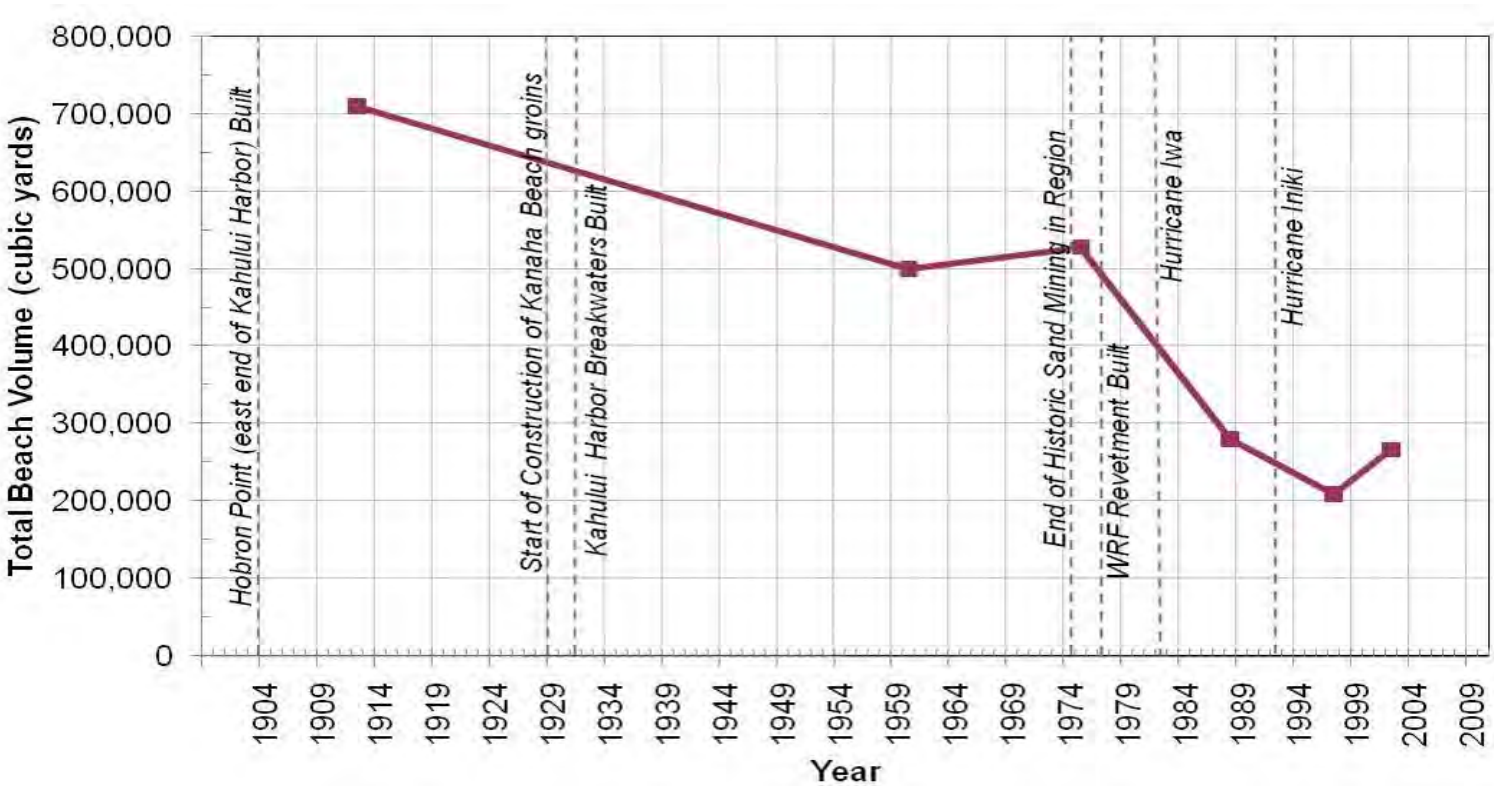


Figure 46. Historical Beach Volumes / Change Rates for Kahului Harbor Littoral Cell



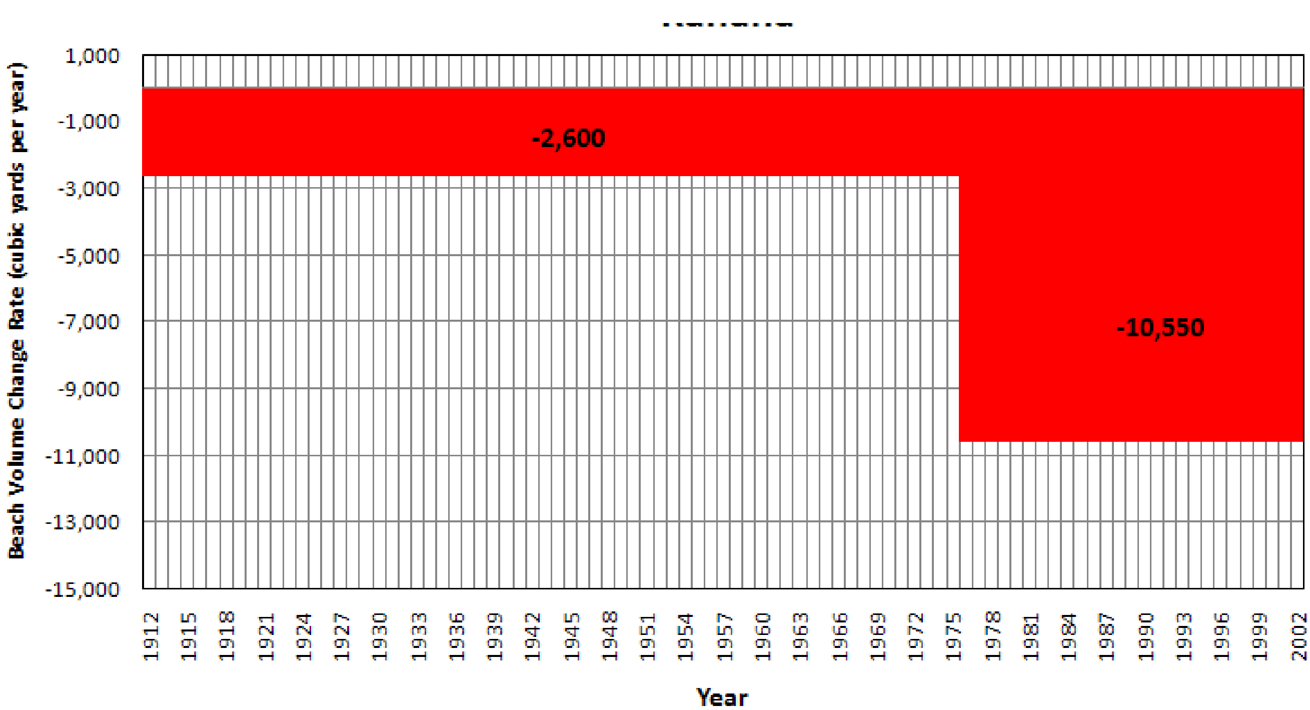


Figure 47. Historical Beach Volumes / Change Rates for Kanaha Littoral Cell

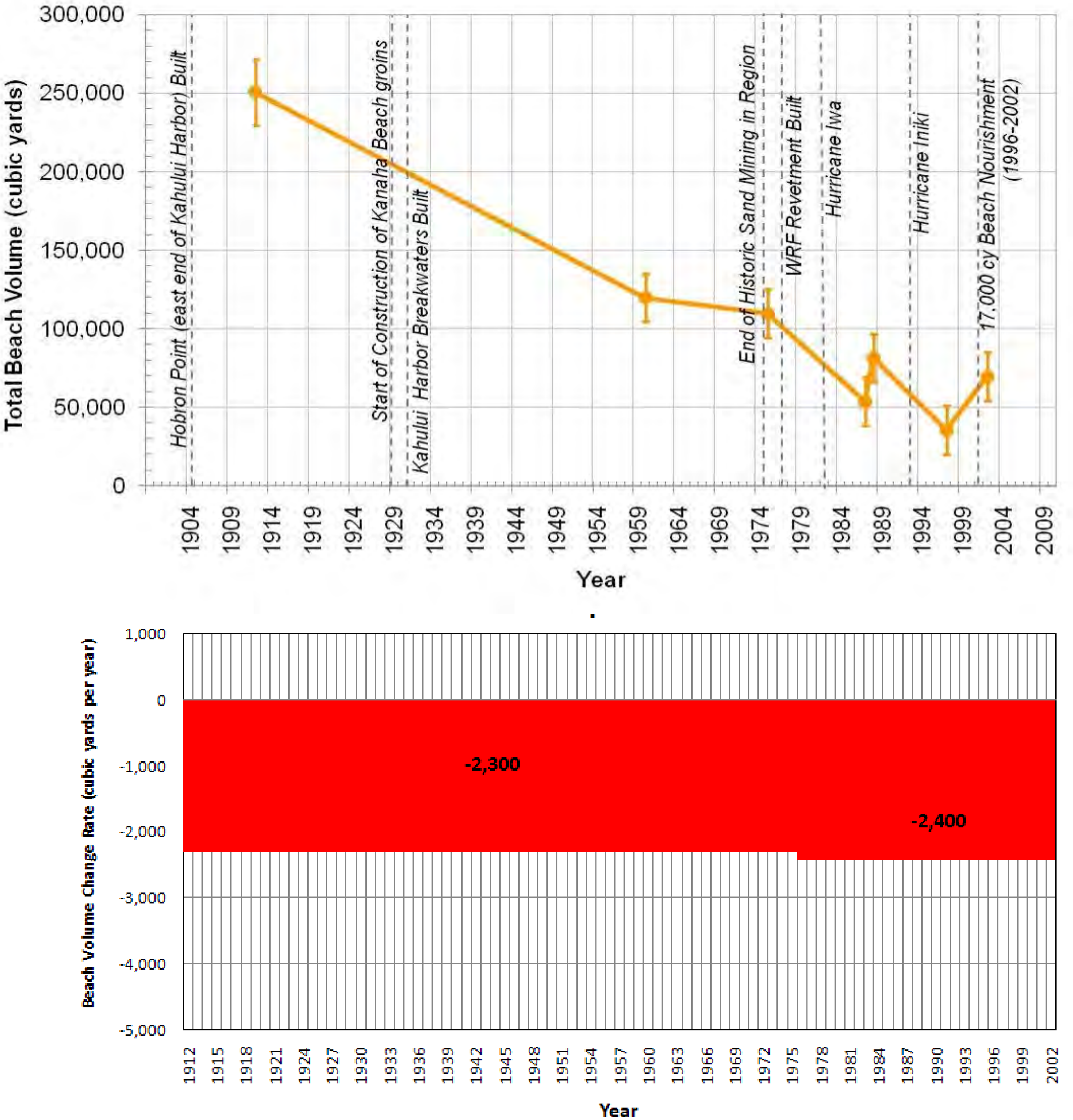
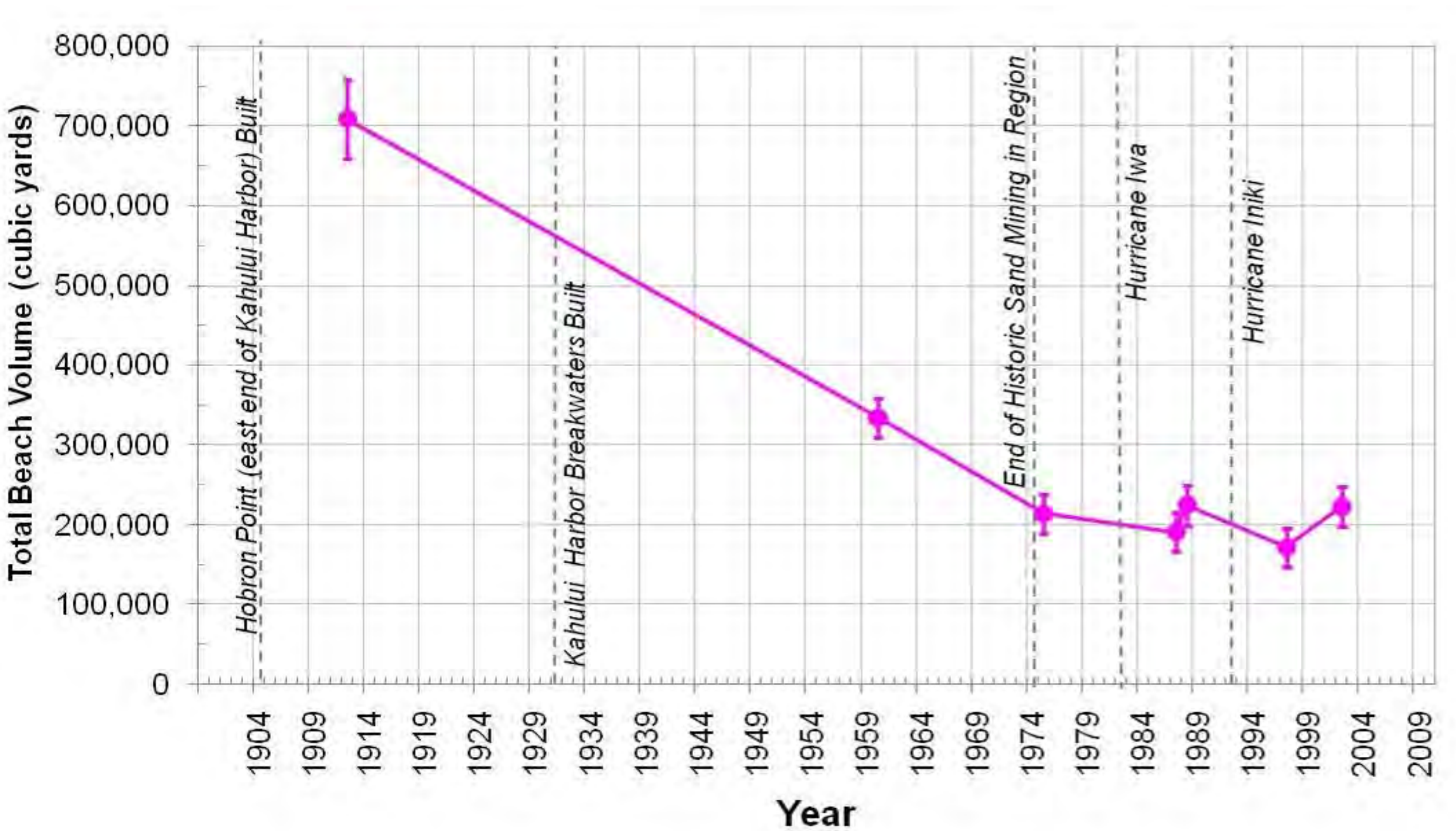


Figure 48. Historical Beach Volumes / Change Rates for Sprecklesville Littoral Cell



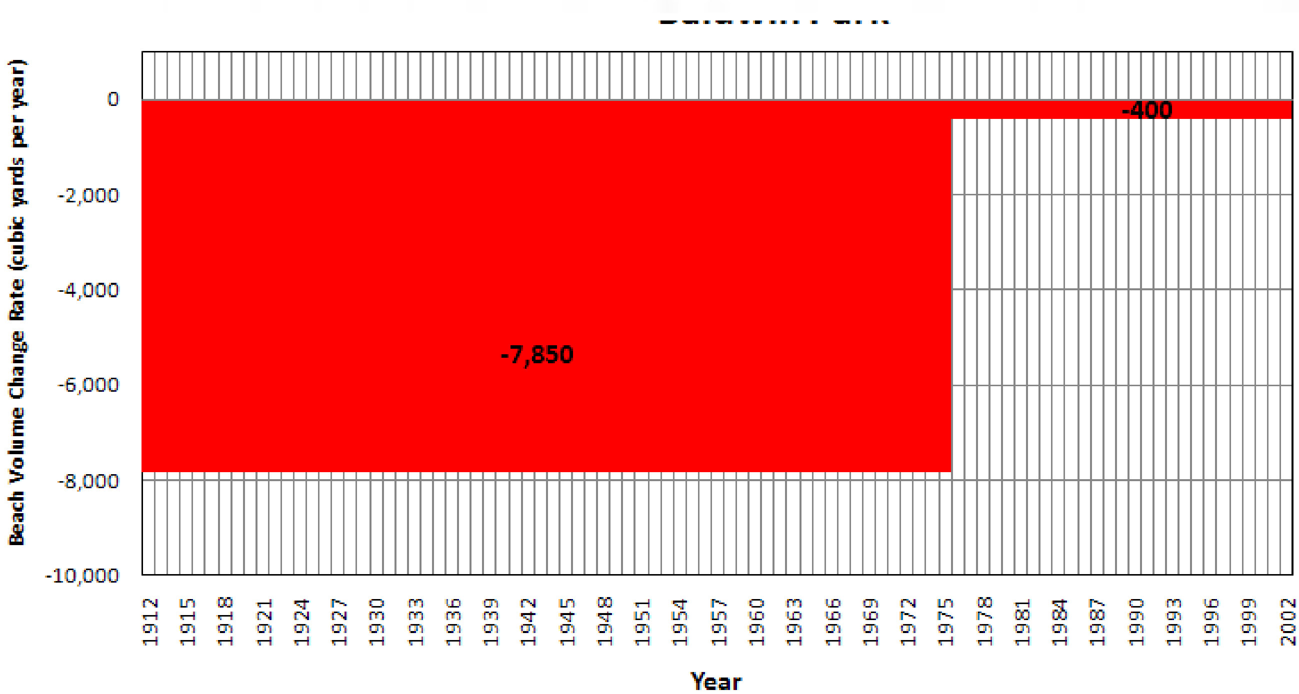


Figure 49. Historical Beach Volumes / Change Rates for Baldwin Park Littoral Cell

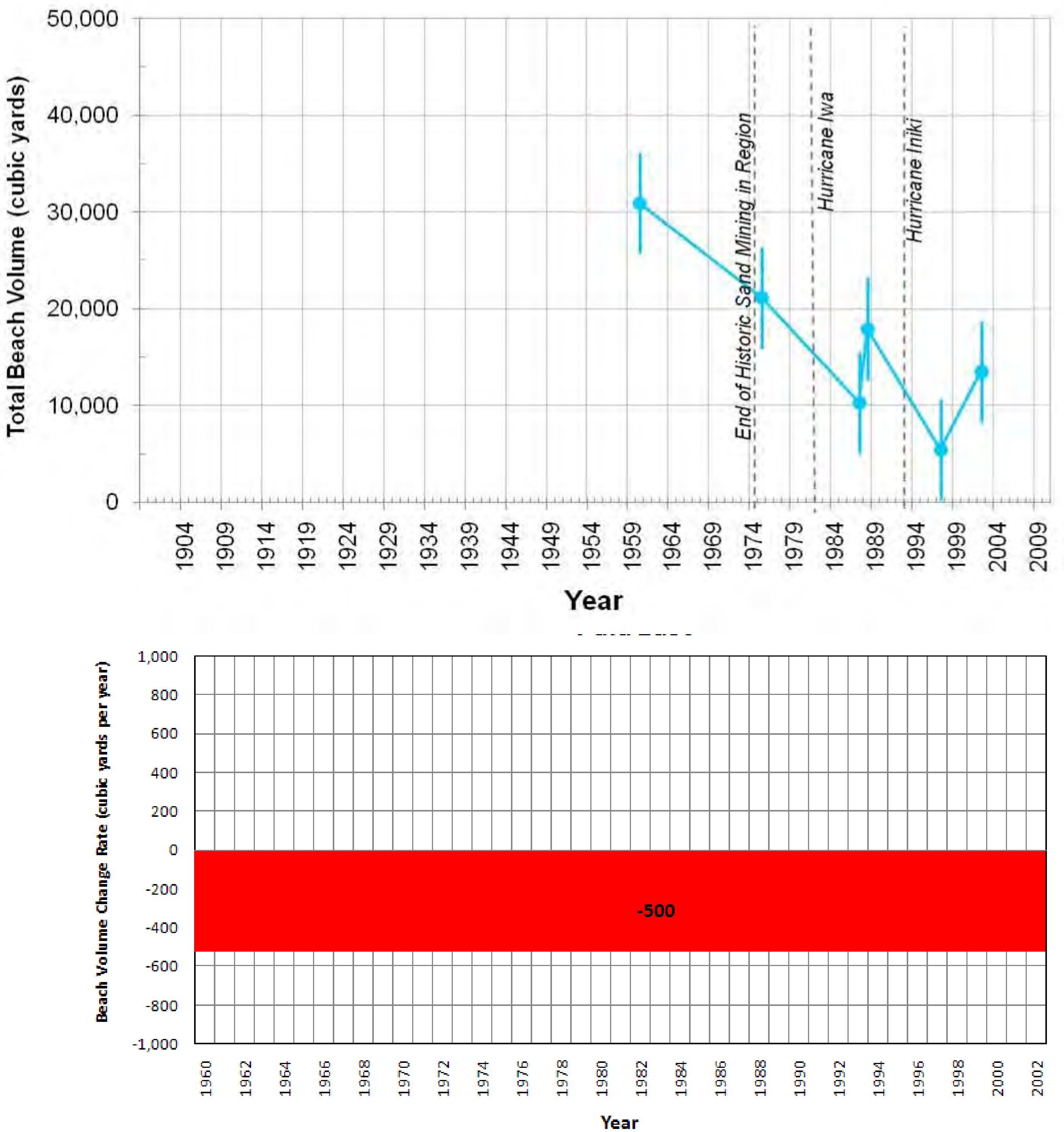


Figure 50. Historical Beach Volumes / Change Rates for Paia East Littoral Cell

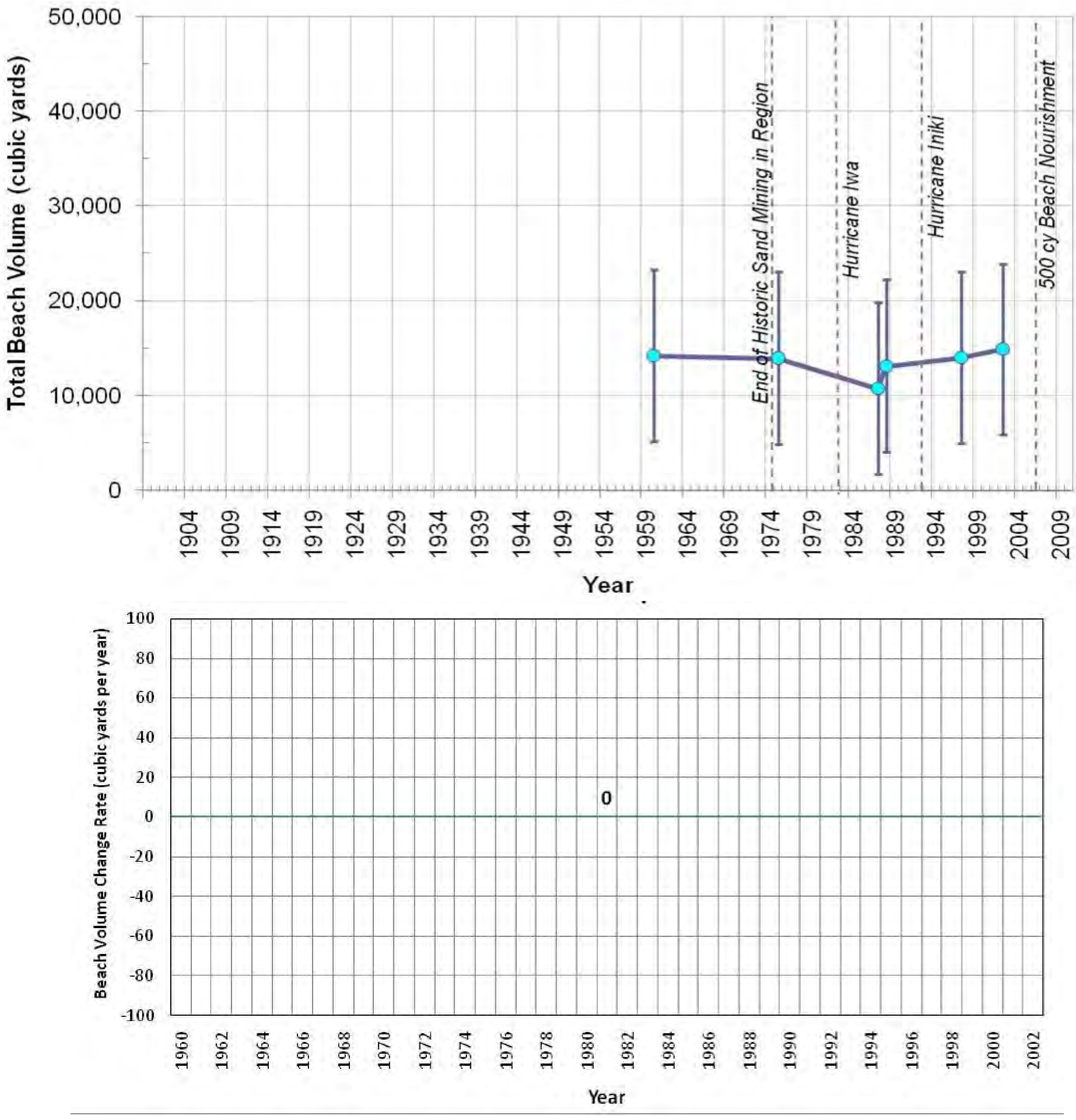


Figure 51. Historical Beach Volumes / Change Rates for Hookipa Littoral Cell

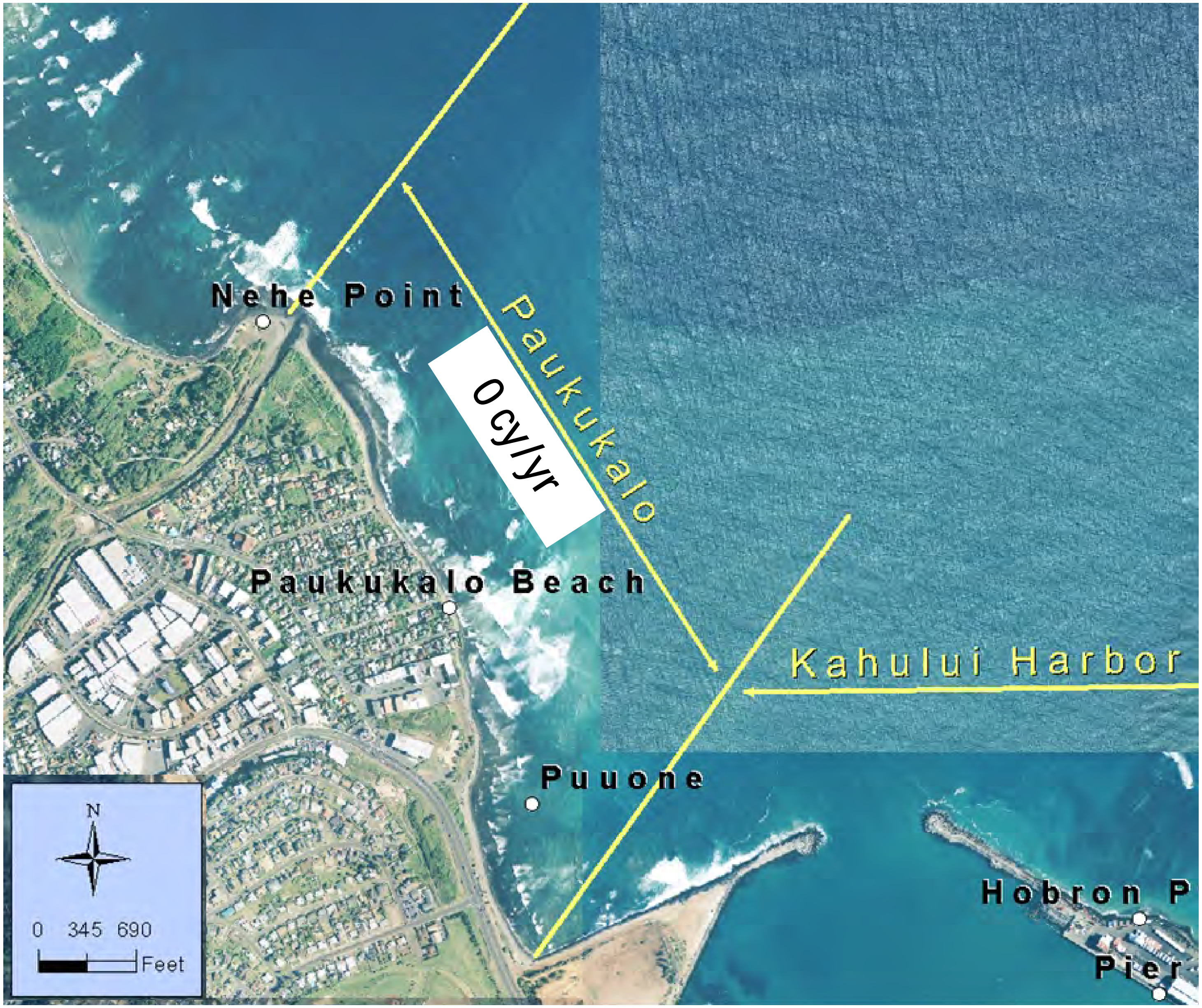


Figure 52. Beach Volume Change Rate for Paukukalo Littoral Cell

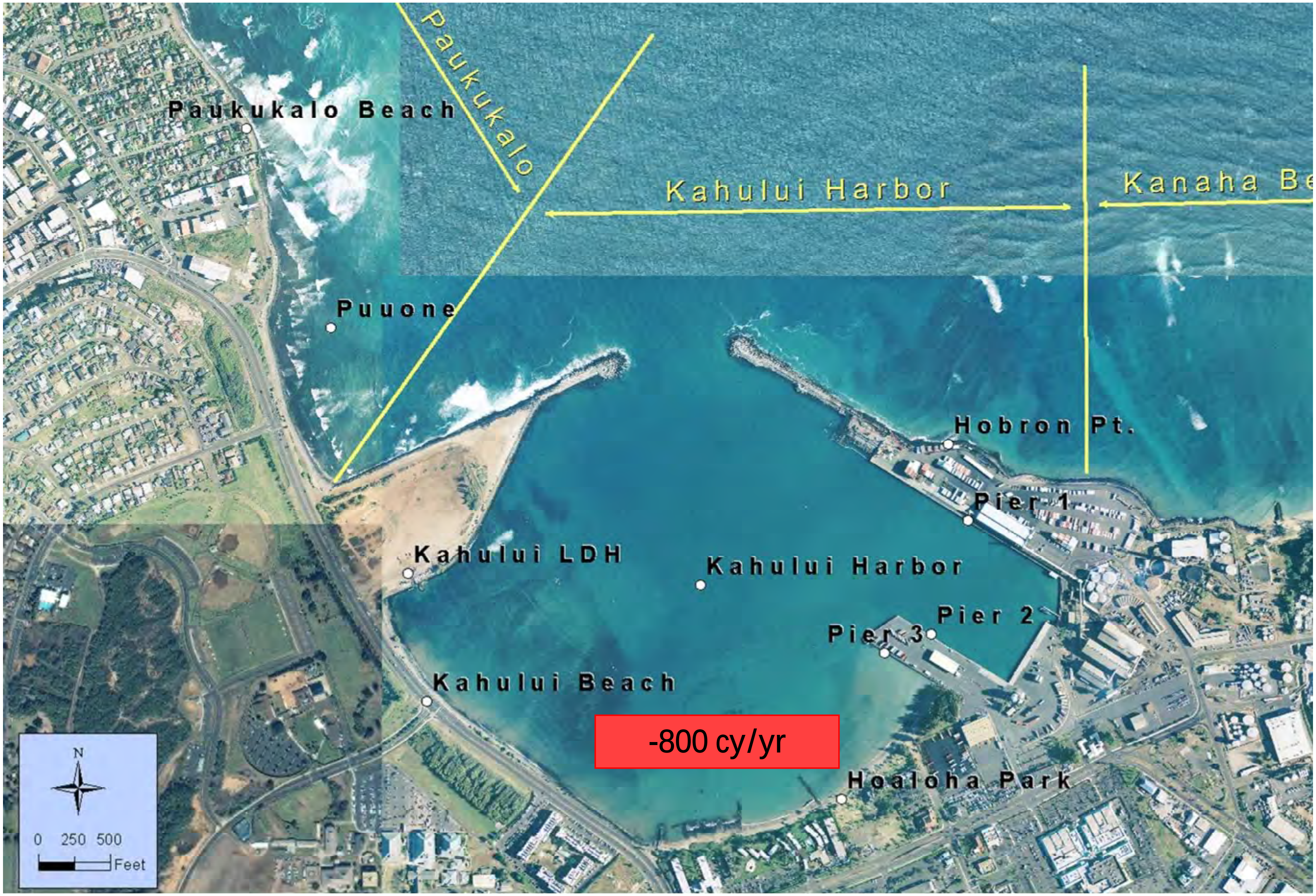


Figure 53. Beach Volume Change Rate for Kahului Harbor Littoral Cell

Figure 54. Beach Volume Change Rate for Kanaha Littoral Cell

Figure 55. Beach Volume Change Rate for Spreckelsville Littoral Cell

Figure 56. Beach Volume Change Rate for Baldwin Park Littoral Cell

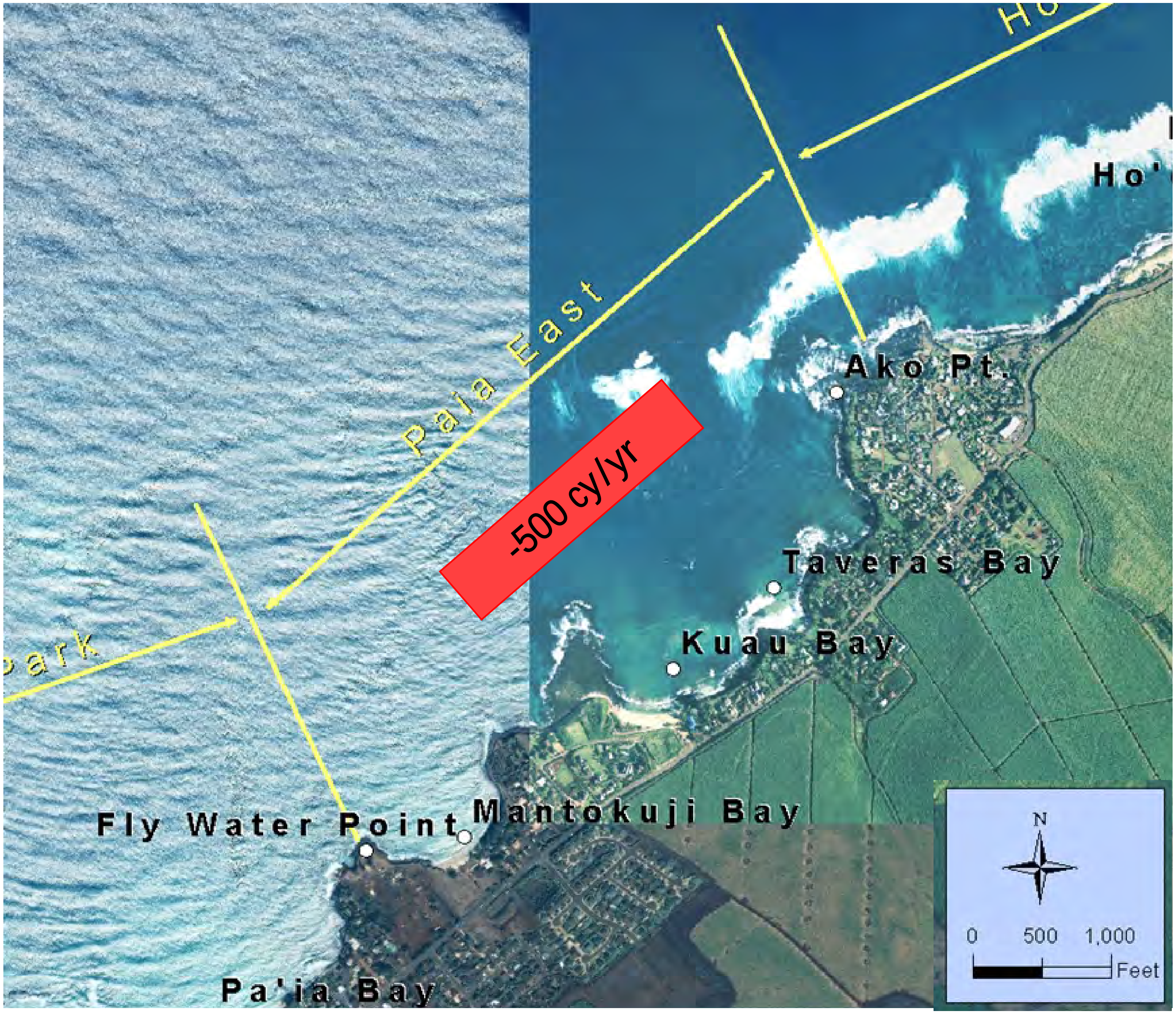


Figure 57. Beach Volume Change Rate for Paia East Littoral Cell

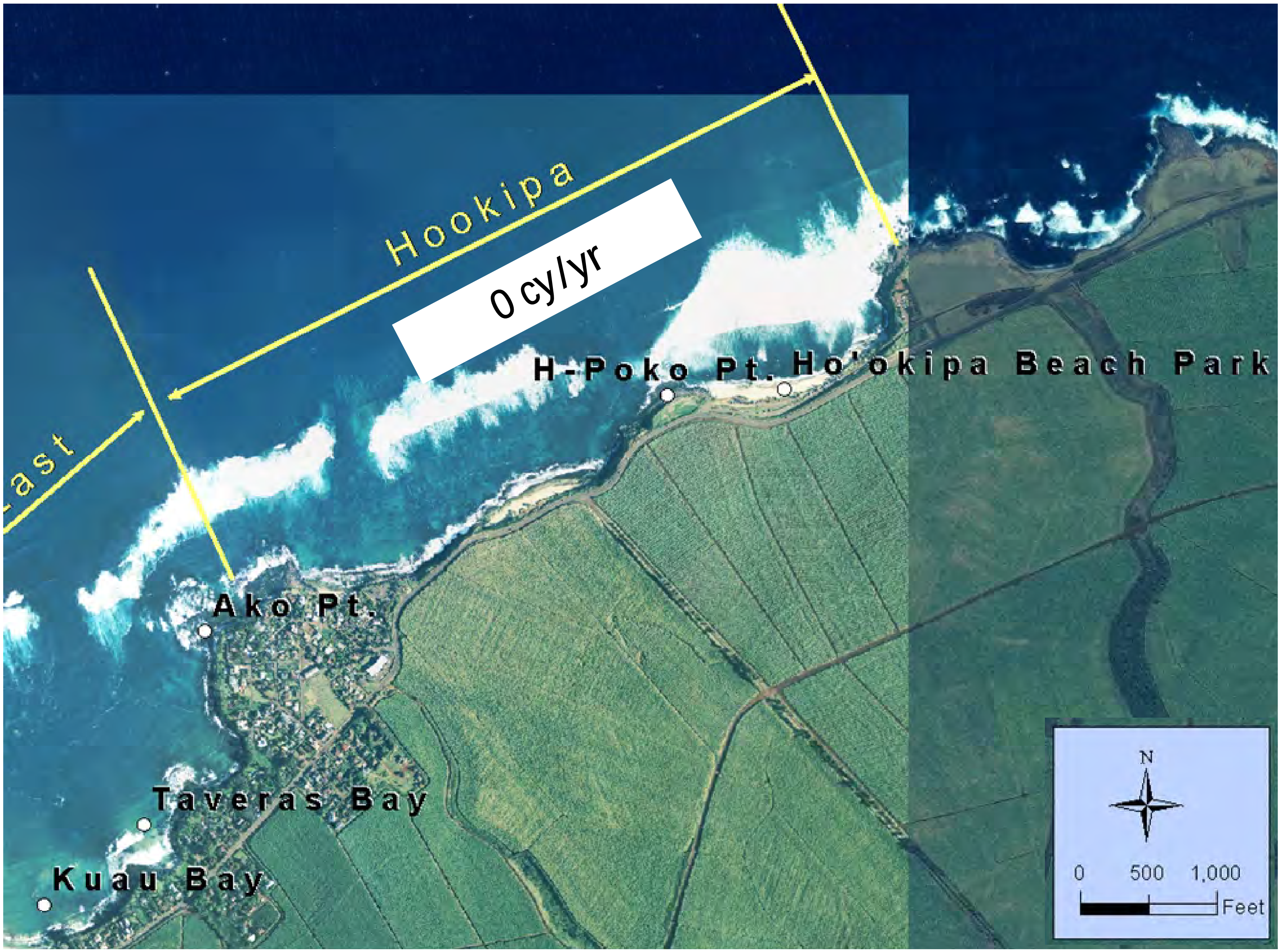


Figure 58. Beach Volume Change Rate for Hookipa Littoral Cell

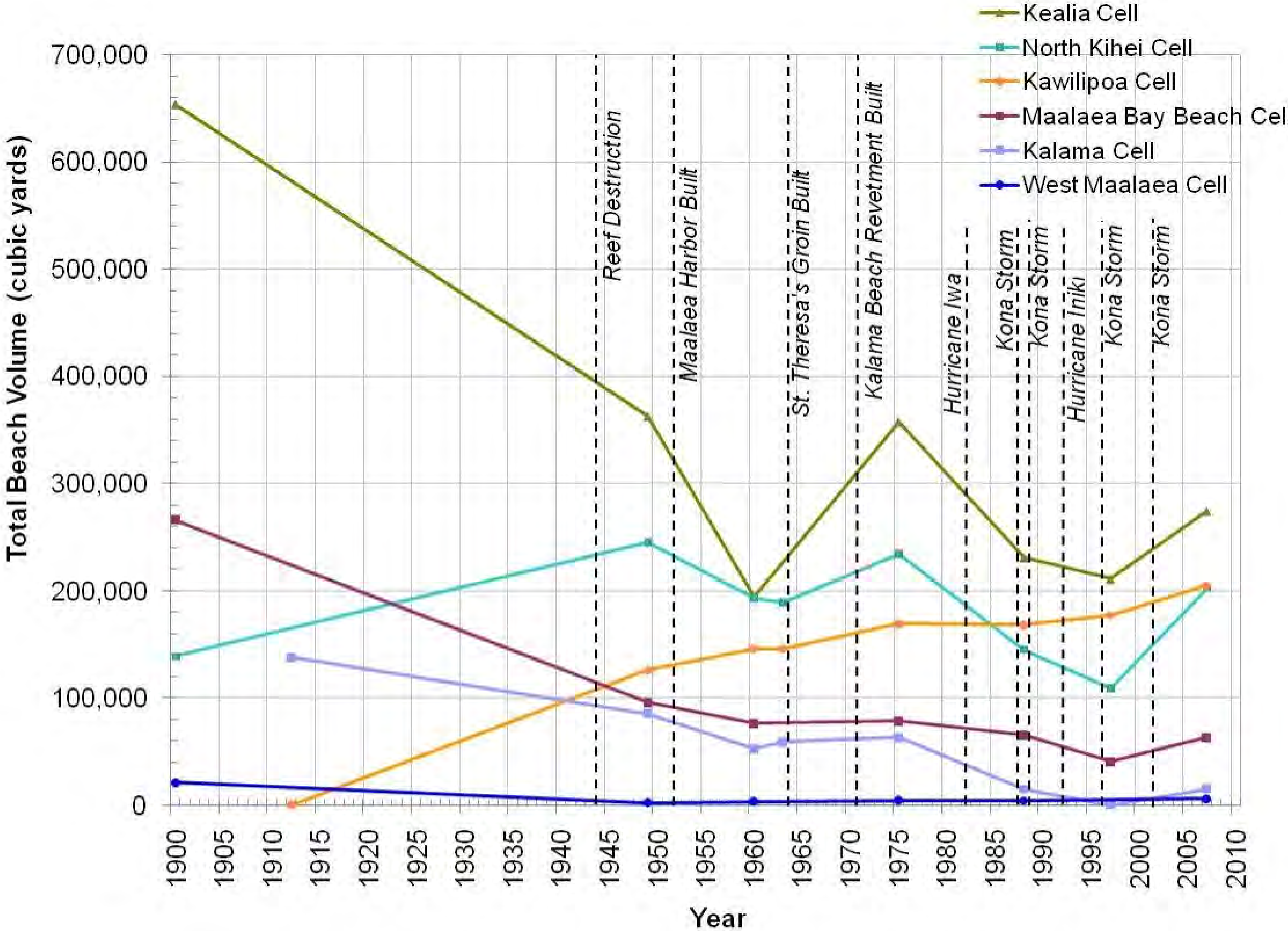


Figure 59. Historical Beach Volumes of Kihei Region Littoral Cells

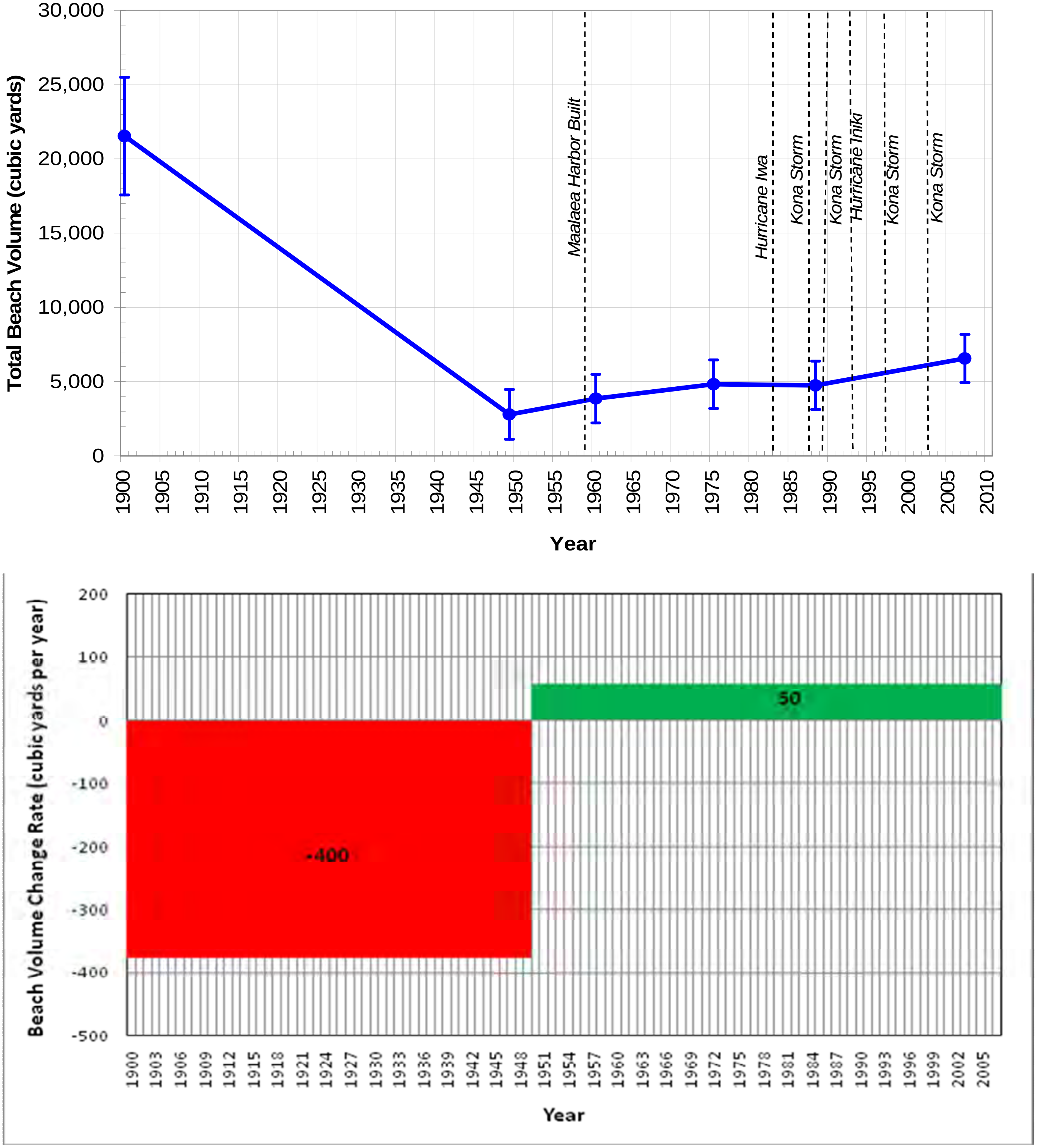
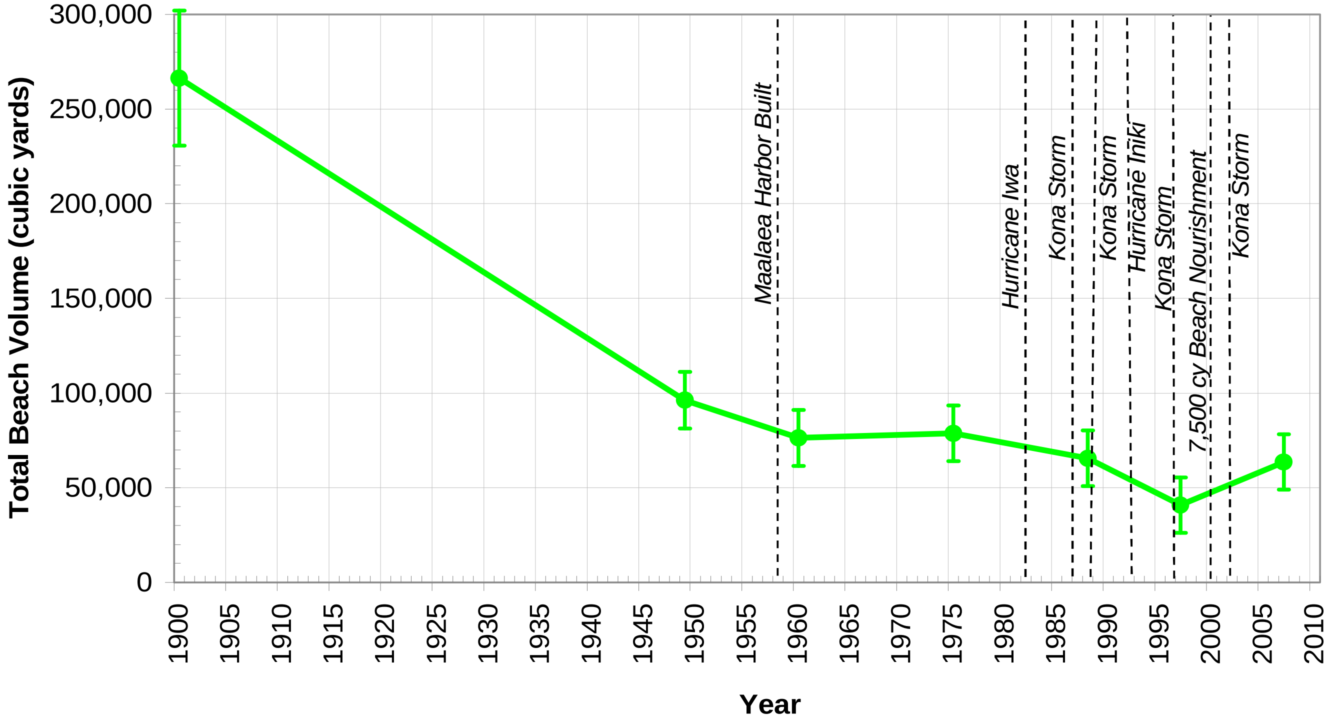


Figure 60. Historical Beach Volumes / Change Rates for West Maalaea Littoral Cell



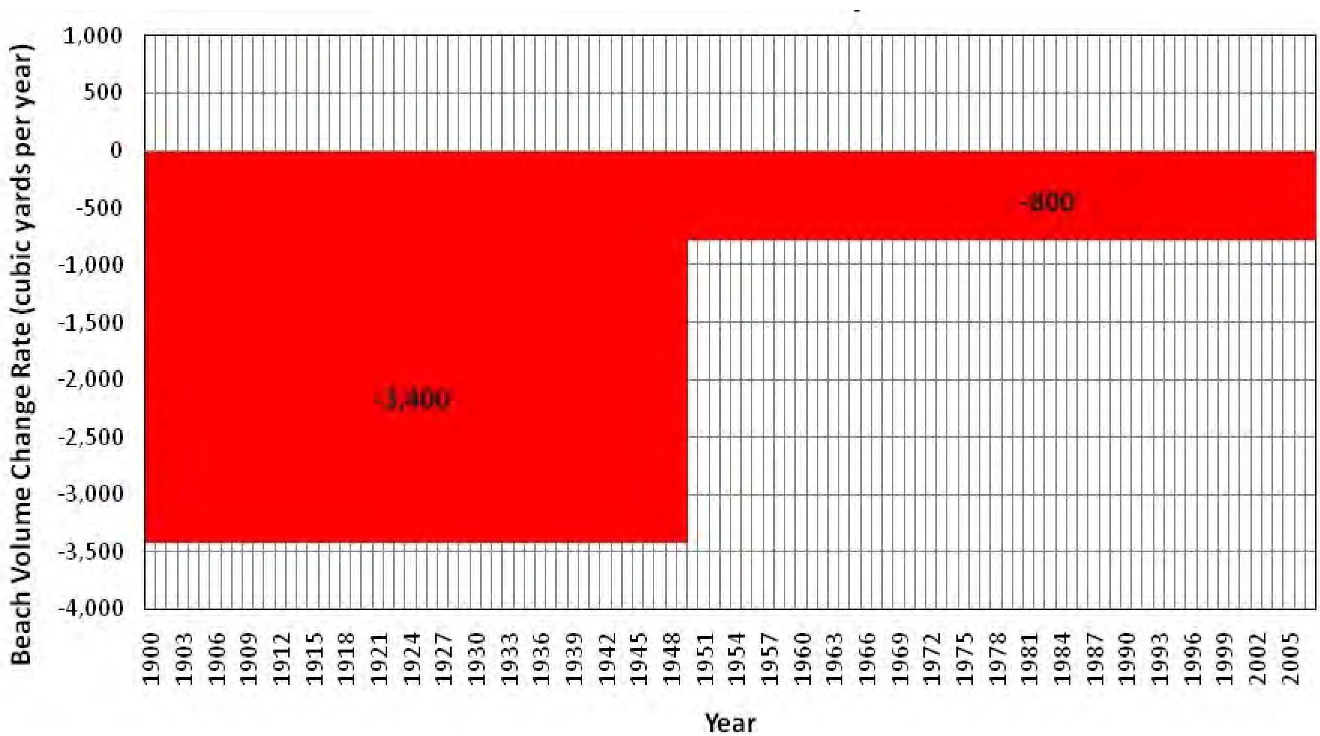


Figure 61. Historical Beach Volumes / Change Rates for Maalaea Bay Beach Littoral Cell

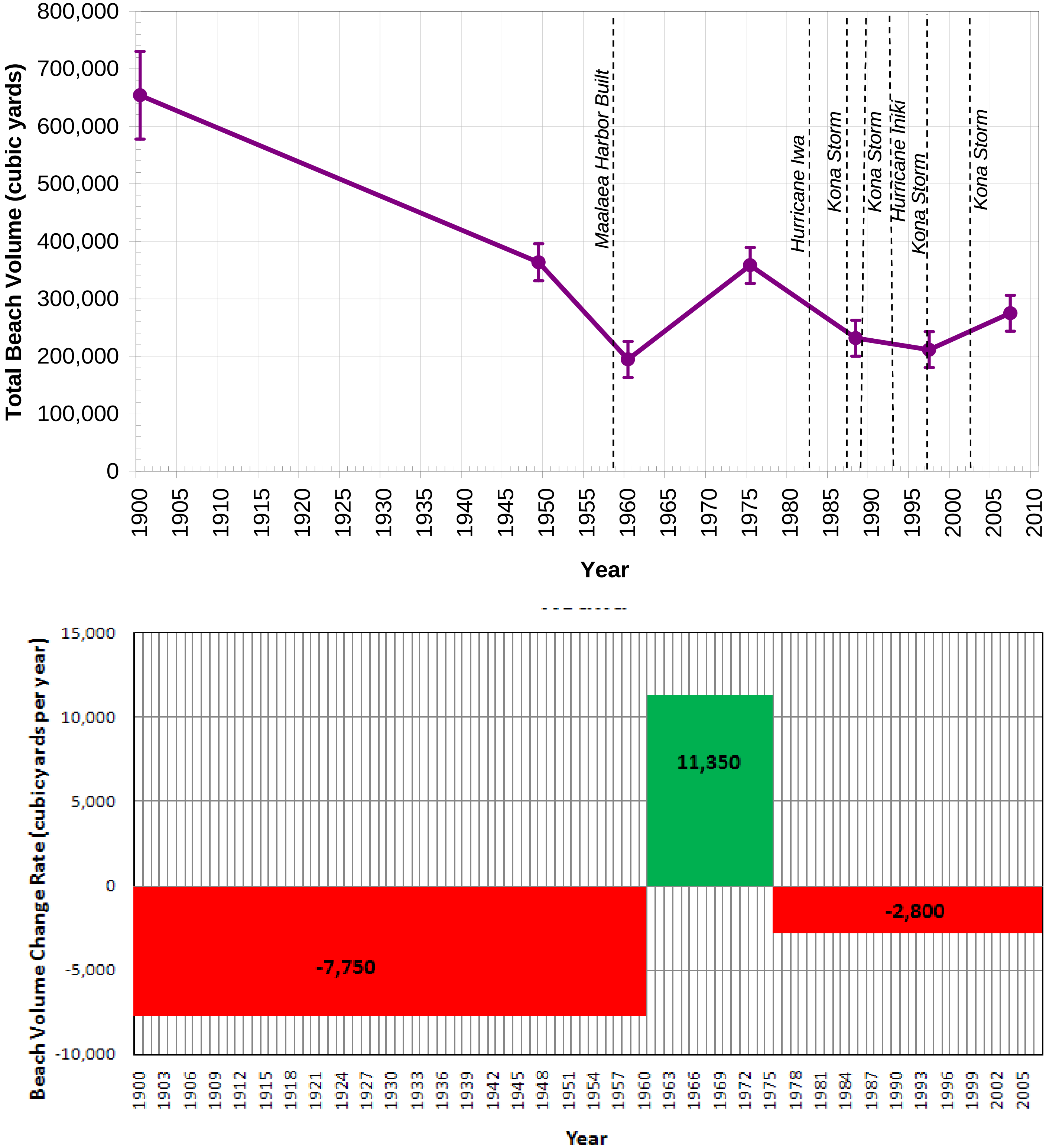
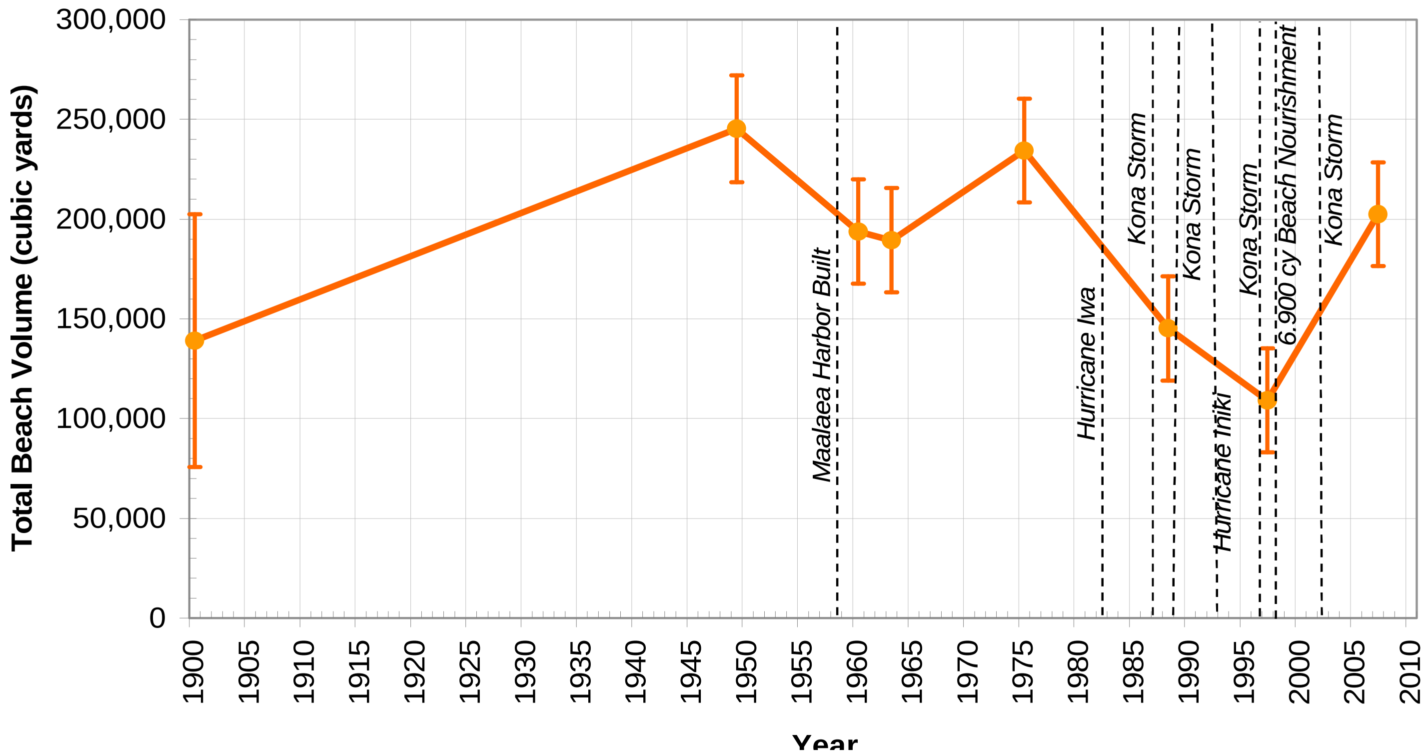


Figure 62. Historical Beach Volumes / Change Rates for Kealia Littoral Cell



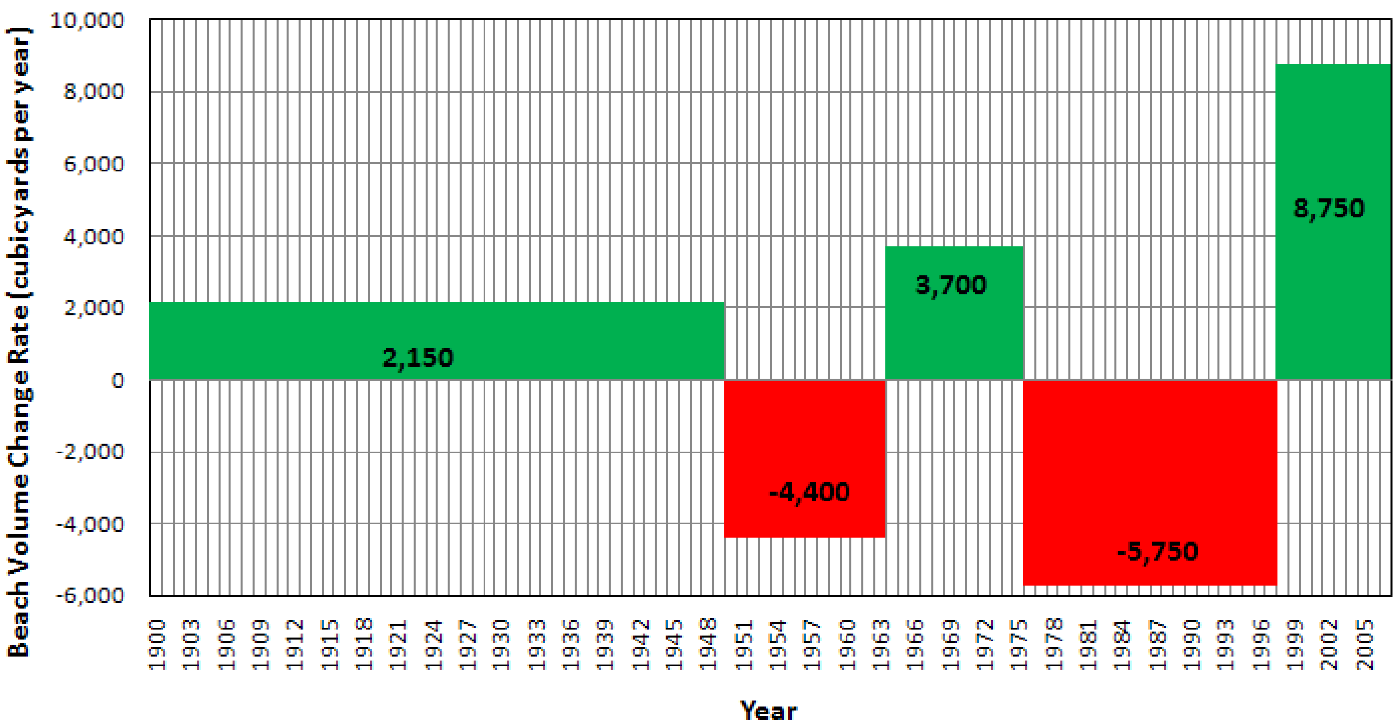


Figure 63. Historical Beach Volumes / Change Rates for North Kihei Littoral Cell

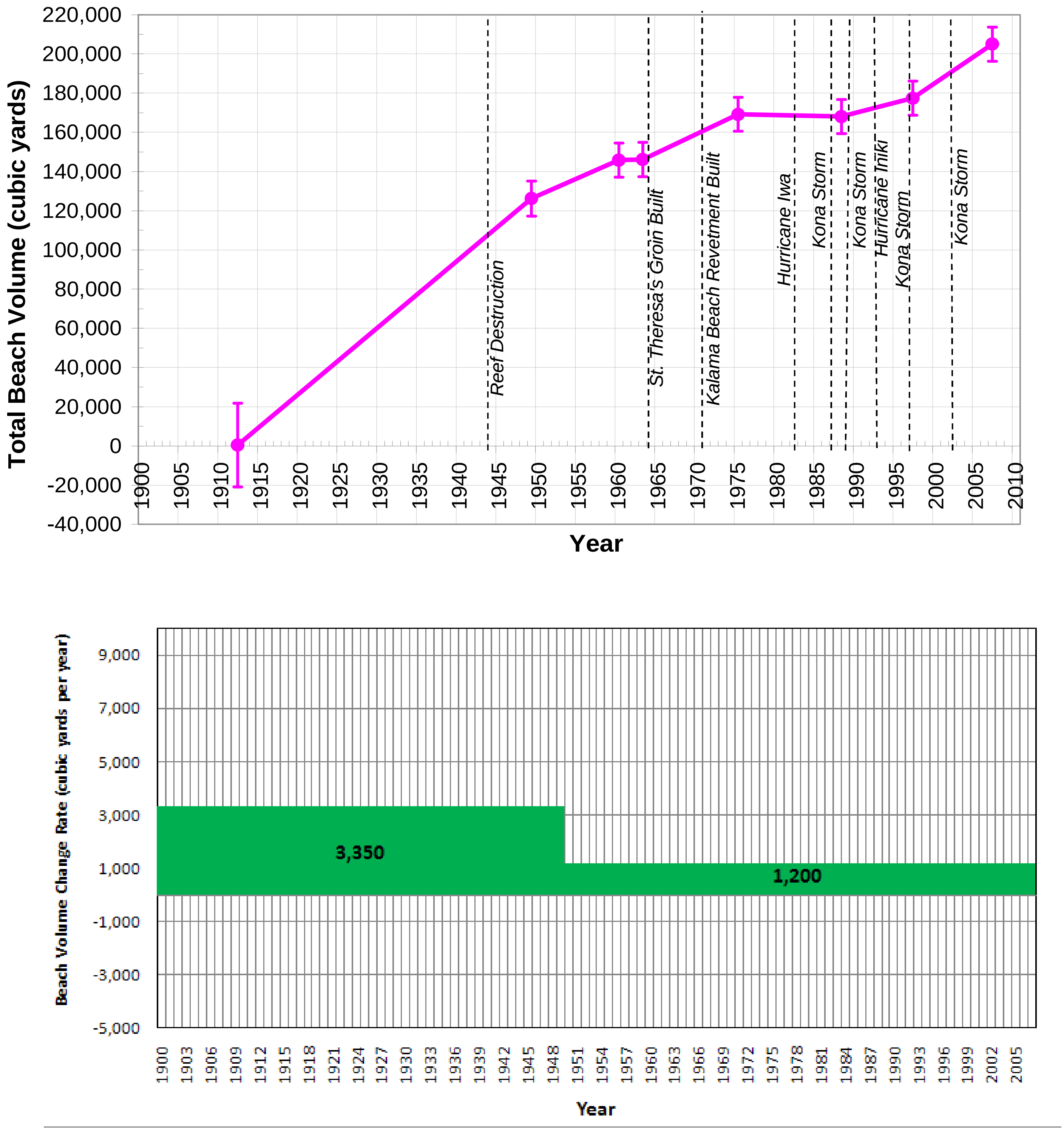


Figure 64. Historical Beach Volumes / Change Rates for Kawililipoa Littoral Cell

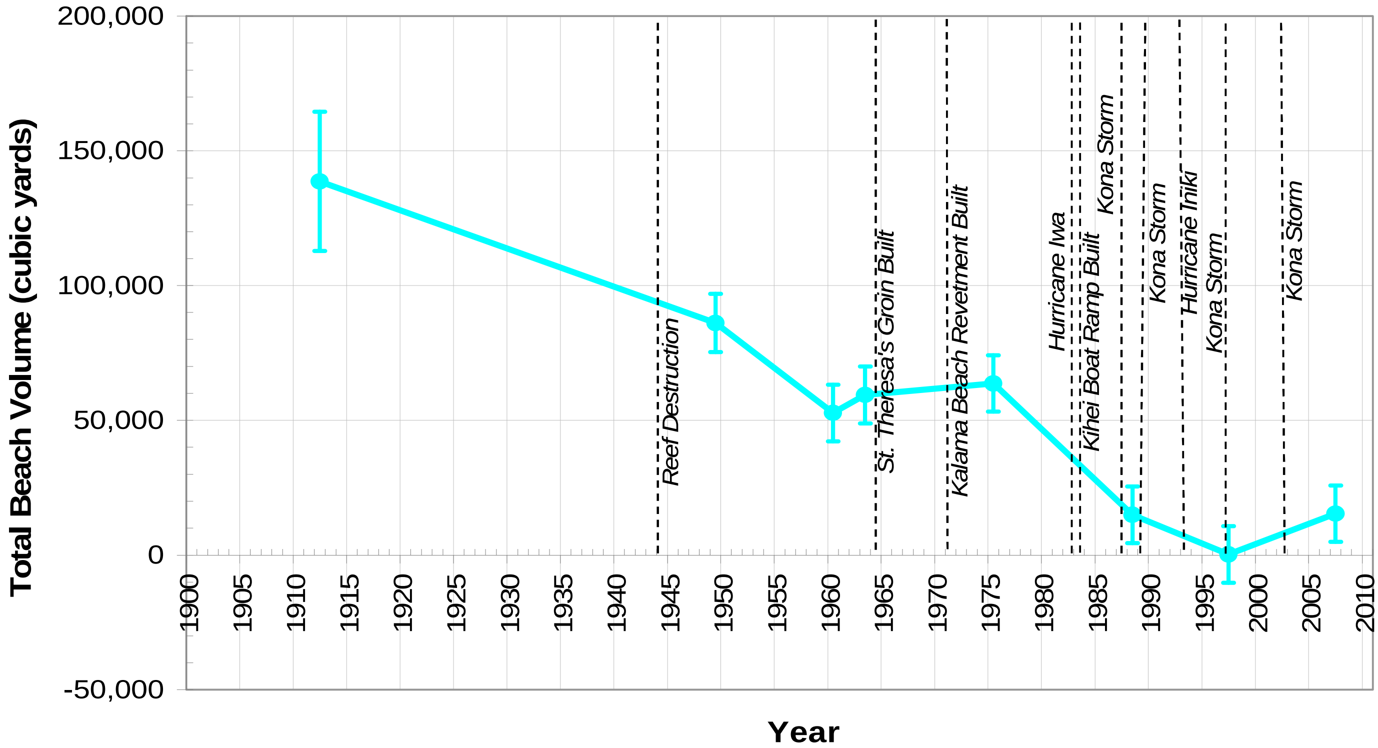


Figure 65. Historical Beach Volumes / Change Rates for Kalama Littoral Cell

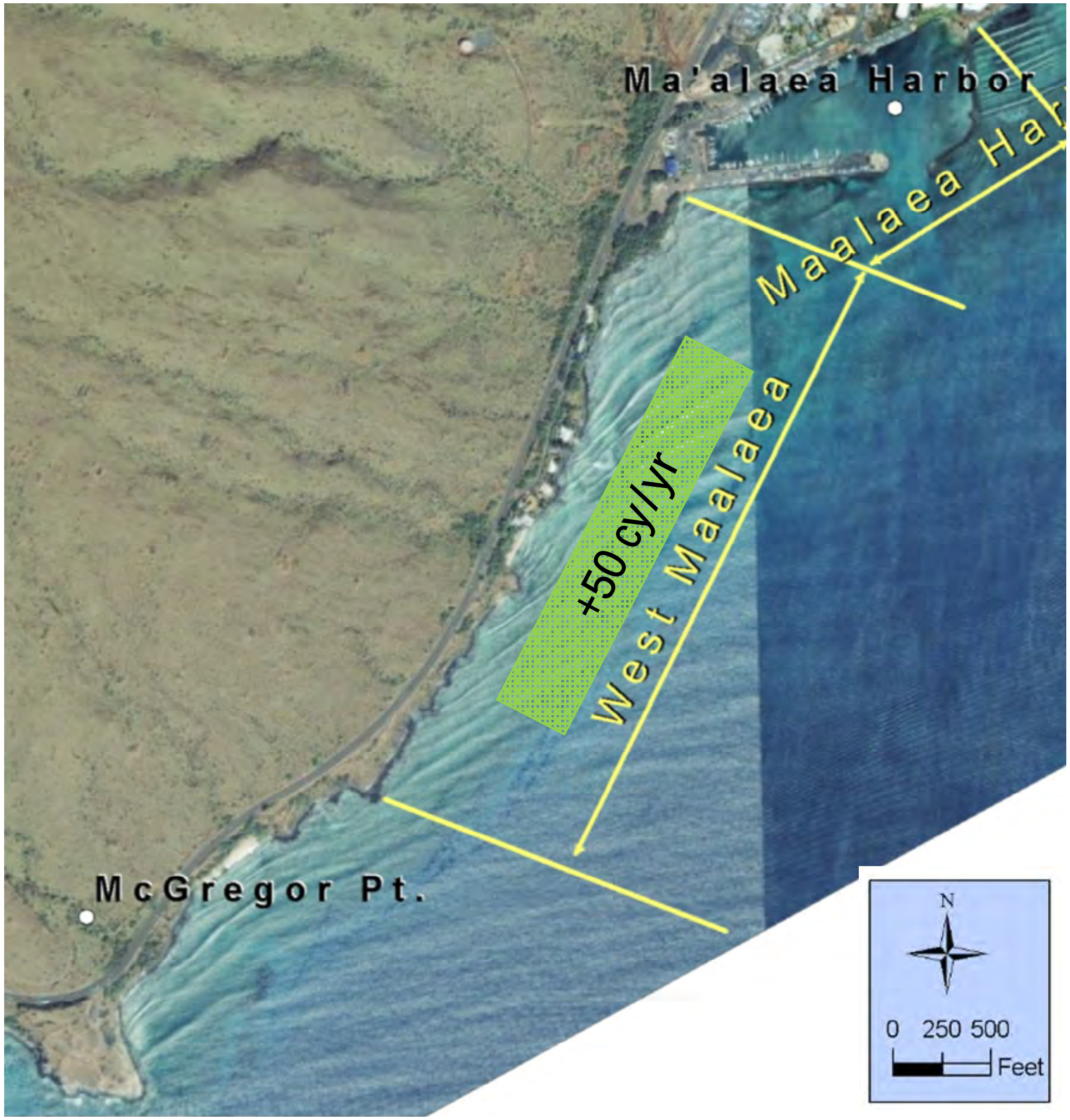


Figure 66. Beach Volume Change Rate for West Maalaea Littoral Cell

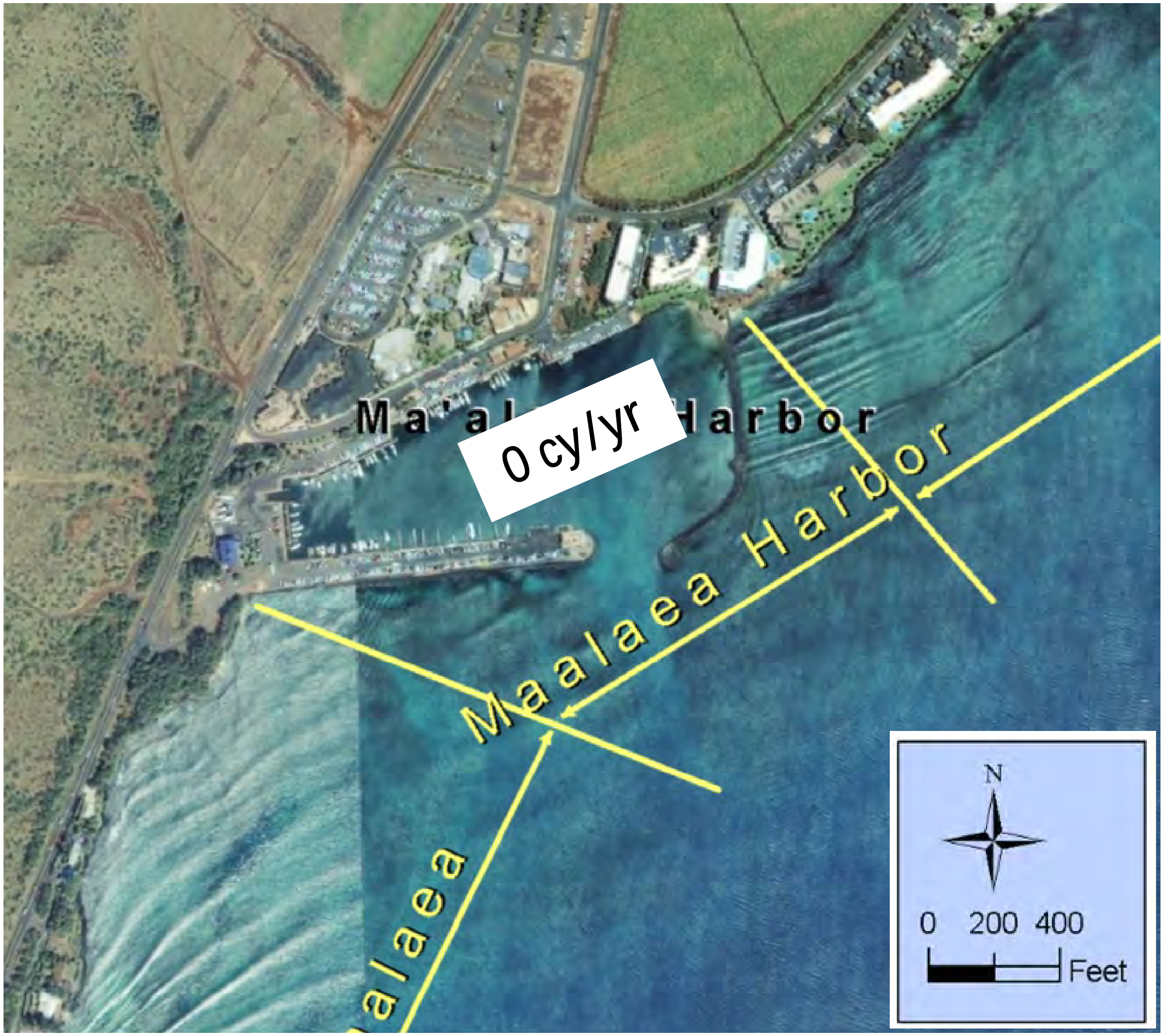


Figure 67. Beach Volume Change Rate for Maalaea Harbor Littoral Cell

Figure 68. Beach Volume Change Rate for Maalaea Bay Beach Littoral Cell

Figure 69. Beach Volume Change Rate for Kealia Littoral Cell

Figure 70. Beach Volume Change Rate for North Kihei Littoral Cell

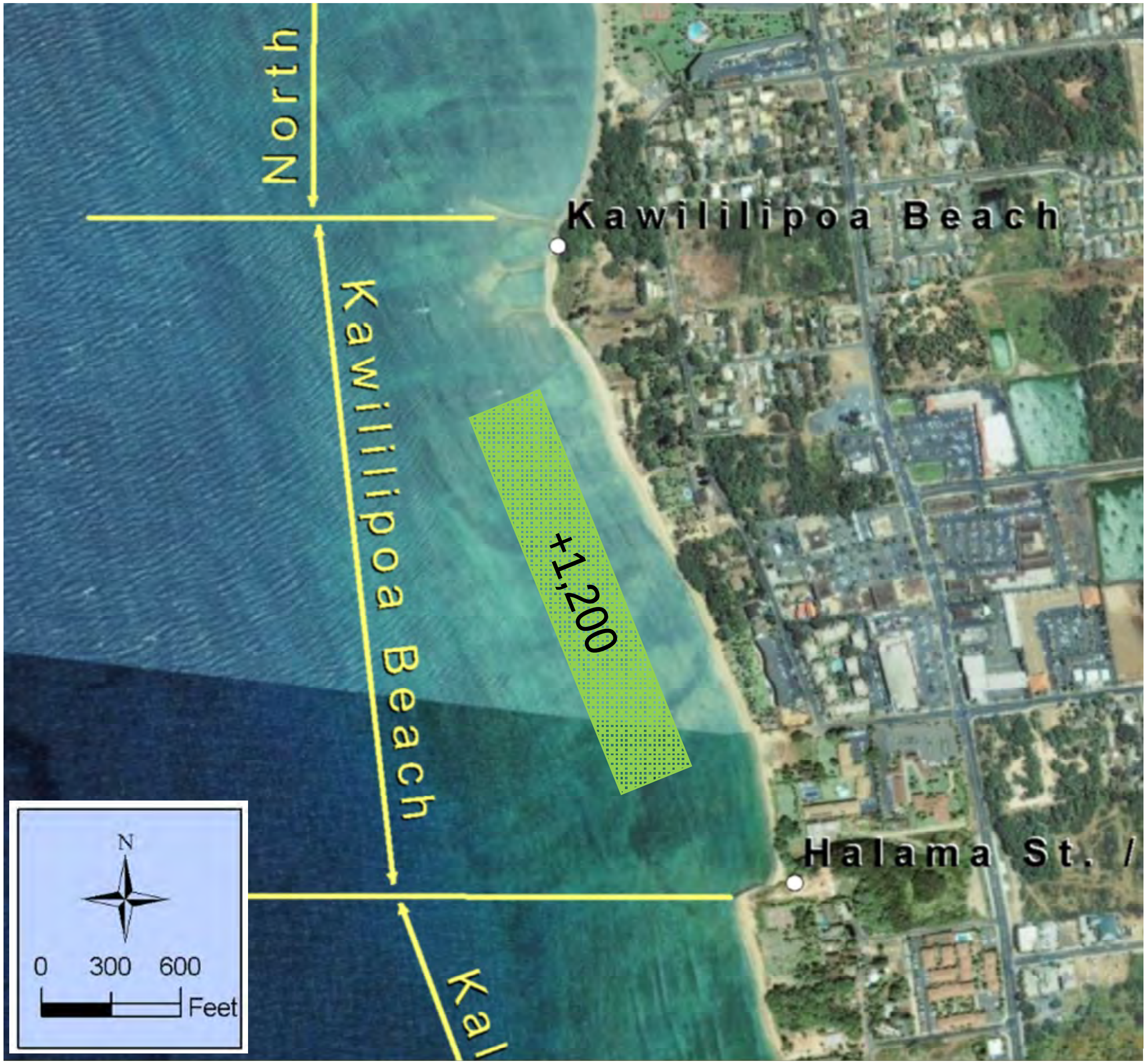


Figure 71. Beach Volume Change Rate for Kawililipoa Littoral Cell

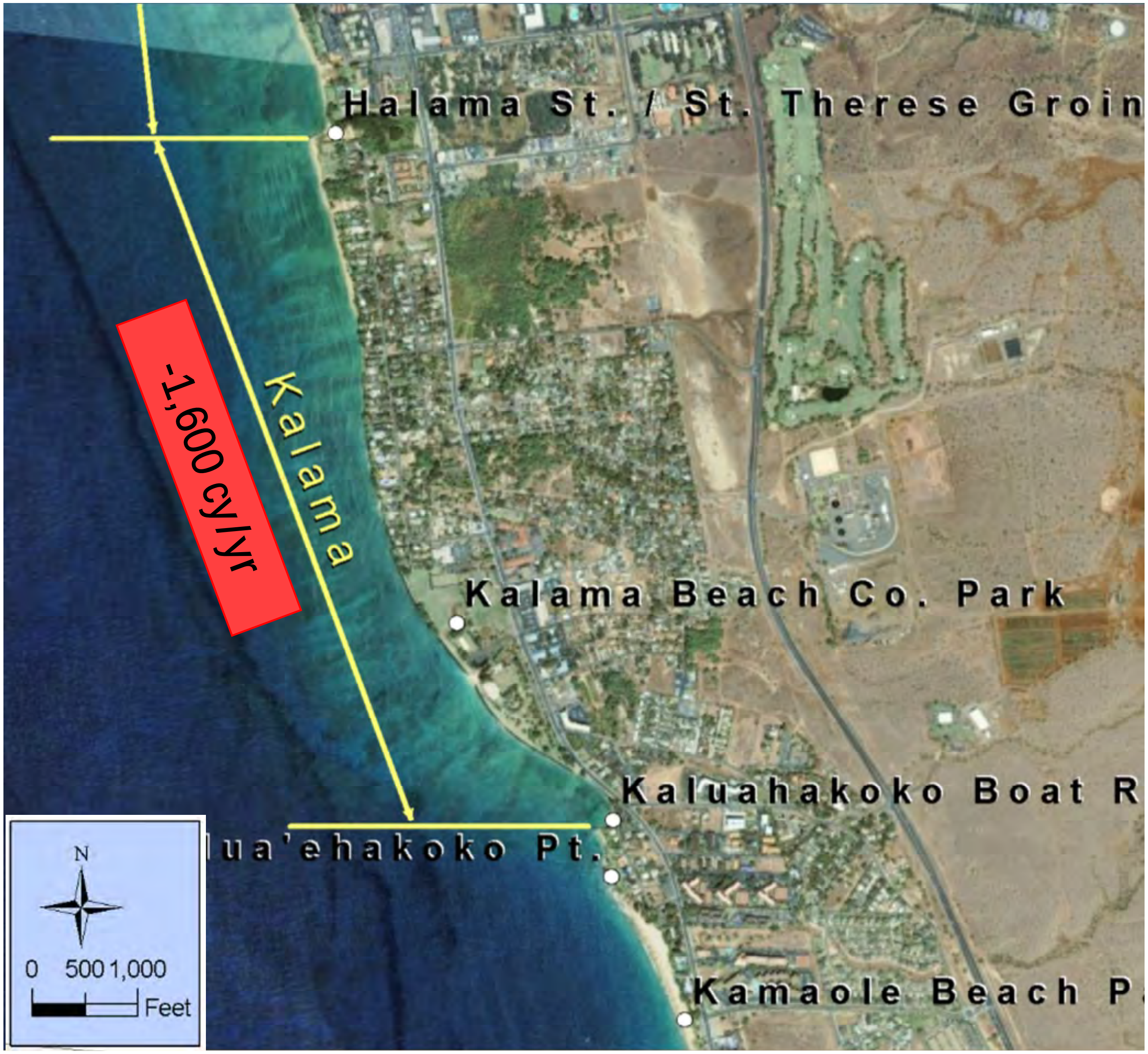


Figure 72. Beach Volume Change Rate for Kalama Littoral Cell

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 Kahului Region littoral cells (listed from west to east):

- The **Paukukalo** cell, to the west of Kahului Harbor, experienced erosion from 1912 to 1960, similar to the other cells in the region, and then was relatively stable, but not accreting, after that time. The slowing of the erosion rate, but lack of accretion is possibly related to construction of Kahului Harbor coupled with a decreased input of sediment from Iao Stream (from channelization of the stream banks). Development of sediment transport direction (potential future task) would provide further insight into this.
- Following construction of the present-day configuration of **Kahului Harbor**, this cell has a clear erosional trend probably due to the effects of winter storm waves pushing sediment into the harbor basin and then that material being dredged and then the shoreline further eroding from over-steep (non-equilibrium) slopes caused by the dredge cuts. As noted previously, several dredge cycles have occurred in Kahului Harbor and the dredge material is disposed offshore at an EPA designated ocean disposal site, i.e. disposed beyond the littoral zone.
- The most significant historic beach volume losses were in the **Kanaha** littoral cell, specifically the western section near the Wastewater Reclamation Facility (WWRF), and in the **Baldwin Park** littoral cell. Whereas the most recent Baldwin Park erosion rate has decreased significantly since approximately 1975, the Kanaha cell erosion rate has increased significantly. The Kanaha loss in the period from 1975 to 1987 was possibly associated with Hurricane Iwa or the construction of the revetment fronting the WWRF. Figure 73 indicates the Kanaha cell erosion since 1975 is primarily in the shoreline reach west of Kaa (“west subcell”), which is the beach area fronting the WWRF.
- The **Sprecklesville** and **Baldwin Park** cells (adjacent to each other) experience very similar patterns. It is interesting to note the accretion of sand in these cells from August 1987 to March 1988. This accretion from a summer profile to winter profile is not typical for this area.
- Almost all of the cells within the Kahului region experienced relatively significant erosion during the time period prior to approximately 1987. This is consistent with impacts from the historic sand mining in the area, which concluded in the 1960-1975 timeframe. It has been hypothesized that the removal of this sand resulted in an erosional wave that proceeded down coast from the lime kiln site (Baldwin Park littoral cell) towards Kahului Harbor. The Kanaha littoral cell seems to still be experiencing this erosional wave. Since 1987, some of the other beaches have been relatively stable (lower erosion rates), but this could be simply from a lower volume of sand now on the beaches.

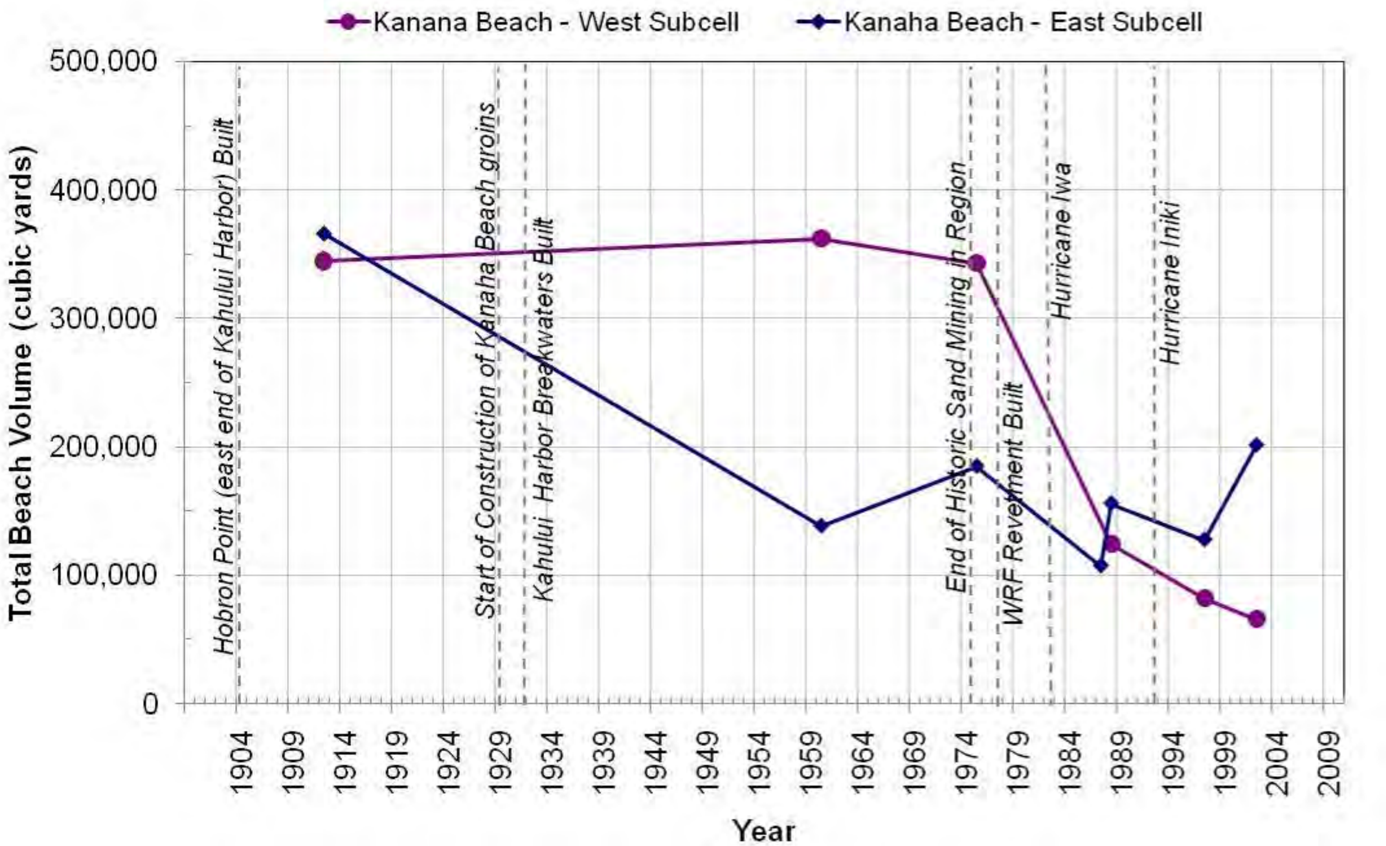


Figure 73. Historical Beach Volumes for West and East Sections of Kanaha Littoral Cell

- It is also interesting to compare these long-term average change rates with volume changes due to only seasonal fluctuation. Based on the median seasonal fluctuation calculated by University of Hawaii (2010) and assuming this median fluctuation occurred along the entire length of beach, the potential seasonal volume fluctuations for the Kahului region's beaches are up to 49,000 cy (for the Kanaha littoral cell), i.e. the seasonal variations are significantly higher than the long-term average change rates. This is consistent with the M&N (2008) study of the beach fronting the Walukui-Kahului WWRF.

Results for the Kihei Region littoral cells (listed from west to east) indicate the following:

- The **West Maalaea** cell has experienced erosion of its already small sandy beach.
- The **Maalaea Bay Beach** cell had a significant erosion period in the first half of the 1900s, and has continued to erode, but at a much lower rate. Development of sediment transport direction (potential future task) would provide further insight into this.
- Since construction of Maalaea Harbor, the **Maalaea Bay Beach**, **Kealia, and North Kihei** cells have experienced very similar long-term cyclical

erosional/accretion pattern as seen in Figure 74. It is also interesting to note that these three cells experienced erosion during the time periods of the two hurricane events.

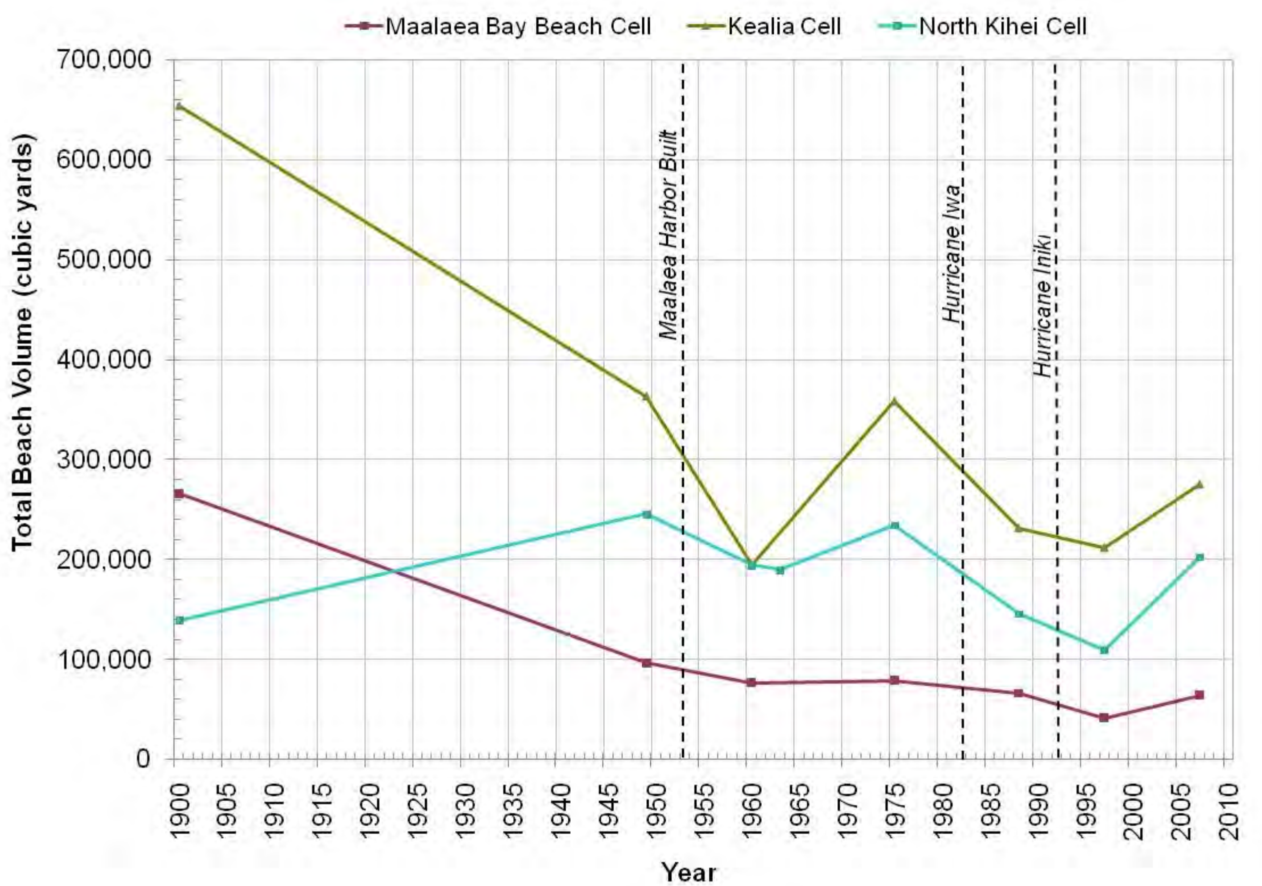


Figure 74. Historical Beach Volumes for Littoral Cells Along North Tip of Maalaea Bay

- It is interesting to note that the **Kawililipoa** cell accreted when the **Kalama** cell (to the south) was eroding. This is possibly an indication of a dominant sand transport direction from south to north, and a loss of source to the Kalama area.
  - The unique reef rubble formation (most likely an ancient Hawaiian fish pond) in the nearshore at the north end of the Kawililipoa Beach littoral cell may act as a groin and interrupt sand transport to the north, causing accretion on its downcoast side.
  - The upcoast littoral sand source to the Kalama littoral cell is likely interrupted by the old boat ramp cove area near Kaluahakoko Point, just south of Kalama Beach Park.

A further discussion of the preliminary sediment budgets for the Kahului and Kihei region littoral cells are provided in Appendices F and G, respectively.

IX. Ocean Sand Source Inventory

There are believed to be significant sources of sand offshore of the Hawaiian Islands, held in low spots and channels on the reef. 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 (two on Maui and two on Kauai) and determine their surface areas. An area on the south shore of Oahu was also previously studied. Changes in the extent of these sand bodies over time help differentiate ephemeral and stable (non-ephemeral) 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 Maui included the following:

1. **North Shore, Maui** – Kahului Harbor to Hookipa Park. For this study area, five mosaics (Kahului Harbor, Kanaha, Spreckelsville, Baldwin Park, and Kuau) were used for each year of coverage. Photomosaics from 1960 were used as the historical coverage, and mosaics from 2002 were used as the modern coverage.
2. **Kihei, Maui** – Kamaole Beach Park to Kealia Pond. Mosaics from 1949 and 1975 were analyzed, but not used for historic coverage because of overall poor visibility of the seafloor. Therefore, photomosaics from 1960 and 1997 were used as historical coverage, and a 2007 mosaic was used as the modern coverage.

The sand source areas on Kauai and Oahu are also potential sources for the even 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:

- 7.8 acres (31,656 m^2) of stable sand is stored on the reef flat off of the north shore of Maui (Figure 75).
- 13.8 acres (55,821 m^2) of stable sand is stored on the reef flat off the coast of Kihei, Maui (Figure 76), serving as potential resource for beach replenishment.

The complete University of Hawaii study report is provided in Appendix H.

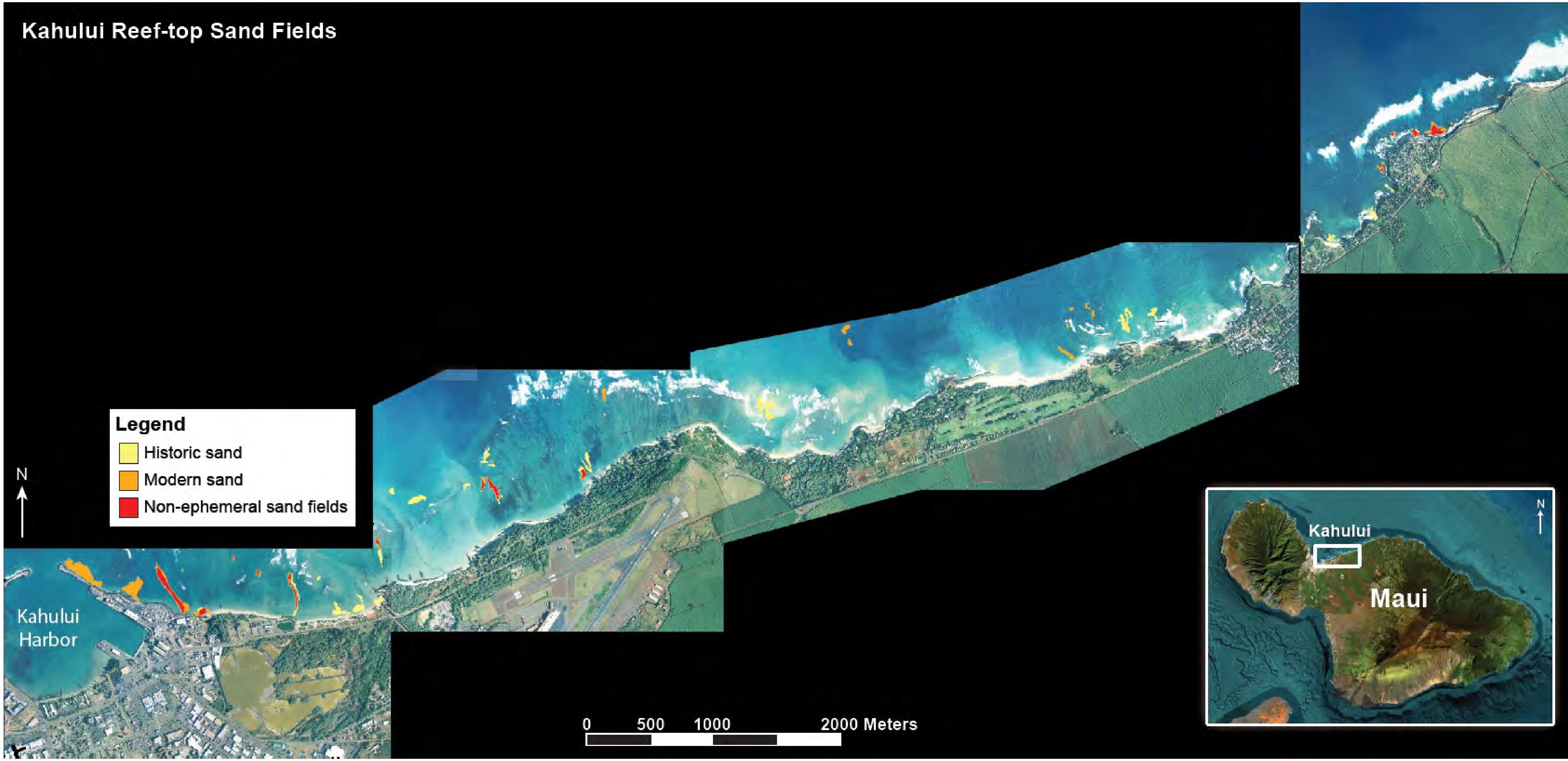


Figure 75. Reef-top Sand Fields Located at Kahului (North Shore), Maui

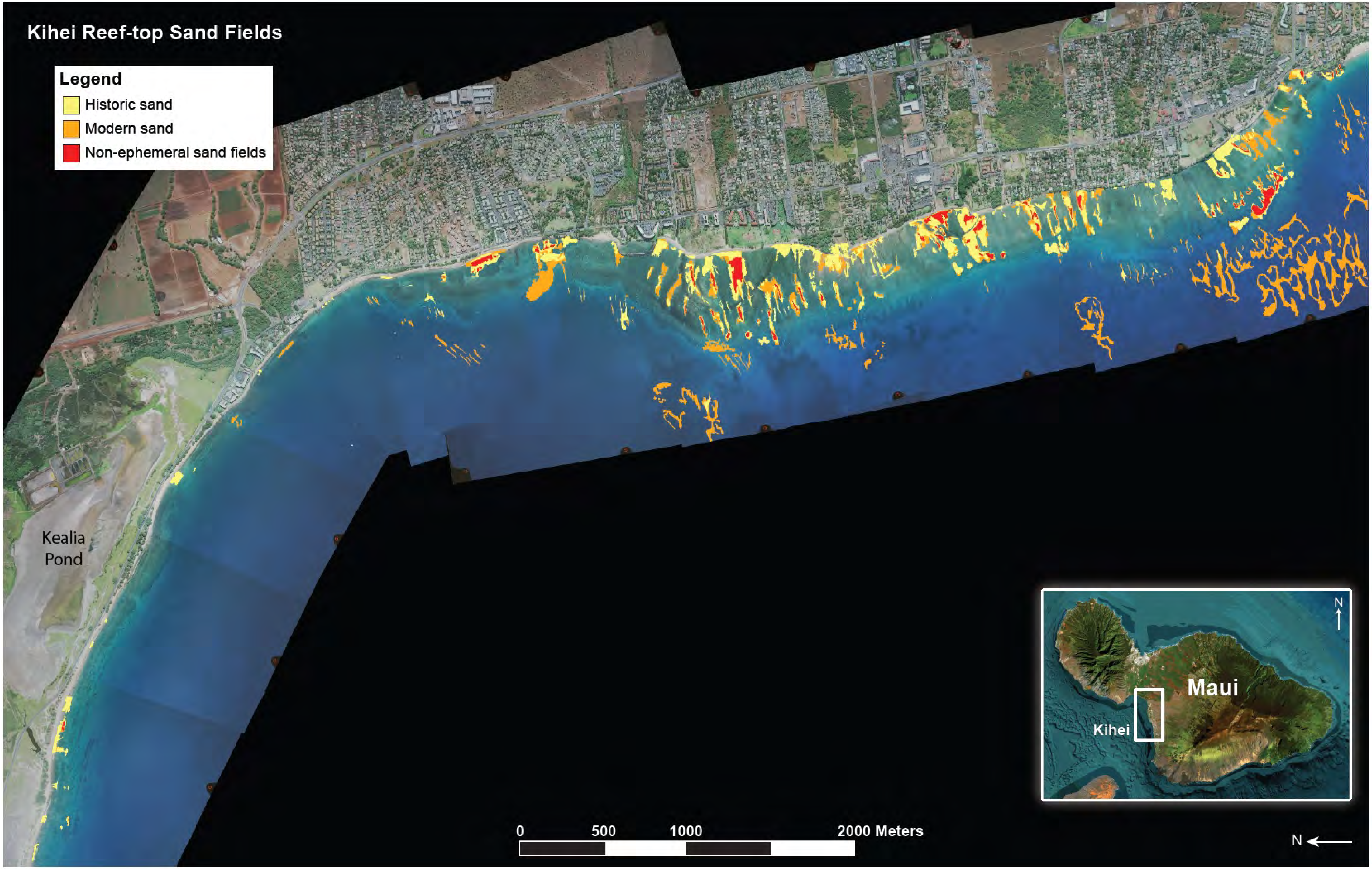


Figure 76. Reef-top Sand Fields Located at Kihei, Maui

Another study was completed by NOAA (2007) of the geomorphology and biology of the nearshore areas around Maui. This study indicated two potential sand borrow areas near the Kahului Harbor as shown in Figure 77. The biological coverage maps indicate that these sites have very limited coral cover, so they may be good candidates as borrow areas from a biological impact aspect.

To further investigate this potential source for sand for a Wailuku Kahului Wastewater Reclamation Facility shore protection project (M&N 2008), M&N subcontracted Sea Engineering, Inc. to perform a sub-bottom geophysical survey with grab samples offshore of the Kahului Harbor. The survey was performed in May 2008, covering an area of approximately 5.5 square miles (3,500 acres) and collecting eight grab samples over the course of two days. The results indicate that there is a large deposit of sand, 10-20 feet deep over much of the sampled area. Figure 78 presents the sampling area, the depths of the sand deposits, and the locations of the grab samples.

Of the nine samples collected, two (Samples 5 and 8) had both good color and grain size for use as beach-quality sand. Figure 79 presents a photo of the sample from location 8 (D50 ~ 0.50mm).

Figure 79. Kahului Bay Grab Sample 8 Sand

The entire Sea Engineering (2008) study report is provided in Appendix I.

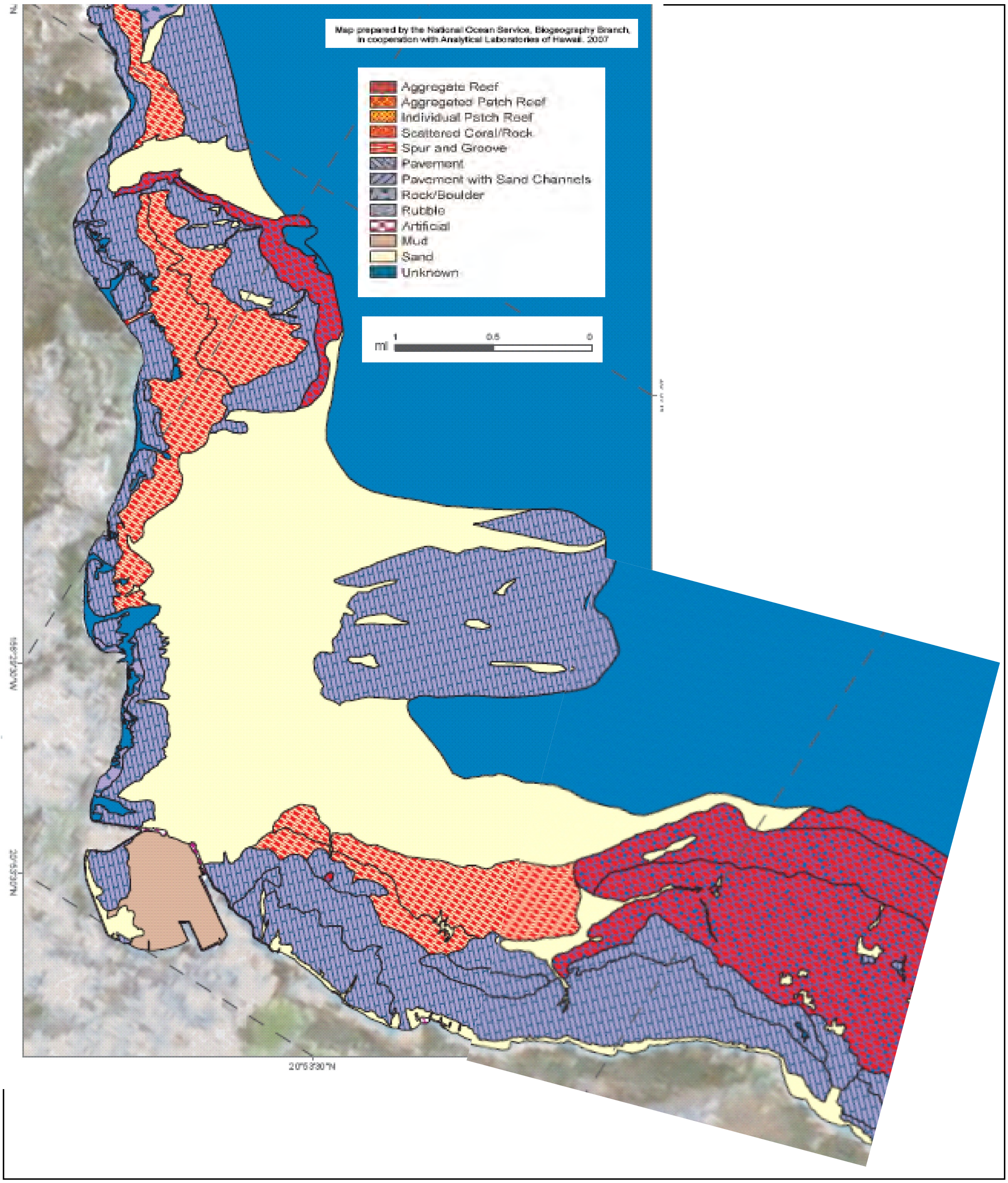


Figure 77. Nearshore Geomorphology near Kahului Harbor (NOAA 2007)

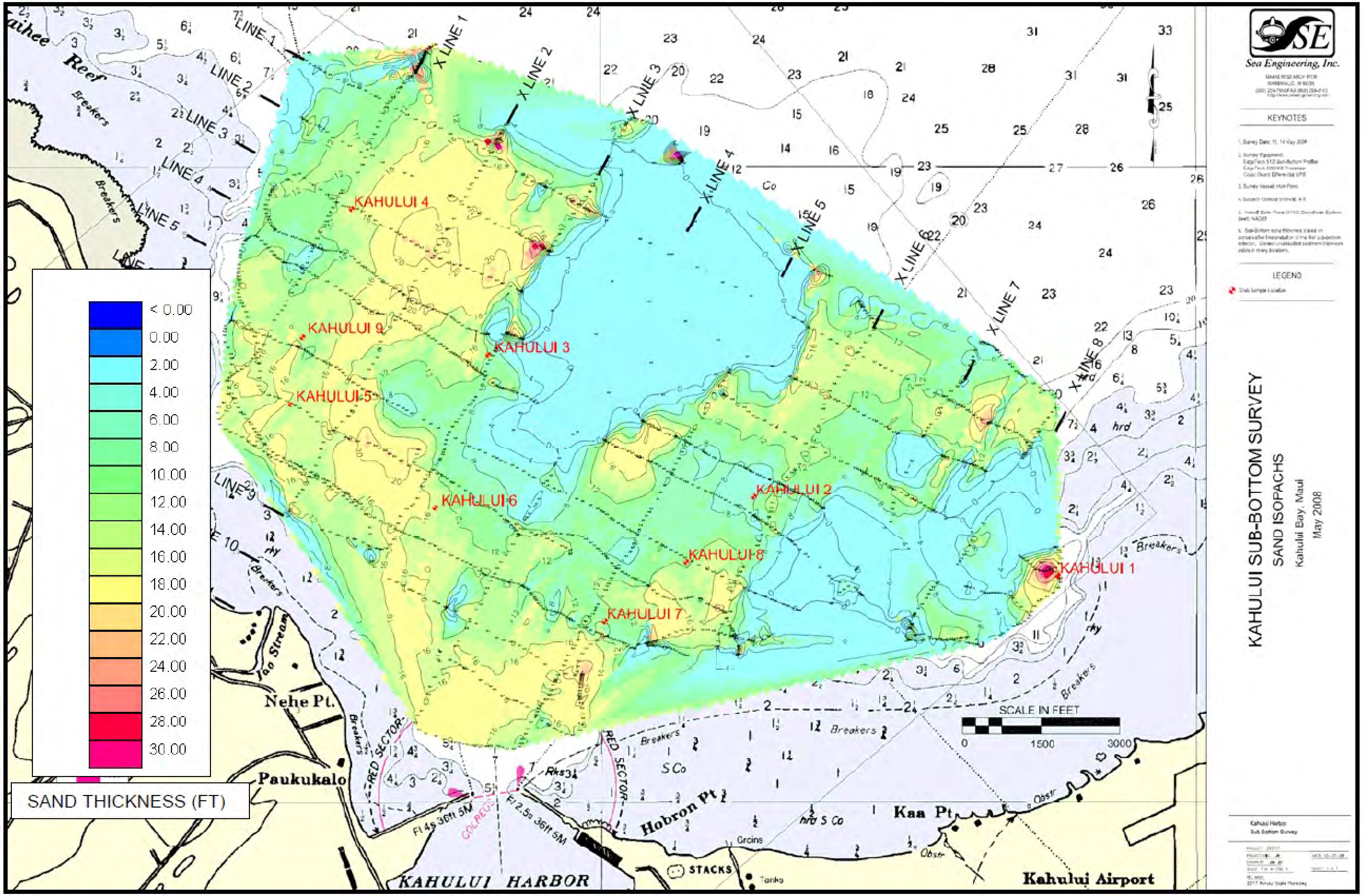


Figure 78. Kahului Bay Sand Thicknesses and Grab Sample Locations (Sea Engineering 2008)

X. Maui Stream Sediment Management

There are numerous rivers/streams/gulches within the two Maui regions. As discussed previously, in the Kihei region, dune breaching to drain mauka streams has and continues to cause a detrimental impact on the Kihei shoreline (M&N 2000). Measures should be taken to mitigate these impacts. The South Maui and West Maui Watershed Projects have recently been initiated and may provide opportunities to partner with RSM to address sediment related issues including stream sediment management. 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 study task.

XI. Potential RSM Projects

A. Wailuku Kahului Wastewater Reclamation Facility Shore Protection Project

The potential project area is on the shoreline fronting the Wailuku Kahului Wastewater Reclamation Facility (WWRF). The County of Maui owns and operates the WWRF. As discussed previously in Section IV, the USACE constructed a 450-foot rock revetment seaward of the treatment pond in 1979.

The permanent removal (historical mining) of sand from the littoral system has resulted in a deficit in the sediment budget and erosion over the length of the area from Baldwin Beach to Kahului Harbor. While the erosion rates of other beaches within this reach have slowed, the rate of shoreline erosion at the WWRF is still significant and must be considered for the safety of the wastewater facility. As part of the long-term shore protection strategy for this area, two potential beach nourishment alternatives were investigated: one for a 3,800-ft long beach replenishment and one for a 2,400-ft long replenishment (M&N 2008).

The project reach for the first alternative extends from approximately the WWRF western property boundary to approximately 100 feet east of the stream channel adjacent to Kaa, a distance of approximately 3,800 feet. The purpose of nourishing the entire reach is to develop a relatively natural beach plan form. The net sediment transport is from east to west, so that over the long term the material placed near Kaa would migrate west and could decrease the amount of maintenance replenishment required for the downdrift area fronting the WWRF. In the shorter term (a few years), the initial placement of a natural beach plan would decrease loss of sand from the area fronting the WWRF to adjacent areas through diffusion. This alternative would require approximately 105,000 cubic yards of initial sand placement to create an additional 40-foot wide berm along the full 3,800-feet length of the project (this would create a beach fluctuating seasonally between 40 and 70 feet in width). The nourished beach would continue to erode as it would under natural conditions and periodic maintenance nourishments would be required for the life of the project. It is estimated that approximately 21,000 cubic yards of sand would be required every 8 years to maintain the project design width – about 2,600 cubic yards per year.

The second alternative is similar to the one described above, except that the project length is reduced to approximately 2,400 feet. The replenishment extends along the WWRF property to about 500 feet east of the existing revetment. The initial sand quantity is approximately 65,000 cubic yards. Similar to the first alternative, the replenished area would continue to erode as it would under natural conditions. Approximately 1,200 feet of this stretch of the beach have been erosional over the past decade. Assuming a slightly greater renourishment density to account for the fact that smaller beach replenishment projects typically have less success with retaining beach area over the long term, it is estimated that approximately 16,000 cubic yards of sand would be required every 8 years to maintain the project design width – about 2,000 cubic yards per year.

A sand search seaward of the Kahului Harbor breakwater indicated a very large potential source of beach-quality sand that could be dredged and used for the WWRF project, (reference Appendix I for additional information on this sand source). Dredge sediment from Kahului Harbor (discussed below) could also be a potential sand source.

B. Kahului Harbor Dredge Material Beneficial Reuse Project

Based on sediment sample testing done for the 1999 Kahului Harbor dredging project, the harbor sediment grain size is primarily sand (73% for samples along the western edge of the entrance channel and 60% for samples further from the harbor entrance and closer to Pier 2). In the past, the Kahului Harbor dredge material has been disposed offshore, but these grain size results suggest the potential to reuse dredge material for beach nourishment. A potential RSM project is to place Kahului Harbor dredge material along the Kahului Harbor shoreline, which has a current beach erosion rate of approximately 800 cy per year. The dredge material may also be appropriate and have higher potential benefit for other beach nourishment sites in the region, depending upon grain size compatibility with the other sites.

Also, removal of sediment in the potential sand source field in the area outside of Kahului Harbor could reduce the maintenance dredge cycles in Kahului Harbor by reducing the sediment that potentially is transported into the harbor through the entrance and by creating a sediment trap (sink) near the entrance.

C. Kihei Beach Hurricane and Storm Damage Reduction Project

The potential project area shoreline extends approximately five miles from the northern limit of Kalama Park to northwest of the Kealia Pond adjacent to Highway 310. Figure 80 shows the extent of the proposed project (orange boundary lines), relative to the existing USACE (Section 103) revetment along Kalama Beach Park. This area includes the North Kihei, Kawililipoa Beach, and part of the Kealia and Kalama littoral cells of this RSM study.

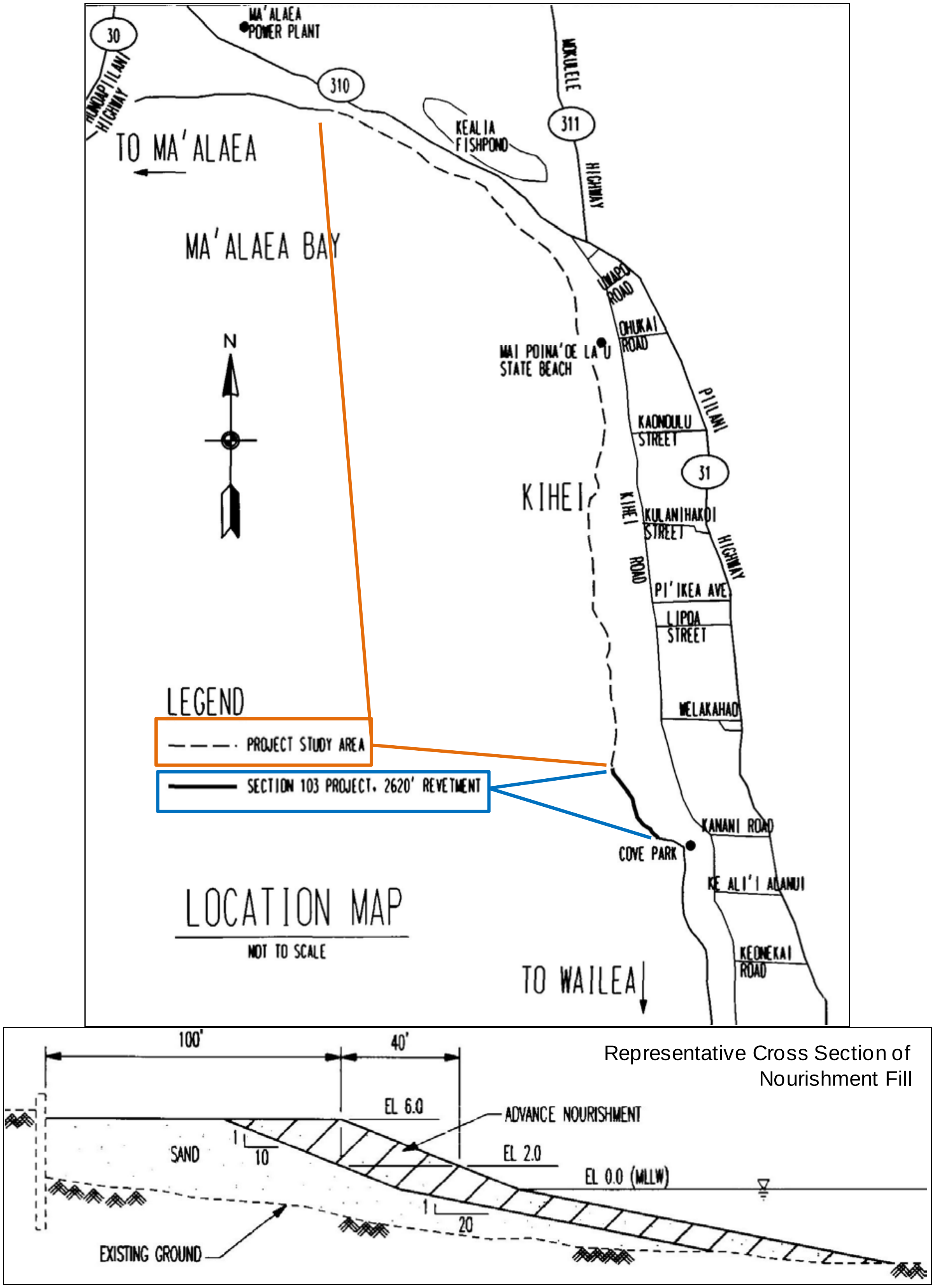


Figure 80. Kihei Beach Hurricane and Storm Damage Reduction Project

The northern 5,700 feet of the project area exhibits a high potential for the generation of hurricane and storm damage reduction benefits in the form of reduced upland development damages and travel delay benefits. The southern 4,130 feet of the study area also has the potential to produce enough primary benefits to offset life-cycle project costs (USACE, 2003).

The project would include an initial beach nourishment, as well as future renourishment. Approximately 358,000 cubic yards of beach quality sand will be required initially to establish the desired beach profile (100 foot beach width, berm elevation of +6 feet (MLLW) and a depth of closure of -4 feet (MLLW)) (USACE 2003). Once the project is in place, the shoreline will be advanced seaward in a uniform manner promoting the unobstructed movement of sand within the project area.

Future renourishment would be to place approximately 36,000 cubic yards of sand every 10 years (USACE 2003). Nourishment needs of the project will be determined as the material placed during initial construction equilibrates to incident wave energy and water levels. Localized “hot spots” may manifest themselves over the life of the project and will be addressed through placement of sand or construction of some or all of the authorized coastal structure project features. In all cases, continued construction of the project will ensure that the design template (beach profile) remains in place during the life of the project.

XII. Conclusions and Recommendations

A. Conclusions

The following initial conclusions result from this Regional Sediment Management Plan:

Kahului Region

- Almost all of the cells within the Kahului region experienced relatively significant erosion during the time period prior to approximately 1987. This is consistent with impacts from the historic sand mining in the area which concluded in the 1960-1975 timeframe. Since 1987, some of the beaches have shown signs of increasing stability.
- The seasonal fluctuations for the Kahului region beaches appear to be significantly higher than the long-term average change rates.
- The Wailuku Kahului Wastewater Reclamation Facility Shore Protection Project is a potential RSM project that could reduce the maintenance costs of a federal shore protection structure while beneficially using sand from a federal dredging project (i.e. Kahului Harbor). The permanent removal (historical mining) of sand from the littoral system has resulted in a deficit in the sediment budget and erosion over the length of the area from Baldwin Beach to Kahului Harbor and the rate of shoreline erosion at the WWRF is still significant. Two beach nourishment alternatives have been identified as part of the long-term protection of the WWRF: one for a 3,800-ft long beach replenishment and one

for a 2,400-ft long replenishment. The former would require approximately 105,000 cubic yards of initial sand placement and the second alternative would require approximately 65,000 cubic yards.

- Another potential RSM project is Kahului Harbor Dredge Material Beneficial Reuse. Based on sediment sample testing done for the 1999 Kahului Harbor dredging project, the harbor sediment grain size is primarily sand which suggests the potential to reuse dredge material for beach nourishment. A potential RSM project is to place Kahului Harbor dredge material along the Kahului Harbor shoreline, which has a current beach erosion rate of approximately 800 cy per year. The dredge material may also be appropriate and have higher potential benefit for other beach nourishment sites in the region, depending upon the grain size compatibility with the other sites.
- The RSM sand sources search identified 7.8 acres (31,656 m^2) of stable sand stored on the reef flat off of the north shore of Maui, serving as a potential resource for beach replenishment.
- A sand search done as part of a separate project also indicated a very large (~3,500 acres) potential source of beach-quality sand seaward of the Kahului Harbor breakwater
- There are currently six Federal projects in the Kahului region.

Kihei Region

- The Kihei region experiences both wave-driven longshore sediment transport direction that is from south to north and wind-driven sand transport from north to south. A major contributor to erosion on the beaches is due to wind blowing sand onshore, out of the littoral cell.
- While many of the beaches along the west-facing shoreline of the Kihei region have experienced erosional trends prior to 1998, the Kawililipoa littoral cell area has been steadily accreting. This is possibly associated with a unique rubble formation in the nearshore at the north end of the Kawililipoa Beach littoral cell which acts as a groin and interrupts sand transport to the north, causing accretion on its downcoast side.
- The Kihei Beach Hurricane and Storm Damage Reduction Project is a potential RSM project. The potential project area shoreline extends approximately five miles from the northern limit of Kalama Park to northwest of the Kealia Pond. This area includes the North Kihei, Kawililipoa Beach, and part of the Kealia and Kalama littoral cells of this RSM study. The project would include an initial beach nourishment (approximately 358,000 cubic yards), as well as future renourishment.
- The RSM sand sources search identified 13.8 acres (55,821 m2) of stable sand stored on the reef flat off the coast of Kihei, Maui, serving as a potential resource for beach replenishment.

- There are currently three Federal projects in the Kihei region, one of which is only in the study phase.

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. The line graphs plotting the historical beach volumes (Figures 44 and 59) are simply based on interpolation between available data points.

The potential RSM projects relate to both existing Federal projects and potential future Federal interest. Dredging of beach quality sediment outside the Kahului Harbor entrance (offshore reef-top sand fields) for placement on beaches could minimize dredging cycles at Kahului Harbor (existing Federal project). Beach nourishment at WWRF would also have the potential effect of minimizing the maintenance cycle on the existing WWRF rock revetment (potential Federal assistance project). The Federal interest in the Kihei Beach project would be associated with National Economic Development benefit from erosion protection including loss of land, structural damage prevention, reduced emergency costs, reduced maintenance of existing structures and incidental benefits, and hurricane and storm damage reduction benefit of reduction of damages to existing structures.

The Honolulu District RSM web site has been updated to include the Maui regions. Historical aerial photography, digitized shorelines, ground photography, coastal structure inventory, regional sediment budget, reports and other Maui 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 Kahului and Kihei regions. The workshop provided an overview of the tasks accomplished in the Maui regions and included detailed discussions on the findings presented in the preliminary Maui RSM Plan. The minutes from this workshop are provided as Appendix J.

B. Recommendations

It is recommended that the following work be continued in association with future Maui RSM studies:

- Complete water circulation and wave transformation numerical modeling to refine the Maui regional sediment budgets and define sediment transport directions.
- Perform field visits and jet probing of reef-top sand sources. Also investigate other beach sand sources, such as dredge material from Kahului Harbor and Maalaea Harbor.
- Develop further data on the sediment yield (inputs) to the Maui littoral cells from the streams and rivers to provide a better understanding of the overall sediment budgets. Additionally, stream mouth management, relative to dune breaching,

could be a significant factor and mitigation measures should be implemented and monitored.

- Identify critical dune areas to be targeted for protection.
- Develop a further understanding of seasonal fluctuations of the beaches within each region and use the information to update the shoreline positions and change rates. 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 Maui RSM region beaches.
- Update the preliminary Maui 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 to improve sediment management strategies in the region and across the state. Activities to reduce project costs, streamline permitting, and increase beneficial use of sediments on a regional scale at Kihei Beach and in the Kahului area should be investigated and coordinated with various stakeholders and agencies.

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