SOUTHEAST OAHU, HAWAII

Diamond Head to Pearl Harbor

PRELIMINARY
REGIONAL SEDIMENT MANAGEMENT PLAN

Prepared for

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

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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 preliminary RSM Plan for the Diamond Head to Pearl Harbor (D2P) region has been produced as part of the Southeast O‘ahu Regional Sediment Management Project. The document compiles available information for the study area, including studies produced directly in support of the D2P RSM Plan. This information is to be used 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.

Key findings of these studies include the presence of nearshore sand sources on the reef top in the project area, and generally low sediment transport rates (a few thousands of cubic yards annually). These findings suggest that beach nourishment could be economically viable.

This plan makes the following conclusions regarding potential RSM projects in the Diamond Head to Pearl Harbor region of the SEO/RSM project.

- Waikiki Potential RSM Project: There is ongoing erosion in the Waikiki area as a whole. In the 1970s, this was effectively countered by beach nourishment. Between the early 1980s and 2006, almost no beach nourishment occurred, and the beach narrowed significantly. The 2006 nourishment of Kuhio Beach was successful, but ongoing nourishment in the area is needed. Similarly, sand that was placed along Fort DeRussy Beach has partially migrated to the west. This has resulted in narrowing of the beach on the eastern portion of the reach while the western portion of the reach has experienced dramatic accretion. At present, the beach width along the western shoreline of Fort DeRussy Beach is seven times wider than that to the east. One of the components of the Waikiki Beach PRP will be to facilitate and coordinate sand backpassing at Fort DeRussy Beach.

- Pearl Harbor Potential RSM Project: There is ongoing erosion at the Iroquois Point Housing area near Keahi Point, immediately ‘Ewa of the Pearl Harbor entrance. This may be associated with loss of sand into Pearl Harbor – along the beach at Iroquois Point, and in the channel. There may be opportunities to decrease erosion rates, reduce shoaling in the channel entrance, and nourish adjacent beaches.

- In the D2P region, a good degree of localized coordination appears to be in place. The importance of Waikiki’s beaches to the tourist industry has encouraged coordination between the U.S. Army, the hotel industry, and various State of Hawai‘i offices. The existence of a single organization (Ford Housing, LLC) that manages Iroquois Point housing area has led to the pursuit of a single project to manage 4,200 lineal feet of eroding beach. However, ongoing coordination between the Federal interests, the State of Hawai‘i, and the City and County of Honolulu should be furthered.

- Stream mouth management does not appear to be a major issue in the D2P region and no associated Potential RSM Projects have been identified.

- Dune protection does not appear to be a major issue in the D2P region and no associated Potential RSM Projects have been identified.

The following conclusions are reached regarding future investigations.

- Coastal Processes Modeling: Continue water circulation and wave transformation numerical modeling to refine the D2P regional sediment budget. For instance, in the Waikiki Beach littoral cell, there appears to be significant movement of sand between the beaches and the reef. This sediment circulation is not well understood. Given the likely need for ongoing nourishment at Waikiki Beach, these sediment pathways will be investigated further through field work and more detailed coastal processes modeling analyses.
- Regional Sediment Budget: Update the preliminary D2P regional sediment budget based upon the findings of FY10 investigations.
- GIS/IMS: Update the Honolulu District RSM web site to include the D2P region. Similar to the products that are currently available for the Mokapu Point to Makapuʻu Point (M2M) region, the D2P products will be ported to the web site. Historical aerial photography, digitized shorelines, ground photography, coastal structure inventory, regional sediment budget, reports and other D2P products will be available to the public on the web site. An Internet Map Server will provide real-time mapping capabilities to enhance the utility of the information compiled for the region.
- Potential RSM Projects: Develop details for potential RSM projects identified in FY09 to improve sediment management strategies in the region. Activities to reduce project costs and increase beneficial use of sediments on a regional scale at Pearl Harbor, Waikiki Beach and Iroquois Point will be investigated and coordinated with various stakeholders. For instance, backpassing of sand at the eastern limit of Iroquois Point to beaches to the west could significantly reduce Pearl Harbor dredging requirements. Also, identification of a substantial and sustainable sand source in the vicinity of Waikiki Beach could greatly reduce the cost of restoring its highly utilized urban beaches. Potential backpassing of sand from west to east along the Fort DeRussy shoreline will also be facilitated and coordinated. Due to the limited amount of maintenance dredging that has historically been required at Honolulu Harbor, additional RSM investigations are not recommended for that Federally authorized project at this time.
- RSM Plan Report: Revise preliminary D2P Regional Sediment Management Plan Report to reflect the tasks accomplished in FY10.
- D2P/RSM Workshop: Conduct a series of informational workshops concerning the needs, findings and RSM opportunities within the D2P region. The workshops will provide an overview of the tasks accomplished in the D2P region and include detailed discussions on the findings presented in the D2P/RSMP.

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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 Southeast O‘ahu RSM (SEO/RSM) project is part of this larger program. The Federal sponsor of the SEO/RSM is the Honolulu District of the U.S. Army Corps of Engineers (POH). The non-Federal sponsor is the State of Hawai‘i, Department of Natural Resources, Office of Conservation and Coastal Lands.

This document is a preliminary RSM Plan for the Diamond Head to Pearl Harbor (D2P/RSMP) region and has been produced as part of the SEO/RSM. 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. Southeast O‘ahu Regional Sediment Management Project

A. Overview

The Southeast O‘ahu Regional Sediment Management (SEO/RSM) project is the first project being carried out by the Honolulu District. In the future, additional projects will be conducted on the other Hawaiian Islands, specifically Maui and Kaua‘i. Two regions have been included in the SEO/RSM project: Mokapu Point to Makapu‘u Point (M2M) and the present Diamond Head to Pearl Harbor (D2P) region. Figure 1 is a vicinity map illustrating both regions.

B. Mokapu Point to Makapu‘u Point (M2M)

The first region considered under the SEO/RSM project was the M2M region. The Regional Sediment Management Plan for this region 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 can be found online at <http://gis.poh.usace.army.mil/rsm/index.htm>. GIS data for the study region can be obtained online using the web-based GIS platform at <http://gis.poh.usace.army.mil/MapRoom/MapRoom.asp?Customer=POH>.

C. Diamond Head to Pearl Harbor (D2P)

The RSM Plan for the second SEO/RSM Region, Diamond Head to Pearl Harbor , was initiated in 2009. This region is located along the south shoreline of the island of O‘ahu, from Diamond Head to Pearl Harbor (including Iroquois Point). See Figure 2 for a more detailed view of this region.

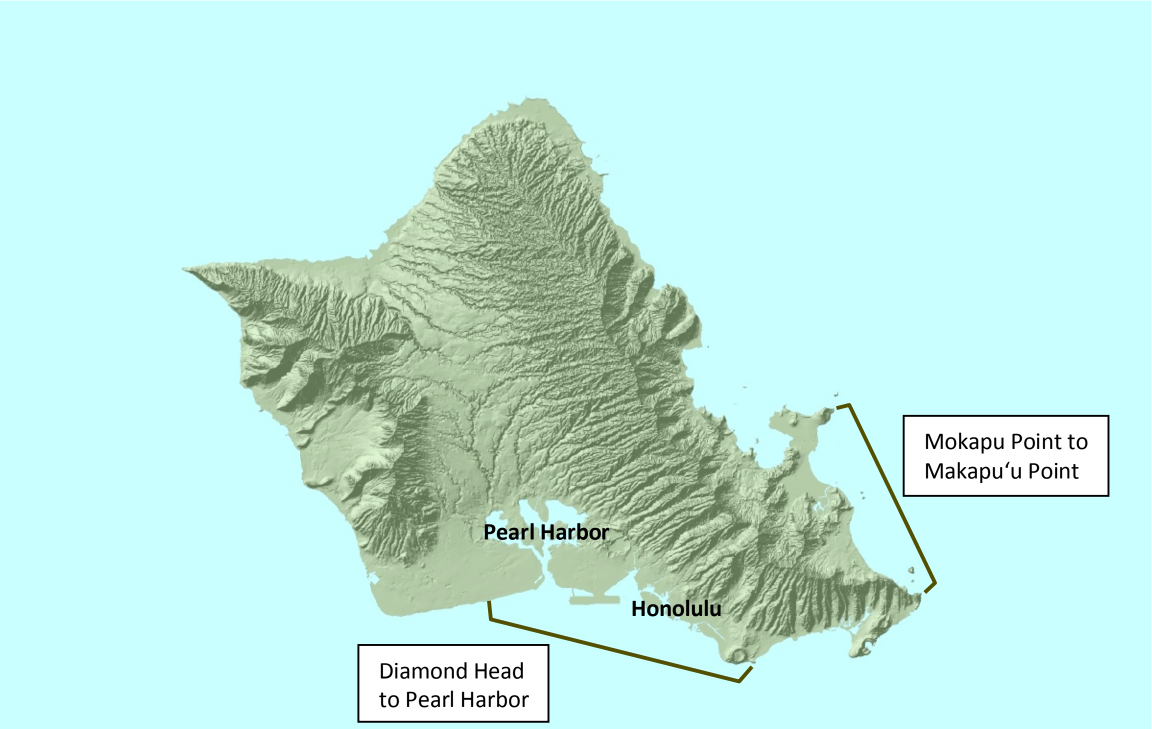


Figure 1. Southeast Oʻahu RSM Regions

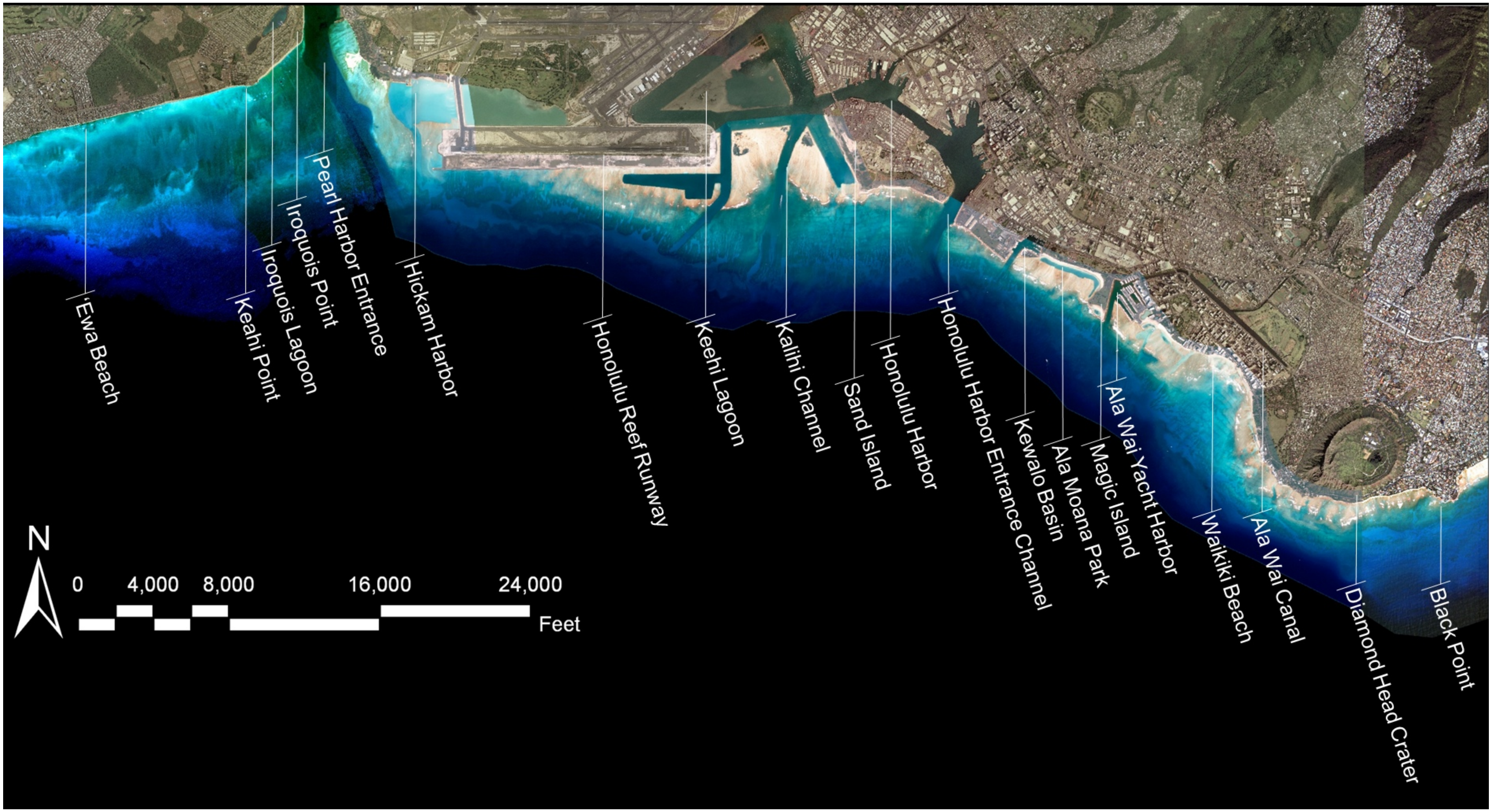


Figure 2. Diamond Head to Pearl Harbor (D2P) Region

Base map is a 2005 Quickbird satellite image mosaic, used throughout this report

IV. Federal Projects in the D2P Region

A. Overview

There are a number of Federally authorized projects within the D2P region. This section outlines these additional projects, based on the description available online at <http://www.poh.usace.army.mil/CW/CWProjects.htm>. In addition, the U.S. Navy maintains the Pearl Harbor Naval Station and associated facilities. The project locations are shown in Figure 3.

B. Federal Navigation Projects

Honolulu Harbor: This project is located at the southern edge of the downtown and industrial portion of Honolulu (Figure 4). It is the principal port for the State of Hawai‘i and an important link in the commerce of the Pacific Basin. The harbor is the largest nonmilitary port on Oah‘u. Since its initial construction by the Hawaiian monarchy in 1899, the harbor has been expanded and deepened many times.

This project represented not only the first Federal improvements to the harbor, but also the first USACE civil works project to be undertaken in Hawai‘i (in 1905). It provides the following infrastructure.

- An entrance channel (Fort Armstrong Channel) 4,000 feet long, 500 feet wide and 45 feet deep;
- A main harbor basin 3,300 feet long, 1,520 feet wide and 40 feet deep;
- A west harbor basin 3,400 feet long, 1,000 feet wide and 40 feet deep;
- A connecting channel 400 feet wide and 40 feet deep.

A 400-foot wide, 23-foot deep Kalihi Channel was also provided in accordance with Section 849 of the Water Resources Development Act of 1986 (Public Law 99-662).

The entrance channel and harbor basin are dredged infrequently. The last maintenance dredging operation was conducted in February 1999 when approximately 153,000 cubic yards of material were removed from the project limits.

C. Federal Hurricane and Storm Damage Reduction Projects

Sand Island – Honolulu Channel: Sand Island is adjacent to Honolulu Harbor on the southwest coast of Oah‘u (Figure 5). This project consists of nearly 2,400 lineal feet of revetment along the shoreline of Sand Island along the Honolulu Channel. The project was completed in 1981. Inspection of the revetment is conducted annually and structure maintenance is accomplished on an as needed basis.

Sand Island Park: This separate project includes 4,000 lineal feet of revetment and three 70-foot long offshore breakwaters at Sand Island Park on the south shore of Sand Island (Figure 6 – the revetment constructed by the Sand Island-Honolulu Channel project is also visible in this photograph). The project was completed in 1980. Damages from Hurricane Iwa were repaired in 1983. Additional shoreline revetments were completed in Sept.1990 to provide for two sections (495 feet and 1,085 feet) of shoreline revetment, and one 360-foot-long reach that consists of three 70-foot-long offshore breakwaters.

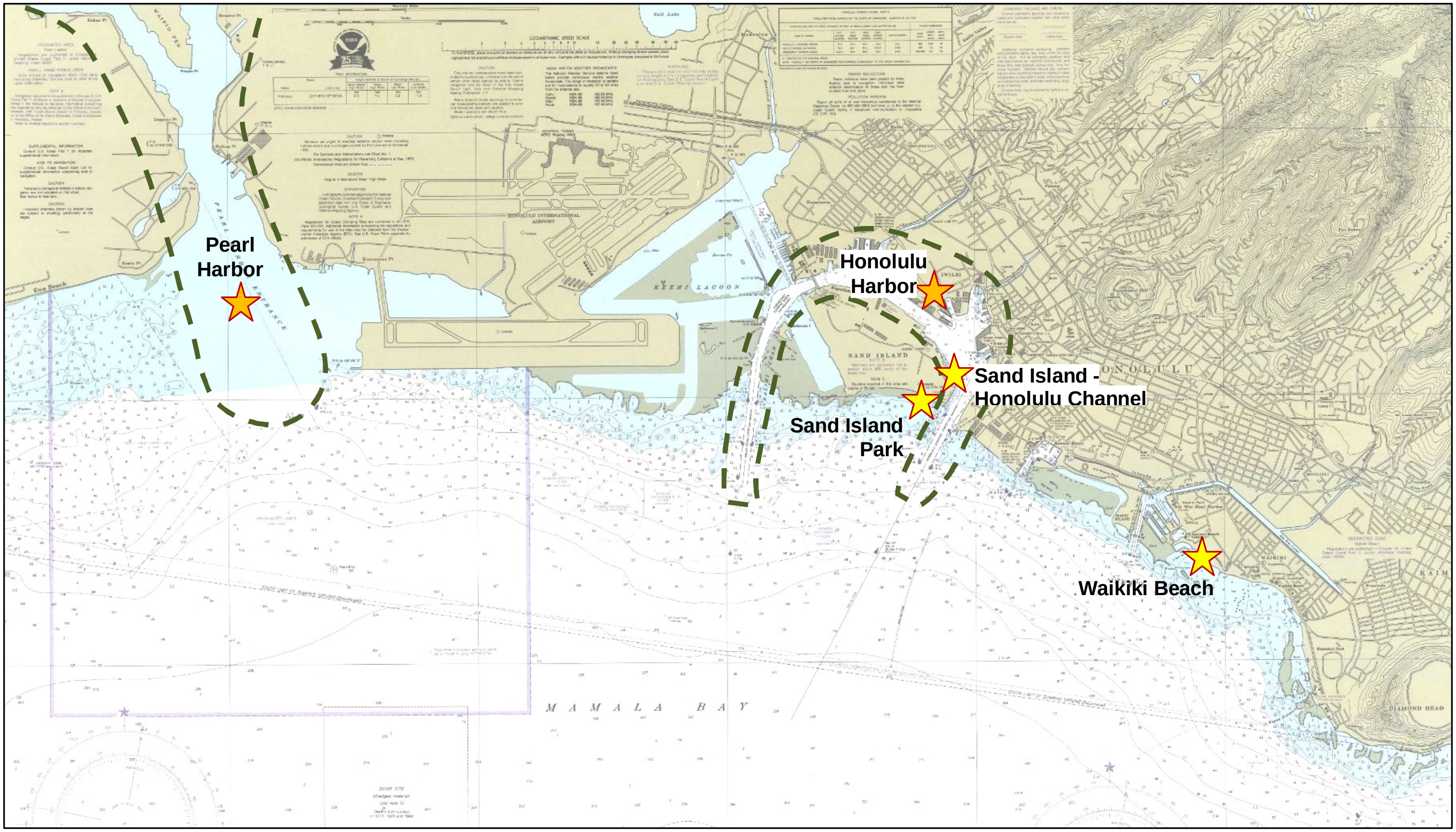


Figure 3. Federal Projects in the D2P Region

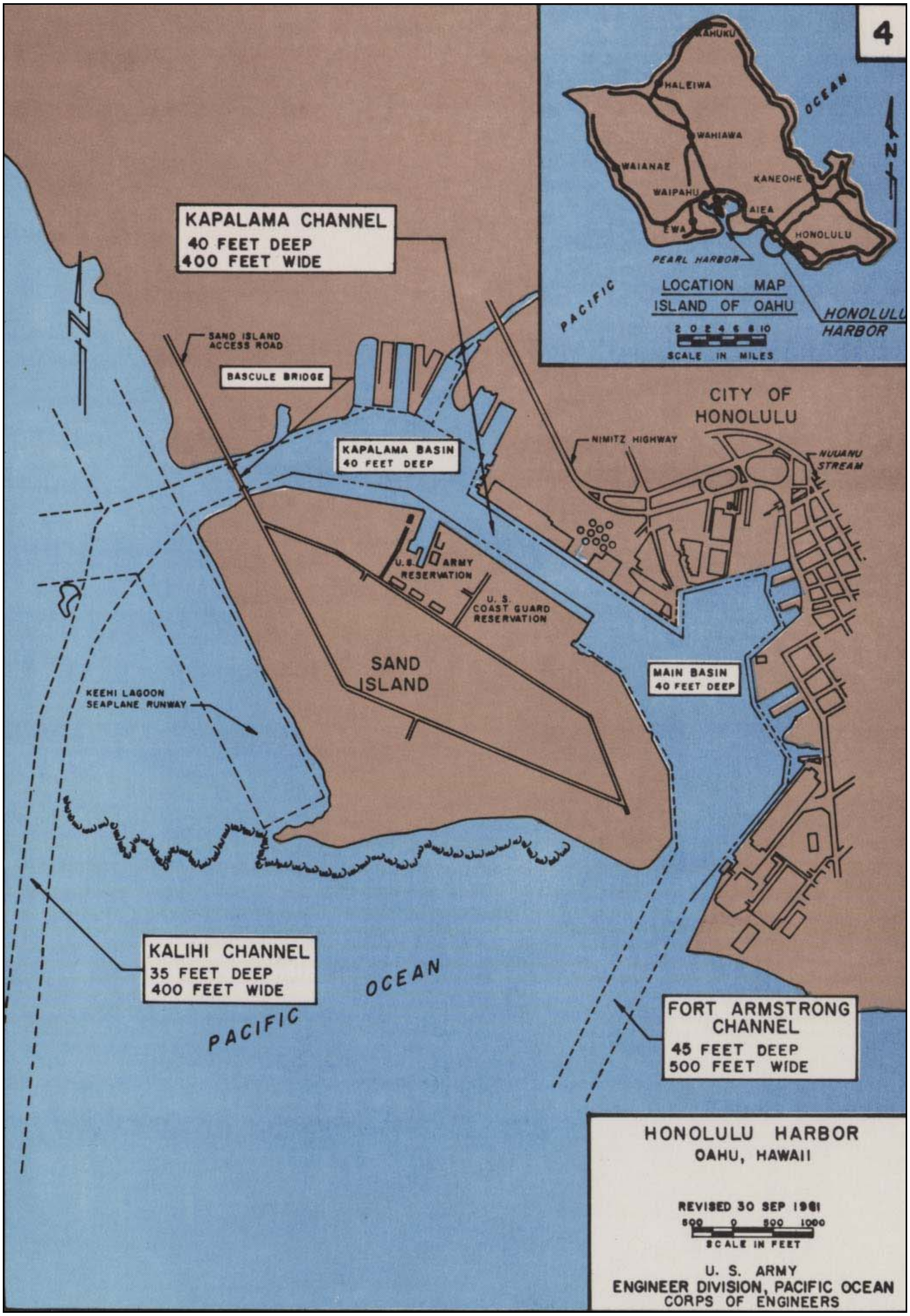


Figure 4. Honolulu Harbor Project Map

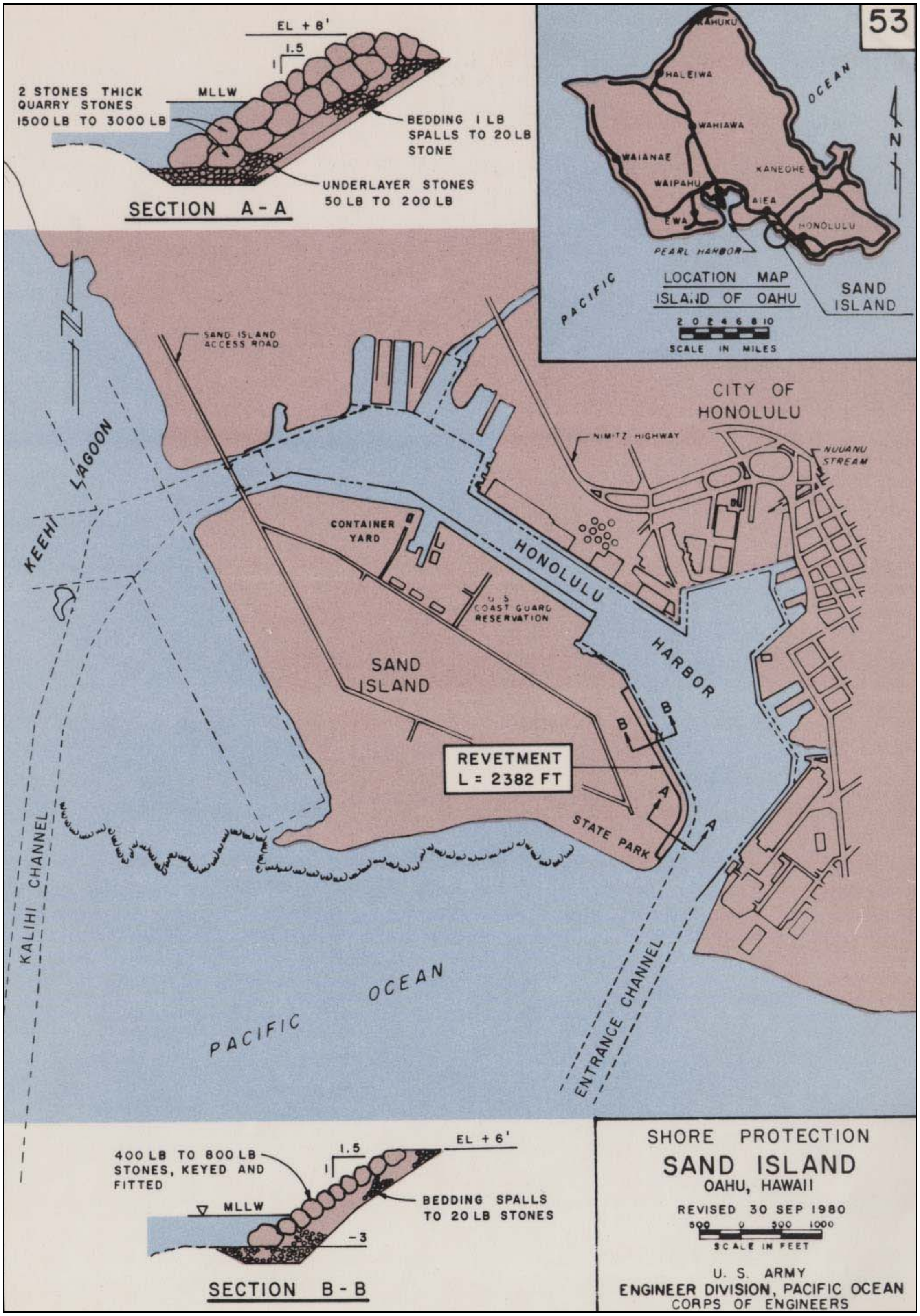


Figure 5. Sand Island-Honolulu Channel Project Map

Figure 6. Sand Island Park Aerial Photograph

Waikiki Beach: The Waikiki Beach, Oah‘u, Hawai‘i, Beach Erosion Control project (Figure 7) was originally authorized by Section 2 of Public Law 520, 71st Congress, approved 3 July 1930, as amended and supplemented. The sector of the beach at Fort DeRussy is included in this project. Improvements to this sector were completed in 1970 and included placement of 160,000 cubic yards of sand to widen the beach, terrace walls, and drainage facilities.

The project has subsequently been modified and authorized for construction by Section 301 of the River and Harbor Act of 1965 (Public Law 89-298). The Act authorized the construction, repair, and preservation of certain public works on rivers and harbors for navigation, flood control, and for other purposes. The current project, which is currently under preconstruction and engineering, represents a comprehensive and cooperative approach to the erosion problem along the entire Waikiki shoreline. It includes the following elements.

- Widening of the average dry beach width to 180 feet from Duke Kahanamoku Beach to the Natatorium, and to 75 feet from the Natatorium to the Elks Club. The design slope is 1V:10H from a crest elevation of +6.0 feet to the Mean Lower Low Water (MLLW) line, and at a slope of 1V:20H to -6.0 feet.
- Extension of an existing combination box culvert and groin at the east end of Fort DeRussy Beach to 350 feet.
- Construction of a new 350-foot long groin located between the Sheraton and the Royal Hawaiian Hotel.
- Construction a new 350-foot long groin at the north end of Kuhio Beach.
- Extension of the existing Kapahulu Avenue storm drain by 130 feet.
- Increasing the elevation of the 190 feet of shoreward crest of the Queen's surf groin from 4.5 feet to 8.0 feet.
- Construction of a new 350-foot long groin near the Aquarium.
- Construction of a 100-foot long stub groin extending from the southwest corner of the Natatorium.
- Construction of up to four additional groins.
- Federal participation in construction of the full 180-foot dry beach width from the Natatorium to the Elks Club, contingent upon provision of public access.
- Detailed investigations of closing existing channels through the offshore reefs in the interest of reducing wave energy along the project shoreline in order to preserve a more uniform beach width.
- Further modifications as may be considered advisable by the USACE Chief of Engineers.

Project implementation is currently on hold at the request of the non-Federal sponsor, the Department of Land and Natural Resources (DLNR).

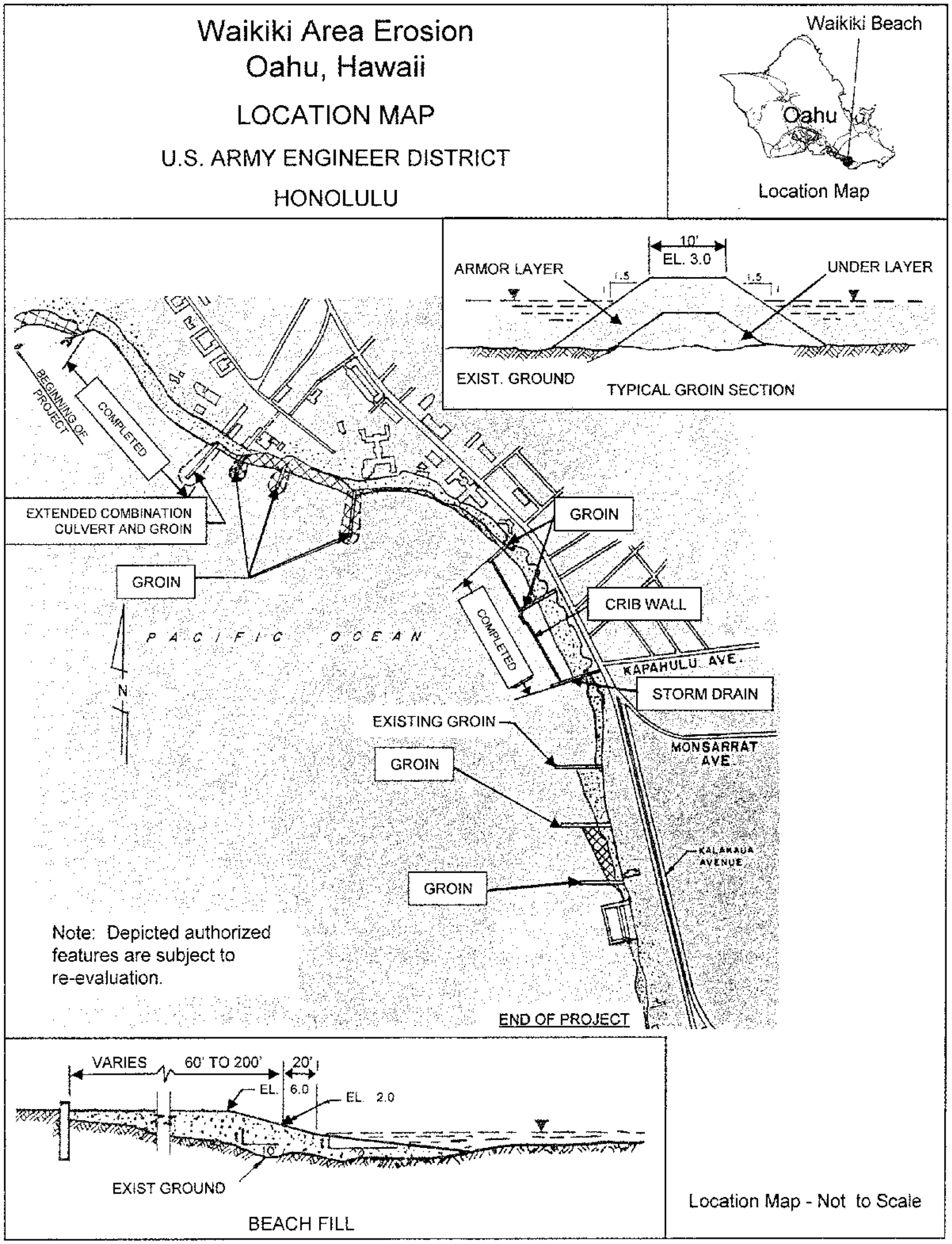


Figure 7. Waikiki Area Erosion Project Map

D. Watershed Projects

Ala Wai Canal Project: The Ala Wai Canal (Figure 8) is a two-mile long man-made waterway constructed during the 1920's to create and protect the Waikiki area on the island of Oah‘u. Its carrying capacity has been significantly reduced by accumulation of silt and debris from the Manoa, Palolo, and Makiki drainage areas in recent years, increasing the potential flood risk to the Waikiki area.

The Ala Wai canal also serves as an important link between the freshwater ecosystems of the upper drainage basins and the marine environment along the coast. The accumulation of silt and pollutants over the years has restricted water flow and circulation resulting in the steady decline in water quality.

During the November 1965 and December 1967 storms and passage of Hurricane Iniki in 1992, the Ala Wai Canal was overtopped causing flooding in the Waikiki district. The 30 October 2004 storm in Manoa caused the community and agencies to seek the expansion of the Ala Wai Canal Project to focus more purposefully on flood mitigation measures in the upper stream areas. has caused the community and agencies to seek the expansion of the Ala Wai Canal Project to more purposefully investigate flood mitigation measures in the upper stream areas. Efforts are underway by all parties to expand the Project and secure additional funding.

West Honolulu Watershed Study: The intent of the West Honolulu Watershed Study (WHWS) was to assess the condition of the watershed, identify water resource problems, investigate possible solutions, and recommend projects, studies, and other corrective measures that would improve overall watershed health. This Study was conducted under the Planning Assistance to States Program in partnership with the Honolulu Board of Water Supply, State of Hawai‘i Department of Land and Natural Resources (DLNR), and the USACE.

The objectives of this planning study included the identification of problem areas related to watershed dynamics in the West Honolulu region. The study did not assess conditions through the collection of primary scientific data, but rather through an analysis of existing information, consultations with relevant agencies and stakeholders, and field reconnaissance. All of the many components that contribute to the natural functions of the watershed were considered, although there are three main objectives based on the specific mission of the study sponsors. These are:

- To reduce the sediment build-up in area streams, including contaminated sediment;
- To identify projects that improve flood control;
- To protect and enhance groundwater resources.

In addition to these objectives, the WHWS also considered the related objectives of:

- Improved surface water quality;
- Increased recreation and public access opportunities;
- Stream ecosystem improvement, with an emphasis on native aquatic species.

Detailed descriptions of proposed projects were developed in an effort to address each of the study objectives.

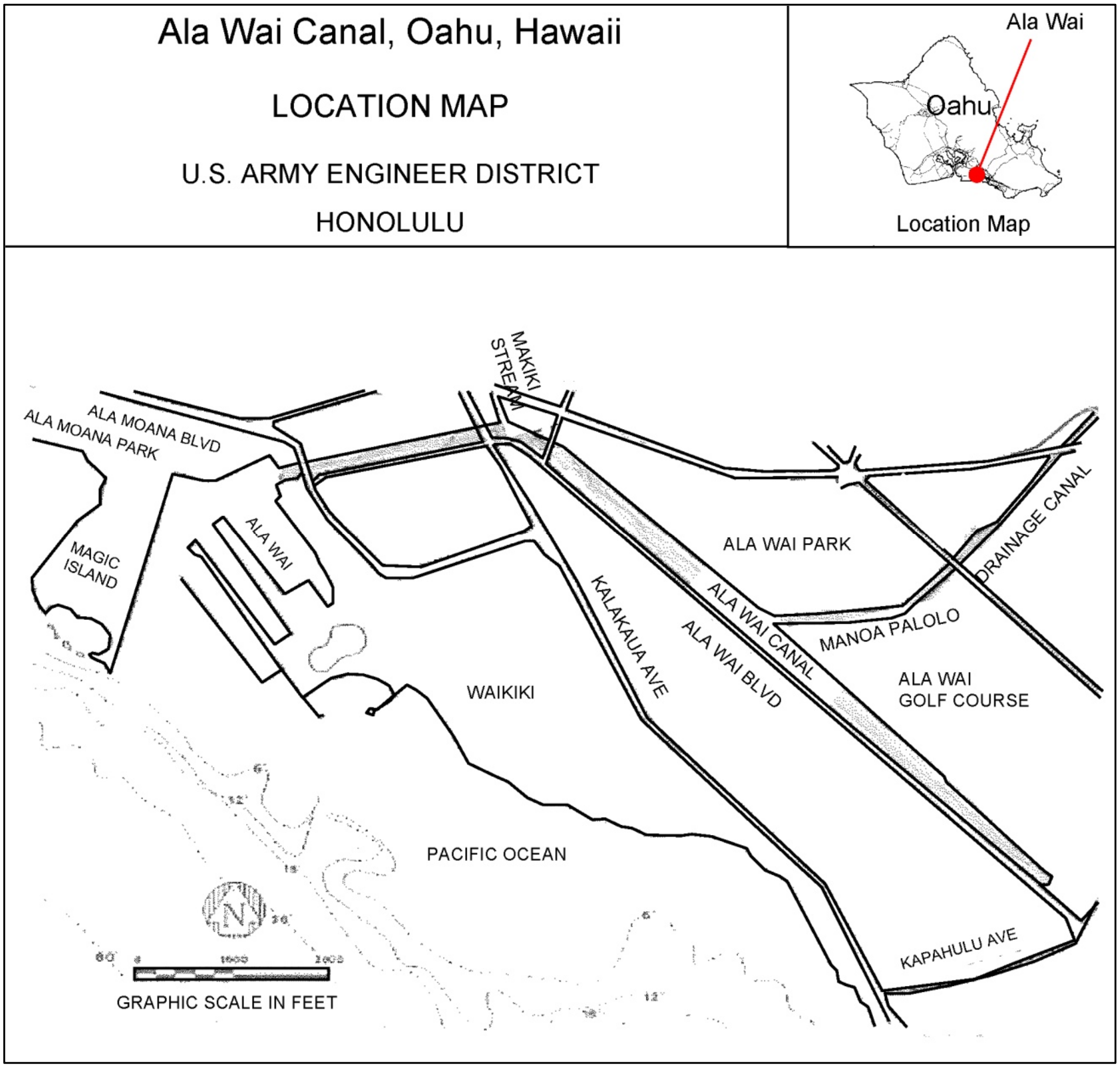


Figure 8. Ala Wai Canal

E. Naval Station Pearl Harbor

Naval Station Pearl Harbor was authorized in 1908. Dredging of the Pearl Harbor channel entrance began in 1910 and, on December 14, 1911, USS California became the first warship to pass through the new channel into Pearl Harbor. Pearl Harbor is fan shaped with an entrance width of 400 yd, and extends inland some 5 nautical miles. Dredging is required in both operational areas (averaging 75,000 cubic yards annually) and in the main navigation channels (averaging 200,000 cubic yards annually). In recent years, dredging of the main channels has been performed by the USACE hopper dredge *Essayons*.

V. Objectives

A. Overview

This section describes the objectives for the Southeast Oʻahu RSM project.

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 most cases, the shoreline has been armored to protect property and development, and there has been a noticeable environmental impact and/or a decrease in recreational use. Erosion hotspots can be restored, but restoration will require substantial economic resources (University of Hawaiʻi and County of Maui 1997).

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

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

A study objective is to identify erosion hotspots and erosion watchspots in the study area. The regional sediment budget described in Section X and provided in Moffatt & Nichol 2009, and the shoreline erosion hazard maps prepared by the University of Hawaiʻi and provided in Appendix D, highlight these erosional areas.

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 guidelines for the planning of shore protection measures that are appropriate, in regulatory, environmental, and engineering terms, for the study area.

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.

An objective is to investigate the feasibility of beach nourishment, sand bypassing and sand backpassing in the study area. 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 D2P region 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, 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 area that may be suitable for protection, either through engineering and/or bioengineering methods (dune stabilization) or through regulatory means. It appears that there are no such dunes in the study area.

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 can also affect reef ecosystems. An objective is to provide recommendations as to how the coral ecosystems in the study area can be better protected.

G. Shoreline Setbacks and Coastal Erosion Hazard Data

The City and County of Honolulu regulates shoreline setbacks. In support of this work, the University of Hawaiʻi is under contract to quantify erosion hazards. One work product from this program is a set of draft erosion hazard maps, available at <http://www.soest.hawaii.edu/asp/coasts/oahu/index.asp> and provided here as Appendix D. While not a specific study objective, the D2P/RSMP 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. 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 Department of Land and Natural Resources (DLNR) regulates work such as beach nourishment seaward of the certified shoreline, while the City and County of Honolulu 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”. Outside the Pearl Harbor Naval Defensive Sea Area, the public has access along the beach seaward of the certified shoreline.

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 National Marine Fisheries Service. Nearshore waters below the high water line within the Pearl Harbor Naval Defensive Sea Area are under the jurisdiction and control of the U. S. Navy.

Given the overlapping regulatory authorities associated with the implementation of RSM projects within the D2P region, 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, and in particular to bring the City and County of Honolulu Department of Planning into full participation of this process. A specific objective of this RSM Plan is to support increased coordination and collaboration regarding issues in the D2P region. Currently, the State of Hawaiʻi Department of Health (DOH) Section 401 Water Quality Certification component of the SSBN application process has lapsed. DOH’s apparent reluctance to continue its support of the SSBN application process will be investigated to facilitate responsible nourishment of the State’s eroding beaches.

J. Structures and Activities within the Shoreline Area

Much of the shoreline within the D2P study region has been modified with the construction of structures such as seawalls, revetments, groins and breakwaters. From Waikiki Beach to Sand Island, there are about nine groins, 1,500 lineal feet of submerged breakwater at Kuhio Beach, and over 1.5 miles of seawalls and revetments. Most of the seawalls are located behind a sandy beach.

The reach from Sand Island to Pearl Harbor has been more significantly modified. The Honolulu Reef Runway is a large artificial structure, not fronted by a beach (its south-facing shoreline is protected with large concrete armor units). The bathymetry in the area has been modified by past dredging of Pearl Harbor and Honolulu Harbor.

The City and County of Honolulu defines minor structures as those structures having little or no effect on shoreline processes (City and County of Honolulu Part 2, Chapter 15). Given this definition, there is no study objective related to minor structures.

In contrast, three study objectives can be distinguished related to major structures – those that are anticipated to affect shoreline processes.

- 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 O‘ahu may encourage coordination between the City and County of Honolulu, 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.

K. Beach Management Districts

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, Ford Housing LLC is pursuing regulatory approvals and permits for a groin field with associated beach nourishment over a 4,200-foot long stretch in the Iroquois Point area. The hotel industry and the Hawai‘i Tourism Authority coordinated with the State of Hawai‘i in the 2006 nourishment of Kuhio Beach: the economic importance of this tourist beach has driven cooperation in the area.

A study objective is to promote the establishment of Beach Management Districts, or other means of promoting shoreline management at multi-property scales, in other parts of the D2P region. The Diamond Head area (east of the Natatorium) and the ‘Ewa Beach to Iroquois Point area (‘Ewa of the Ford Housing project) may be candidates for district formation.

L. Public Awareness and Education

Public awareness of, and interest in, the general problems associated with erosion at Waikiki Beach, Iroquois Point and surrounding areas is high. The objectives of the present project in relation to public awareness are: to inform the public of ongoing studies and plans in the area; and to obtain public input on any plans, particularly pilot beach nourishment projects that may arise as part of the study. This objective can be met through a combination of public workshops and maintenance of the Honolulu District's RSM Web site. This process will be continued through the ongoing development of this D2P RSMP.

VI. Geomorphology

A. Overview

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 succession along the island chain has been from the northwest to the southeast.

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 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. This is found on the westerly islands, such as O‘ahu, which has an uplift rate ranging between 0.3 and 0.6 mm/yr (Fletcher *et al* 2008).

O‘ahu is one of the older islands in Hawai‘i. It was formed by two major shield volcanoes, Waianae and Ko‘olau (Moberly 1963). The eroded remains of these shield volcanoes and associated landslides are visible in the general shape of the island. The area of Pearl Harbor formed as the island subsided at the end of the active volcanic phase, drowning the river valley that drained central O‘ahu (Fletcher and Feirstein 2009).

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 O‘ahu shelf. Kona storm waves and hurricane-induced waves can also be detrimental to reefs.

The offshore shelf of O‘ahu was created by reefal limestone units in conjunction with past sea-level standstills, creating a distinct offshore stair-step bathymetry. The offshore shelf slopes gently seaward to a limestone drop-off at the end of the shelf (near the -60 or -70 ft contour). A second tier exists seaward of this drop, from approximately the -100 ft contour to the -150 ft contour. There is a second drop off and a third tier below the -

150 ft contour (Fletcher *et al* 2008). It is along the first shelf that patches of coral and coralline algae growth occur over a veneer of carbonate sand covering limestone. The second shelf is commonly covered with extensive fore-reef sediments.

The reef structure in the D2P region plays a significant 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.

C. Study Area

The study area is located along the southeast coast of Oʻahu, between Diamond Head in the east and extending past Pearl Harbor to part of ʻEwa Beach in the west. The bathymetry is relatively shallow along most of this reach and the coastline is generally low-lying. The fringing reefs and southern exposure protect the southern coastline from much of the wave activity.

Diamond Head Crater, lying to the east of Waikiki at the southern tip of the island, is a geologically young crater compared to Oʻahu as a whole. Diamond Head was built by hydromagmatic explosions that ripped through 200,000 year old coral reefs and Koʻolau basalt. As a result, large pieces of coral and basalt are mixed in the tuff and magmatic debris of the cone. The shoreline directly south of Diamond Head is accessible only by footpath. The nearshore is generally characterized by large sand plains from the shoreline to about -25 feet. Below this, the area is a flat calcium carbonate surface covered by a veneer of sand and rubble fragments. The beach, composed of calcareous sand mixed with terrigenous sediments, is one of the least developed vistas along the south shore. A fringing reef parallels the coast and widens to the west (Fletcher, Grossman, and Gibbs 2002).

The remainder of the study area has been heavily modified by urban, industrial, transportation, and military developments. The Waikiki Beach area was, until the beginning of the 20th century, a wetland and marsh holding only a narrow sandy strand at the shoreline. Early activities on the beach included sand mining in the early part of the 20th century. Later, the marsh was drained, significant drainage, dredging, and upland fill projects were constructed, and imported sand was placed on the beach (Wiegel 2008).

The Waikiki embayment is characterized by a fossil reef surface that extends offshore about one mile. The same reef surface is reported to extend about the same distance inland, rising several feet above current sea level. The reef is intersected by several paleostream channels and as well as channels dredged for navigation and to obtain fill materials. Further west, the reef has been dredged to reclaim land at Magic Island, Sand Island, and for the Honolulu Reef Runway.

The Pearl Harbor embayment formed as the island sank approximately 1,200 feet (360 meters) toward the end of the main shield building phase, drowning the river valleys that drain central Oʻahu. Pearl Harbor contains almost 30 miles of shoreline backed by extensive wetlands through which highly sedimented waters enter the harbor. A fringe reef extends nearly one mile offshore in this area, except at the mouth of the harbor.

West of Pearl Harbor is ʻEwa Beach, a nearly flat marine terrace. The nearshore has a very low slope with poorly defined fringing reefs running along the length of the coast. These reefs are mostly comprised of hard coral and calcareous algae with a few sand channels running in between. The shallow and broad fringe reef along ʻEwa Beach is effective at dissipating wave energy far offshore (Fletcher, Grossman, and Gibbs 2002).

However, the Iroquois Point littoral cell, on the ‘Ewa side of Pearl Harbor, includes the most erosional beach in the study area.

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 detrital (land-based) origin. Modern sand production on Hawaiian reefs is believed to be relatively low compared to that 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 sand in the D2P study area is predominantly calcareous, and this RSMP focuses on this sediment. Calcareous sand can be lost to the beach system in a number of ways.

- Beachrock is formed by cementation of 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. Relatively little beachrock is found in the study area, however, so its formation is not believed to be a significant component in coastal erosion in that area.
- Calcareous sand can be lost through abrasion (it is much less resistant to abrasion that 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.
- 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 mechanism for returning it to the beach system.
- 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 has impounded this sand. Sand is also stored in channels and depressions on the reef systems.
- Sand mining is an obvious mechanism for beach erosion. In the early 1900s, large quantities of sand were removed from Waikiki Beach. Large-scale sand mining is now prohibited: the few exceptions include clearing sand from stream mouths.
- Sand is also stored in channels and depressions on the reef systems

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 D2P study area, the available sand ends beyond the toe of the beach in a water depth of 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.

VII. Coastal Processes

A. Water Levels

Hawai‘i shorelines are microtidal, with ranges much smaller than those observed over the west coast of the continental United States. Water level datums measured by NOAA at Honolulu Harbor and reported on their web site are given in Table 1 (NOAA 2009a).

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

Datum	Value (feet, MLLW)
Highest Observed Water Level (2/14/1967)	3.39
Mean Higher High Water (MHHW)	1.90
Mean High Water (MHW)	1.44
Mean Sea Level (MSL)	0.82
Mean Tide Level (MTL)	0.80
Mean Low Water (MLW)	0.16
Mean Lower Low Water (MLLW)	0.00
Lowest Observed Water Level (4/30/1911)	-1.41

There are significant nonastronomical 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 area, particularly during storm conditions, because nearshore wave heights in areas affected by the fringing reefs are limited by the water depth.

B. Sea Levels

Based on measurements at Honolulu Harbor, the mean sea level in the study area has increased at an average rate of 1.50 ± 0.25 mm per year (5.9 ± 1.0 inches per century) between 1905 and 2006 (NOAA 2009b). This rate is less than the eustatic (global average) rate of sea level rise over the 20th century. O‘ahu has the greatest rate of uplift of any of the Hawaiian Islands, as a result of its position on the buckling Pacific Plate that underlies the islands (Fletcher *et al* 2008).

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

C. Wave Climate

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

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

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

- **Northeast Trade Waves**: These waves usually dominate the local wave spectrum during the summer (April to November). They result from the strong trade winds blowing out of the northeast quadrant over long fetches of open ocean. The waves typically have periods ranging from 5 to 8 seconds and heights up to 12 feet. They are present 90 percent or more of the time during the summer, and more than 50 percent of the time in the winter. In the D2P region, trade winds are generally offshore and are not the dominant wave generation mechanism.
- **Southern Swell**: South swell dominates during the summer in the D2P region. 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 9. The south shore of Oʻahu 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. The south shore is also exposed to infrequent Kona storms and to hurricane waves. Figure 9 shows that the annual significant wave height for waves approaching Oʻahu from the south is approximately 2 meters or 6 feet.

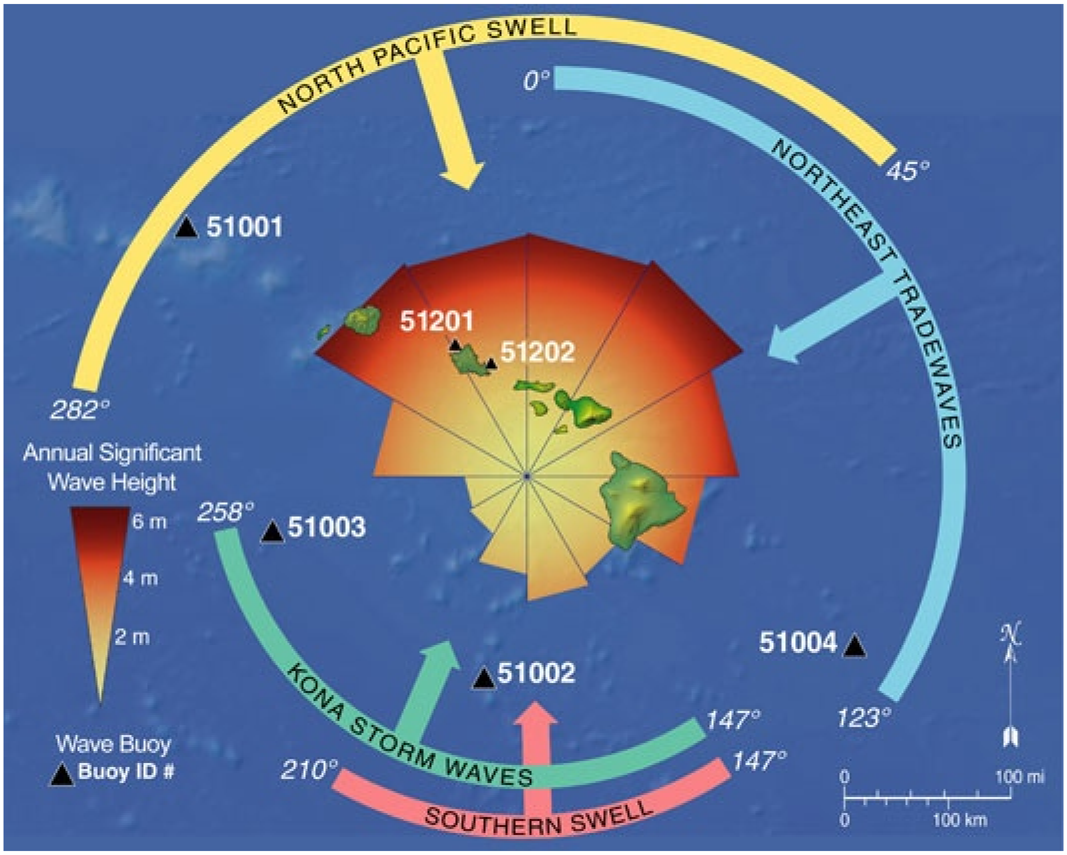


Figure 9: Dominant Wave Directions, Swell Wave Rose, and Monitoring Buoy Locations (Vitousek and Fletcher 2008)

Other wave types occur much less frequently. Hurricane waves can approach from the southeast through southwest directions. Hurricane Iwa, in November 1982, may have triggered sand delivery to Waikiki Beach (Miller 2002), while Hurricane Iniki in September 1992 may have caused erosion at Waikiki Beach but not at Ala Moana (Wiegel 2002). The study period for the STWAVE transformation analysis described in Section VII.D and Appendix B included Hurricane Iniki; the peak hindcast deepwater wave height in this modeling work was approximately 26 feet. The hindcast deepwater waves during Hurricane Iniki approached from the southwest: this is normal for hurricane waves.

The last type of wave to be considered is tsunamis. These can approach from any direction and can create significant scour on reef fronts. The 1960 Chile tsunami included a wave crest more than 4 feet above sea level and a trough approximately 6 feet below (Houston 1978) – low enough to uncover much of the reef surface in the study area.

D. Numerical Modeling of Wave Transformation

The nearshore wave climate in the study area has been investigated by the USACE Engineer Research and Development Center (ERDC) using the STWAVE model (Tracy 2009, included here as Appendix B). 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 this model study were based on Wave Information Studies (WIS) Station 116 – hindcast deepwater wave values based on available bathymetry and wind data. WIS hindcast data are available for the Pacific and Atlantic Oceans, as well as the Gulf of Mexico. The Pacific hindcast is currently undergoing a reanalysis to check if a new set of input wind fields will correct the problem of excess swell energy from the storms in the North Pacific during the winter. However, the south shore of O‘ahu is sheltered from the wave energy from the North Pacific winter storms and comparisons of wave energy coming from the south at Christmas Island (NDBC 51028) do not show this excess swell bias during the summer months. Therefore, wave results at WIS Station 116 should provide a good starting point for the wave transformation into the south shore of O‘ahu. Figure 10 shows the WIS stations surrounding the Hawaiian Islands, including WIS Station 116 directly south of O‘ahu.

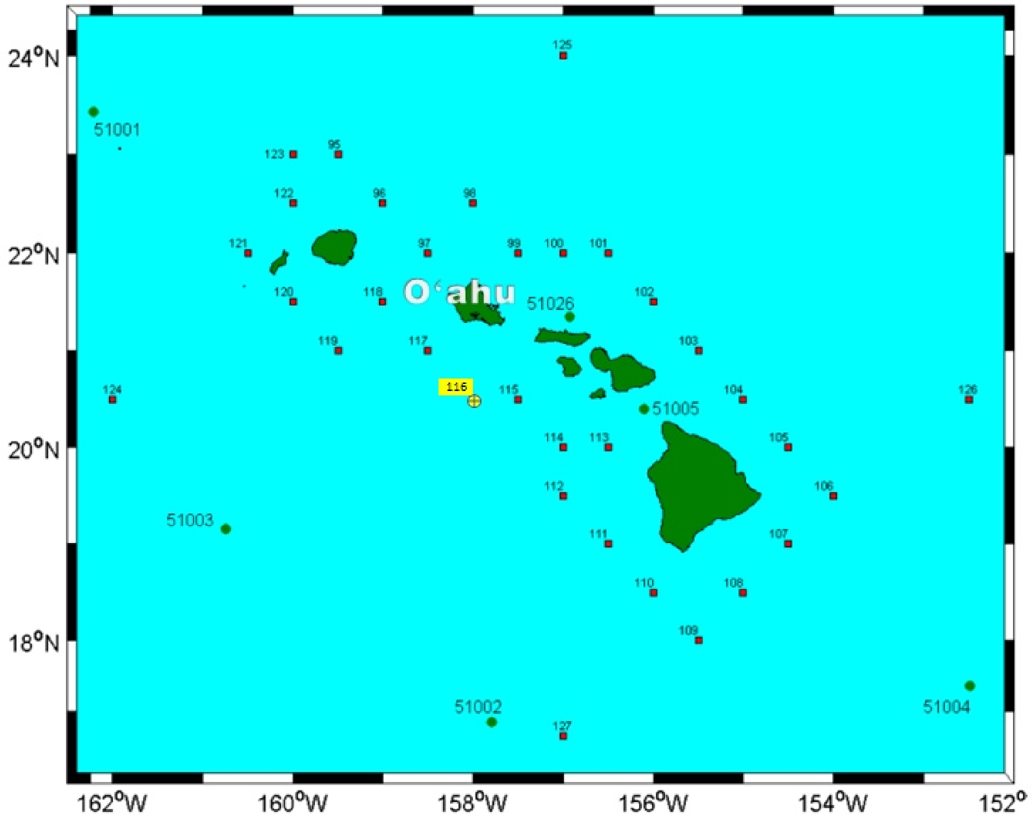


Figure 10. WIS hindcast stations in the Hawaiian Islands

POH requested the selection of three years that were representative of the wave climate at this location. A low wave condition (1984), a medium wave condition (1992), and a high wave condition year (1994) were selected. The medium wave condition year also included Hurricane Iniki in September, 1992. Hurricane Iniki produced the largest waves at this station – approximately 26 feet – during the period of the hindcast. The average significant wave height is approximately 2 to 3 feet – consistent with the annual maximum significant wave height of a little over 6 feet (2 meters) shown in Figure 9. The deepwater wave rose based on the three-year study period is shown in Figure 11.

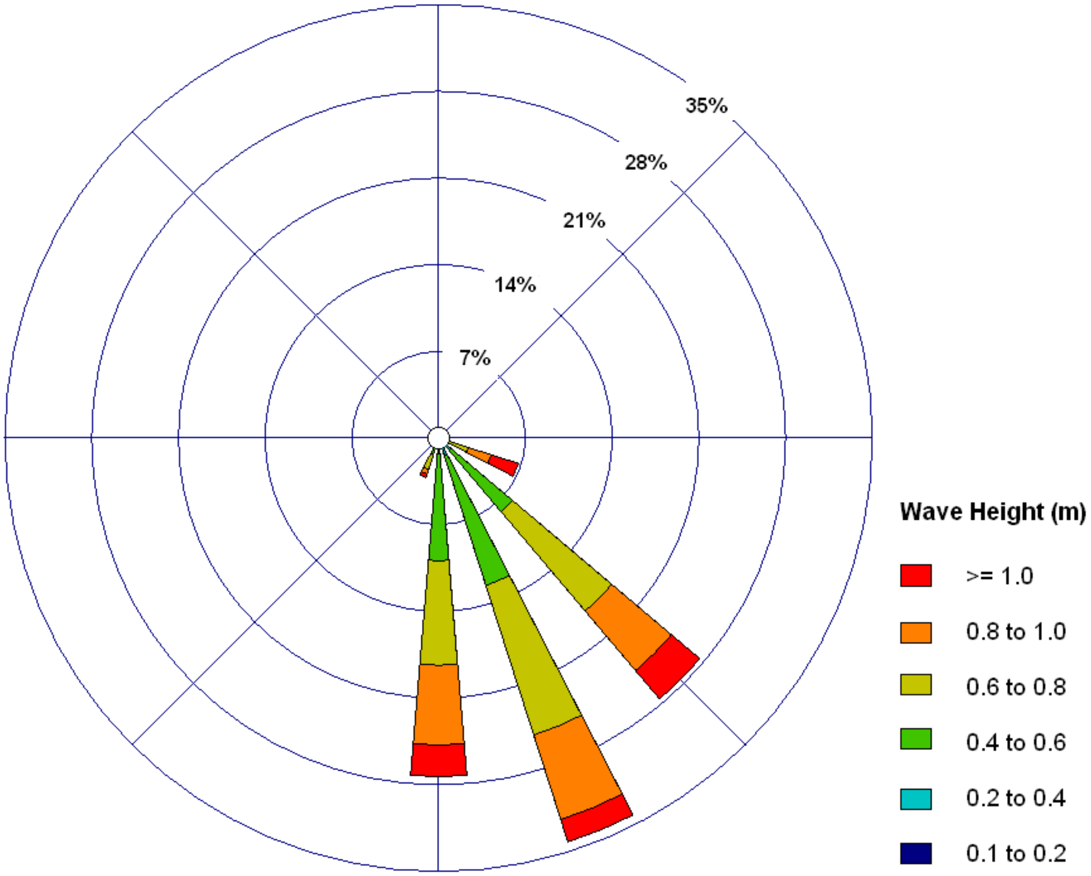


Figure 11. Deepwater Wave Rose for WIS Station 116: 1984, 1992, and 1994

Figure 12 and Figure 13 illustrate the wave transformation for conditions on April 5, 2000 – which had a deepwater significant wave height 4.0 feet (1.22 m), wave period 6.3 seconds, and direction 116 degrees (from approximately the southeast). This date was chosen by ERDC for illustration because calibration data were provided by a wave buoy off Diamond Head at this time (April 1-5 2000, see Appendix B).

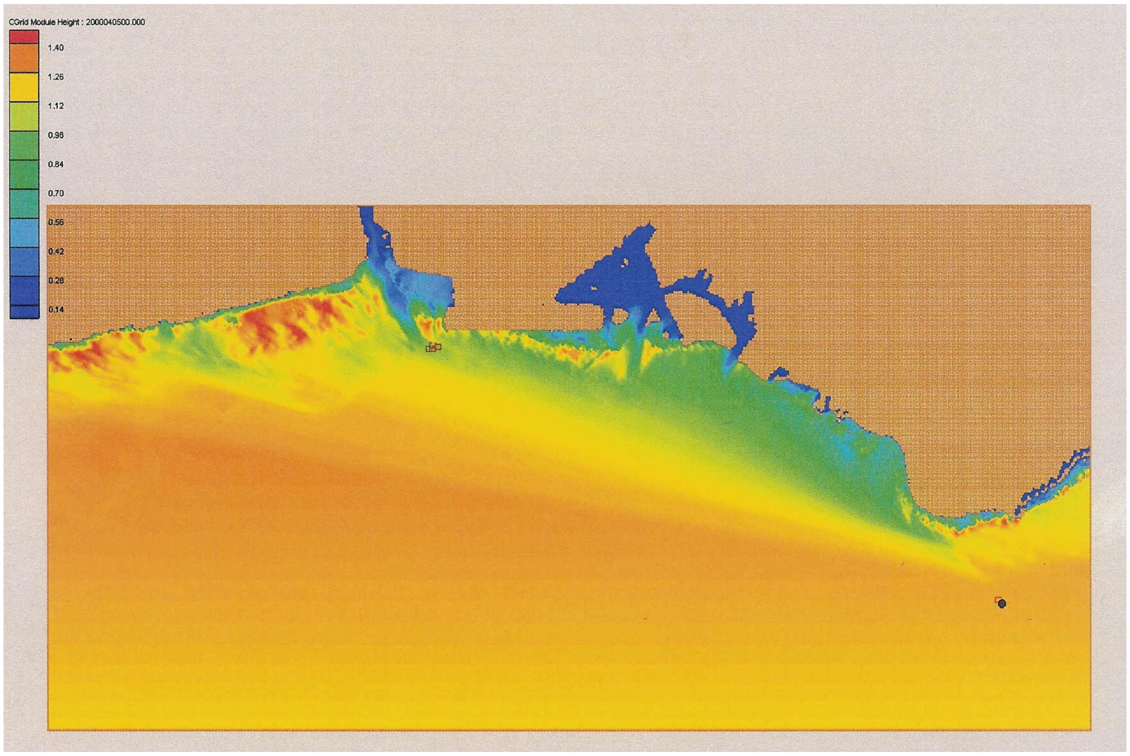


Figure 12. STWAVE wave height results for case corresponding to April 5, 2000

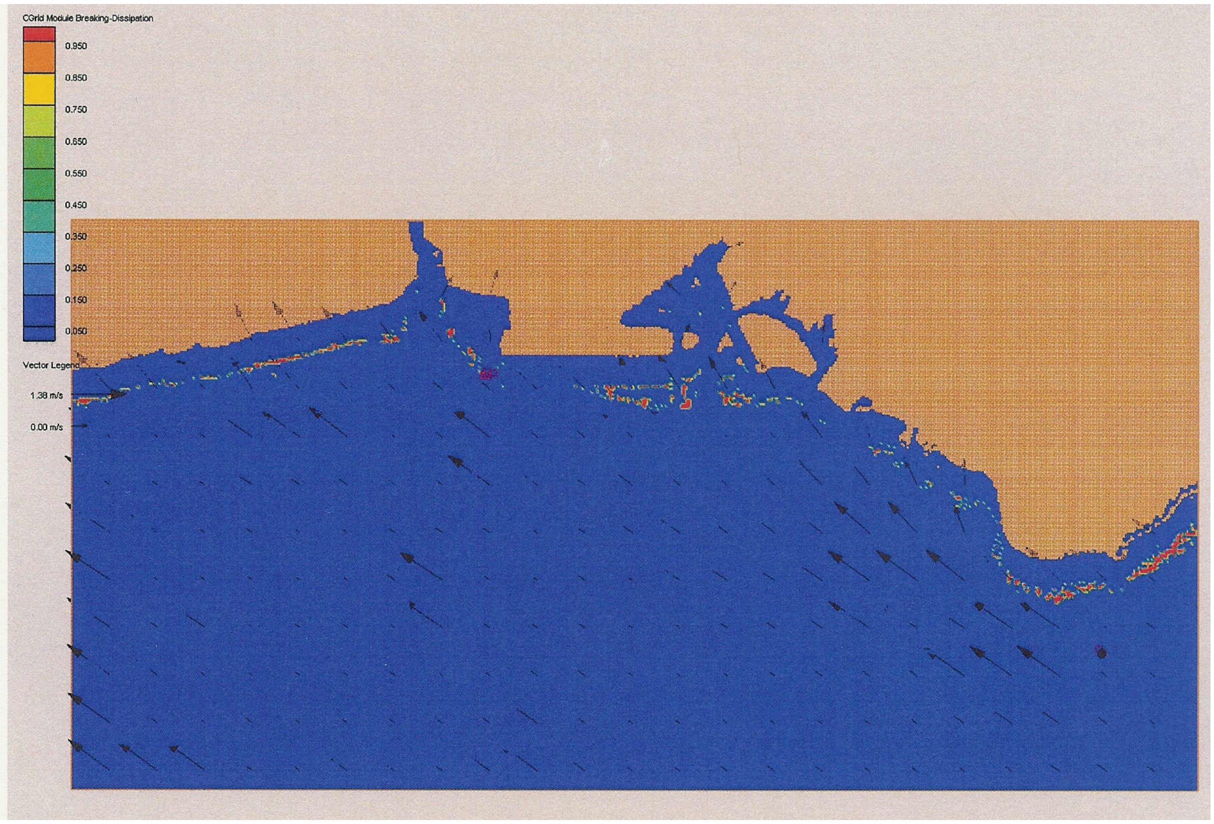


Figure 13. STWAVE dissipation for the same case; arrows show wave direction

Figure 14 is a photograph (date unknown) with clear wave crests illustrating the effects of the reef in causing wave refraction and breaking near Diamond Head. The area shown in Figure 14 is typical, in that incoming waves dissipate energy breaking over the reef over much of the D2P study region.

Figure 14. Waves refracting and breaking on the reefs off Diamond Head

Another way of looking at the refraction effects is through nearshore wave roses – Figure 15 provides wave roses, covering the 3-year study period, for a subset of the output points near Diamond Head. The model results show that, because of refraction over the reef, most of the waves are oriented almost directly onshore once they are at a water depth of 5 feet or less. The average significant wave height near the shoreline ranges from less than 1 foot (0.3 m) (in sheltered areas such as Ala Moana Beach Park) to more than 3 feet (1 m) (locations immediately offshore of Diamond Head and Sand Island, where irregularities in the reef focus the waves).

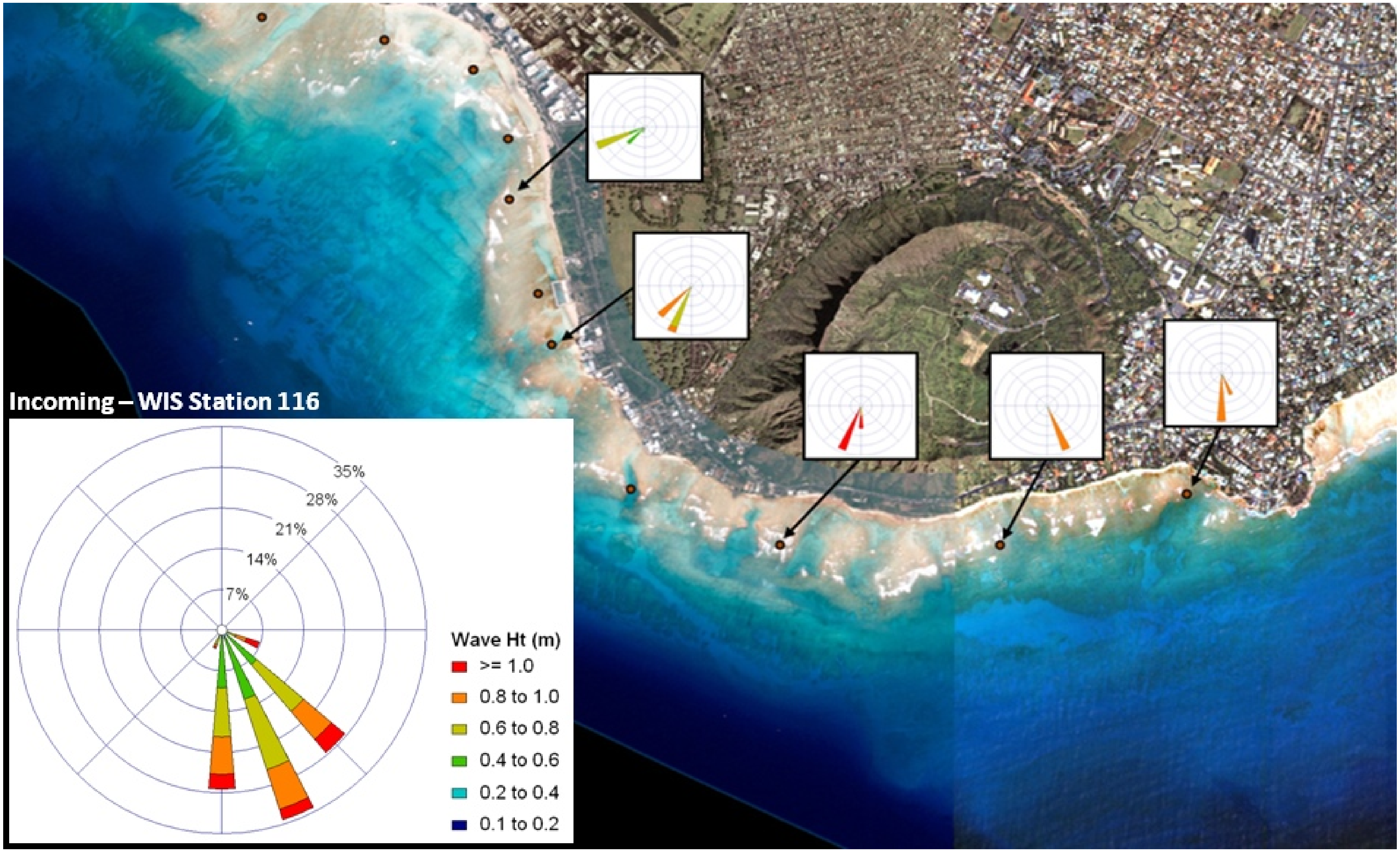


Figure 15. Wave roses at a subset of locations on the reefs off Diamond Head

E. Numerical Modeling of Water Circulation

Sand is transported by waves (which mobilize the sand) and tidal or wave-generated currents (which transport the sand). As a result, water circulation is critical in understanding sediment transport.

In the open ocean near the Hawaiian Islands, the tide wave is progressive; peak tidal currents are towards the SSW under the wave crest (high tide) and towards the NNE under the wave trough. Around the islands, the tide wave interacts with the island masses. The tide wave on the south side of O‘ahu approaches from the northeast, diffracts around the southeastern tip of the island and then Diamond Head, passes the south shore, and continues to the southwest (Noda and Associates 1991). The tidal current is important in deep water off the study area, where it is directed west (high tide) or east (low tide). However, it is much smaller than wave-driven currents in the breaker zone (where most sediment transport occurs), and is not considered further here.

Currents in the Waikiki area have been studied through a combination of numerical modeling efforts (Sea Engineering 2008), dye studies (Eversole 2004), and field reviews of littoral drift as observed on the beach (USACE Honolulu District 1992). Relatively little information has been obtained for the western part of the D2P study area, particularly on the ‘Ewa side and at Pearl Harbor. However, recent modeling work by the POH (Appendix C) has provided insight into the behavior of currents in this western region. The modeling work is consistent with previous studies of the Waikiki area. In particular, it illustrates the formation of rip currents, which carry sand offshore through reef channels to deeper water and which are a significant factor in Hawaiian coastal erosion (Wang and Gerritsen 1995, Miller 2002). Rip currents result from water brought towards the shore by waves, which moves alongshore until it reaches a channel in the reef that allows it to move offshore, providing a mass balance.

The currents modeling by POH used the CMS software model. The model setup and the specific wave conditions used are detailed in Appendix C. The modeling covered a period in August 2007, to illustrate circulation associated with southern hemisphere swell; and in December 2008 and January 2009, to illustrate circulation associated with Kona storm waves. A separate run was performed with purely tidal circulation: this showed that tidal currents are very small compared to wave-driven currents, and need not be considered explicitly in the sediment budget.

Wave conditions used as input to this modeling were based on a wave buoy (National Data Buoy Center 51203) at Kaumalapau, Lana‘i. The wave heights at this buoy location are representative of wave heights south of O‘ahu (Sea Engineering and Group 70 International 2008), although the buoy is sheltered from the east so waves at the buoy tend to be more westerly than would be representative of the project site. To investigate the effect of this, the August 2007 period was also simulated with the wave approach rotated counterclockwise by 30 degrees. The resulting currents differ in detail from the currents with no rotation, but the general pattern is the same. It is concluded that the results of this modeling work are representative of actual conditions.

The outputs of the modeling work by POH are described in some detail in Moffatt & Nichol 2009. Figure 16 and Figure 17 provide two illustrative results.

Figure 16 corresponds to a strong Kona storm condition (December 10, 2008). This is a case with strong offshore currents at Waikiki and at the south side of Diamond Head – a condition in which offshore transport of sediments is possible. Figure 17 illustrates a case of light southern hemisphere swell in the vicinity of Pearl Harbor. With the exception of a weak rip current off the Honolulu Reef Runway, this figure shows that most of the currents are directed towards Pearl Harbor.

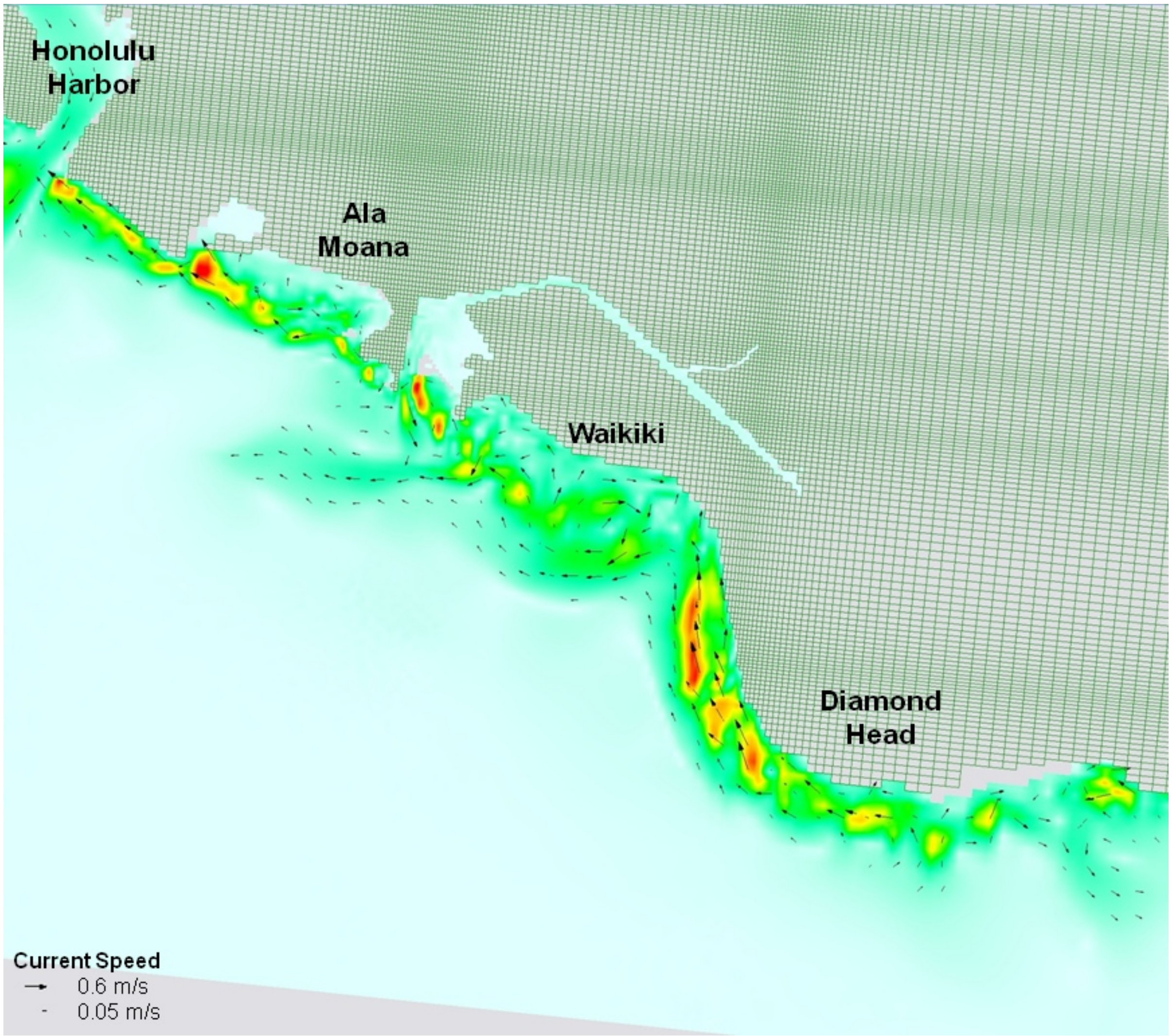


Figure 16. CMS Model results for Diamond Head to Ala Moana, showing strong offshore currents at Diamond Head and Waikiki

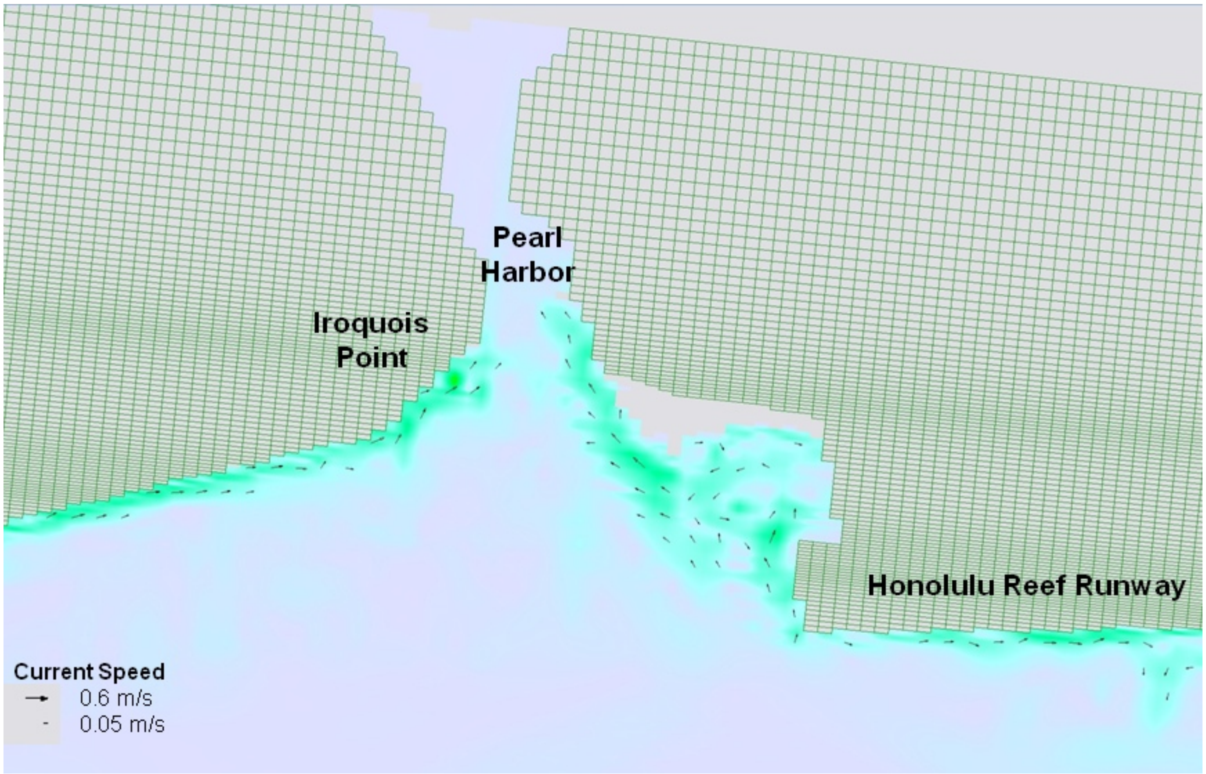


Figure 17. CMS model results for the Pearl Harbor region, typical case

VIII. 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 (not significant in the study area), 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 channels at Pearl Harbor.

The primary sediment source along the south shore of O‘ahu is from biological production – little of the beach sediment results from terrigenous sources (weathering of basalt). The unconsolidated sediment, which is available to build beach systems, is from two main sources:

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

In Waikiki, most of the sediment on the beach has been imported in beach nourishment projects. Over the rest of the study area, the majority of the sediment has been generated on the fringing reefs. It is not known whether this 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. As described in Moffatt & Nichol 2009, the rate of modern sediment production is a major unknown in the sediment budget for the D2P region.

Anthropogenic changes in the area are significant. Waikiki Beach is a heavily modified system. Honolulu Harbor, the Honolulu Reef Runway, and Pearl Harbor all represent massive engineering works with the potential to modify littoral processes significantly. Numerous channels have been dredged in the reef from Waikiki Beach to the Honolulu Reef Runway, for navigation, access, and as a source for fill material; and coral heads have been cut off to improve the nearshore sandy bottom for swimmers.

Water quality and silty runoff have the potential to decrease the productivity of the remaining reef. These stresses on the reefs are likely to decrease the, already rather small, productivity of the reef organisms (e.g., Wolanski *et al*. 2009) and thereby to decrease the sediment supply. Beach nourishment itself can smother reef organisms (USACE Honolulu District 1992). Whether this is significant for the health of the beaches depends on the rate of modern sediment production, which should be investigated further. Of course, this would only add to the many good reasons to protect the reef.

B. Shoreline Change Rates

Draft erosion hazard maps, including shoreline change rates (as derived from historical aerial photographs) along much of the study area, have been developed by the University of Hawaiʻi as part of their Coastal Hazard Mapping program. The erosion hazard maps are provided in Appendix D.

Generally, the calculated shoreline change rates indicate the following.

- Beaches in the Diamond Head cell are narrow but relatively stable
- Beaches in the Waikiki cell are the most variable. This heavily engineered shoreline can readily be divided into a number of subcells – some of which are accretional, some erosional. At Fort DeRussy Beach, significant nourishment efforts have led to a beach that is approximately stable overall, but longshore drift has engendered erosion on the Diamond Head side with corresponding accretion on the Ewa side.
- At Ala Moana, the beach is somewhat erosional overall. Again, longshore drift is evident in the pattern of some erosional and some accretional reaches. The constructed beach at Magic Island has been effectively protected by offshore breakwaters. However, this heavily engineered approach does not appear suitable for the cell as a whole.
- Shoreline change patterns at Sand Island, where a beach is present, is similar to that at Ala Moana Beach. There is a mixture of accretional and erosional areas and longshore drift being a dominant feature. Sand Island is an artificial island, and much of its shoreline has been hardened with riprap.
- The Honolulu Reef Runway – Pearl Harbor cell has not been mapped by UH. The majority of this area is hardened shorelines with no beach.

- Much of ‘Ewa Beach and Iroquois Point is stable. However, Keahi Point, at the entrance to Pearl Harbor, is the most erosional shoreline in the study area – with retreat rates up to 5 feet per year observed.

These erosion maps and the underlying measurements of shoreline position, based on available aerial photography, are one of the main inputs to the regional sediment budget prepared by Moffatt & Nichol 2009.

IX. Coastal Ecosystem

Marine life in the area 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 reefs offshore of the study area not only provide shoreline protection, but also provide food and habitat for many threatened and endangered species in the waters around O‘ahu. Macroalgae covers over fifty percent of the benthic habitat in the reef system and listed species that may occur in or near the study area could include the Hawaiian monk seal, humpback whale, green sea turtle, 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).

A number of important management sites are also located within the study area. Fishery Management Areas (FMAs) are located at Honolulu Harbor and the Waikiki-Diamond Head Shoreline and a Marine Life Conservation District (MLCD) is located at Waikiki (NMS 2009). The Hawaiian Islands Humpback Whale National Marine Sanctuary is southeast of Diamond Head (NMS 2009).

X. Regional Sediment Budget

Moffatt & Nichol 2009 presents a preliminary sediment budget for the D2P region. The budget is based on available information regarding reef productivity, shoreline accretion and erosion, and the patterns of wave-driven currents. However, the significant uncertainties in the different elements of the budget, and the fact that the losses offshore and into the deep channels have not been quantified individually (the values are selected to balance the budget) mean that the actual numbers should only be considered a guide. However, the values are adequate for planning and evaluating potential sediment management and beach nourishment projects in the region.

The sediment budget was developed based on volume changes in the past few decades. Six littoral cells are defined, as shown in Figure 18.

The timeframe for the analysis varies by littoral cell, based on the extent of recent human modifications and the availability of aerial photography: from 1957 to 2005 for Diamond Head, Sand Island, and the Reef Runway cell; and 1968 to 2005, after the construction of Magic Island, for Waikiki and Ala Moana; and 1961 to 2005 for Iroquois Point. .

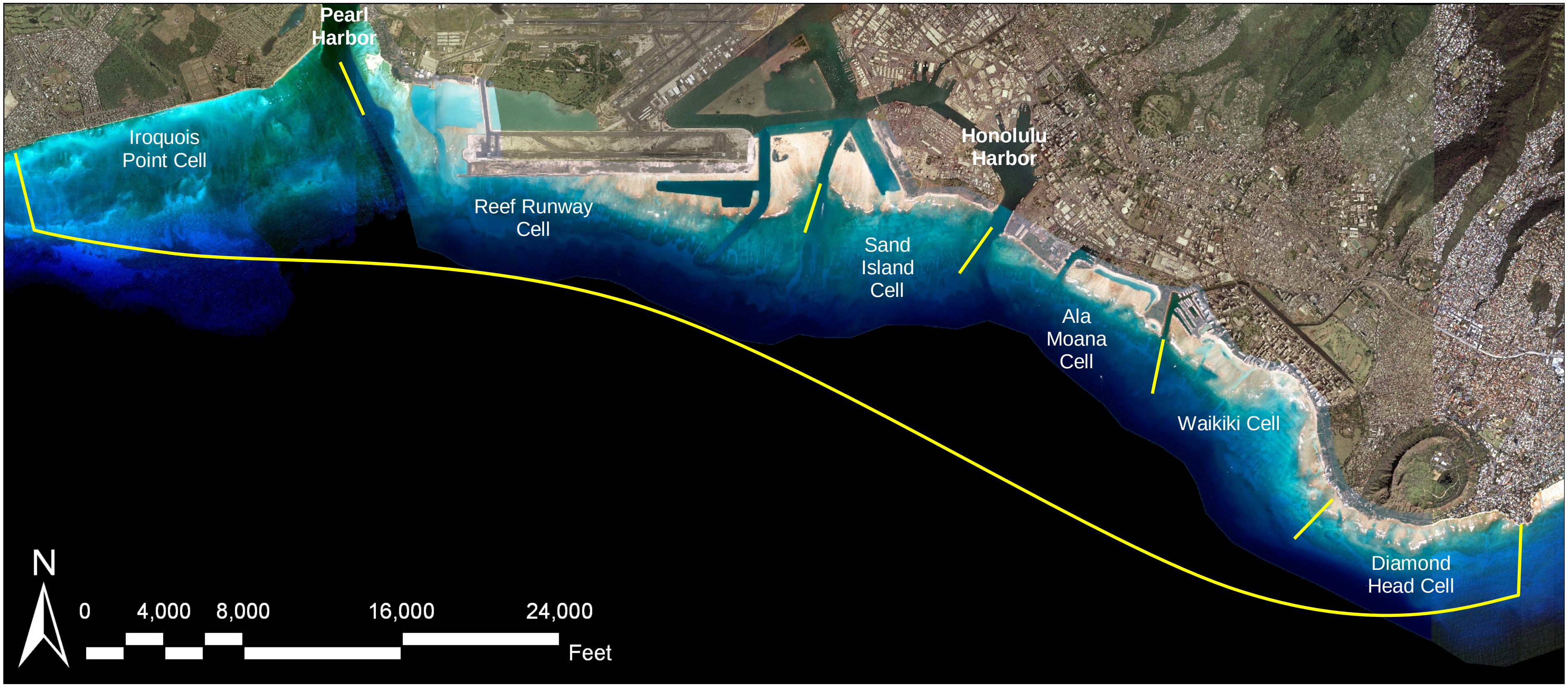


Figure 18. Diamond Head to Pearl Harbor (D2P) Littoral Cells

The general approach to budget development is as follows.

- The volume of sediment released from beaches through erosion, and impounded in beaches and upland areas through accretion, was estimated based on the analysis of aerial photography prepared by the University of Hawai‘i (Hawai‘i Coastal Geology Group 2009; see Section VIII.B). Minor additions and modifications were made for the present application, and retreat distances were converted to retreat volumes using a conversion factor of 0.44 cubic yards per square foot of beach, based on available measurements of local beach profiles.
- Historical beach nourishment volumes were taken from work by Wiegel 2002, 2008.
- The rate at which new calcareous sediment is produced by reefs is highly uncertain. An approximate estimate is given based on the reef area and its likely low productivity. However, the rate of modern reef production is a significant data gap.
- The majority of loss mechanisms are included in the budget through balancing, rather than through independent estimation.

With the volume changes established, the sediment transport pathways are developed based on coastal processes – particularly the current modeling described in Section VII.E – and on general morphological considerations. The resulting preliminary sediment budgets for the different littoral cells are illustrated in Figure 19 through Figure 24.

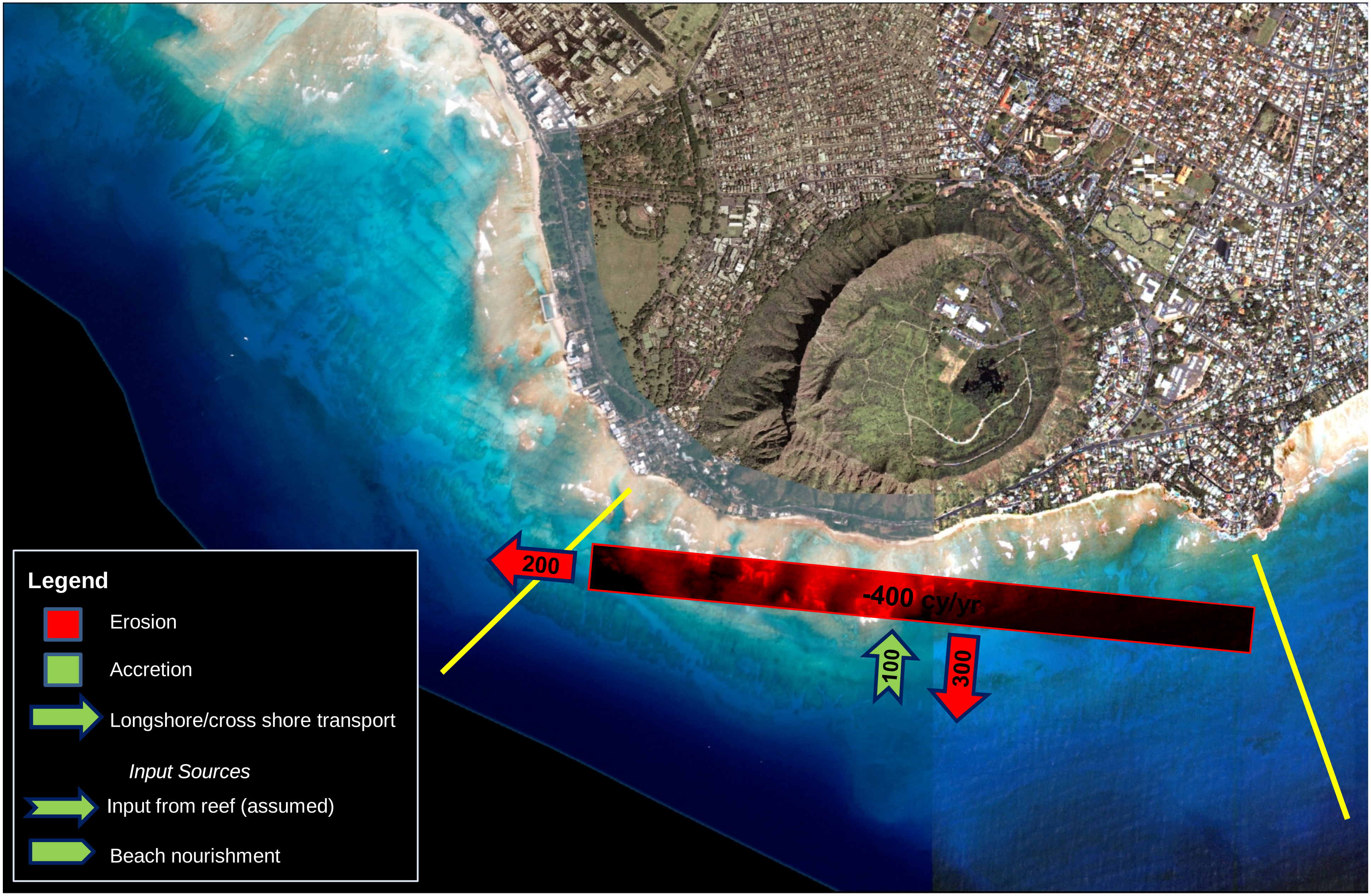


Figure 19
Preliminary Sediment Budget for Diamond Head
Analysis dated December 2009

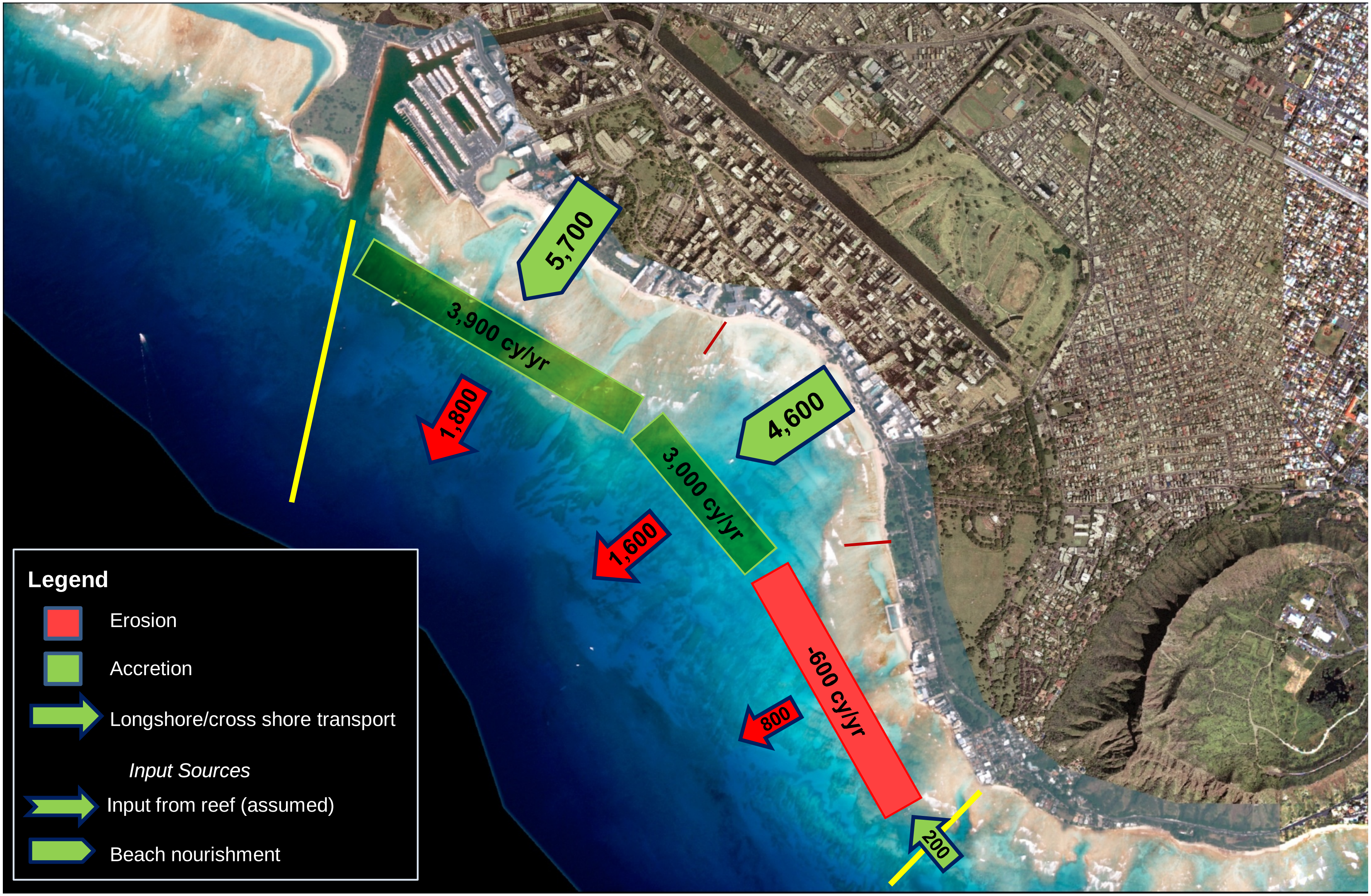


Figure 20a
Preliminary Sediment Budget for Waikiki 1965 to 1985
Analysis dated December 2009

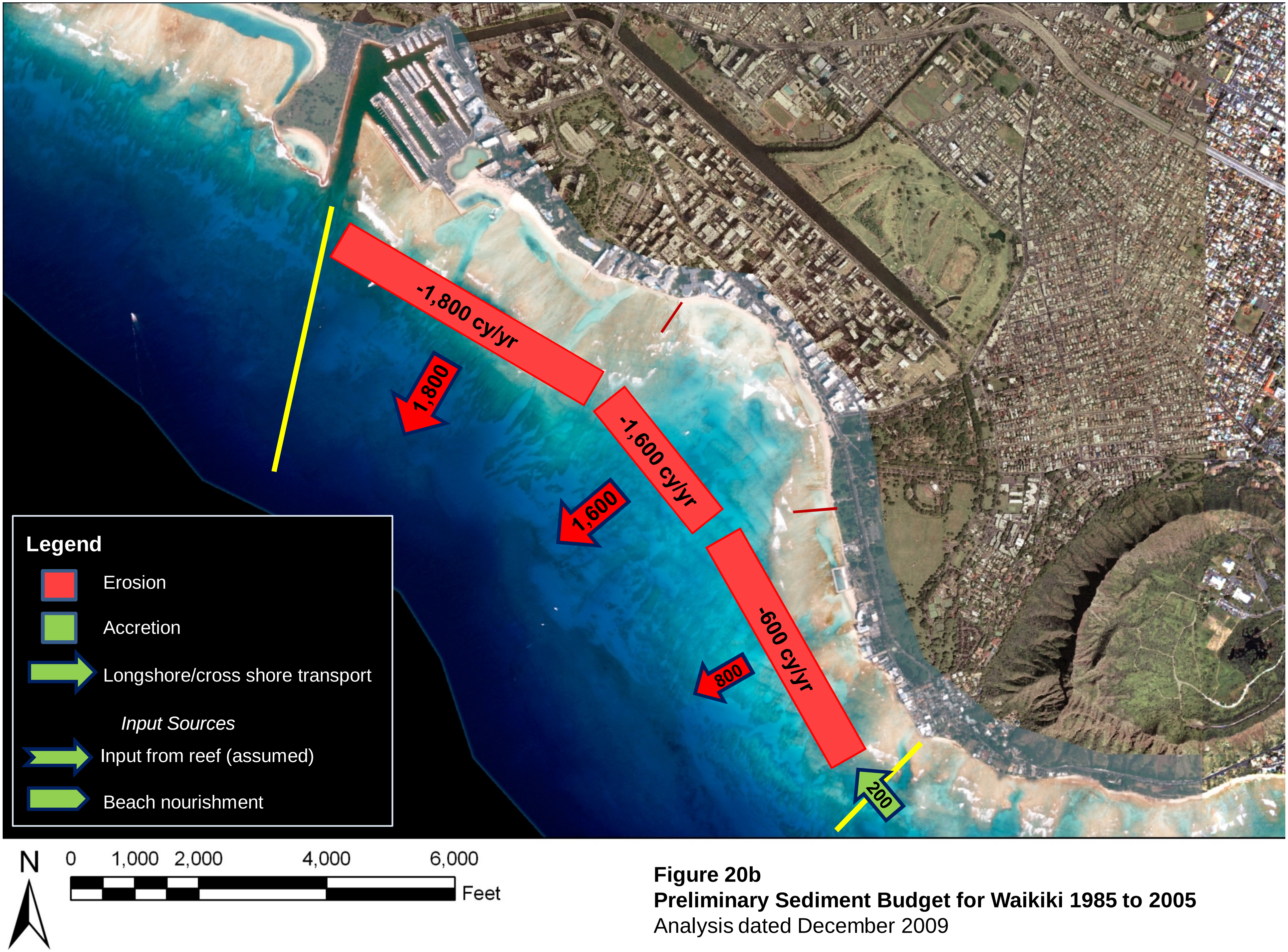


Figure 20b
Preliminary Sediment Budget for Waikiki 1985 to 2005
Analysis dated December 2009

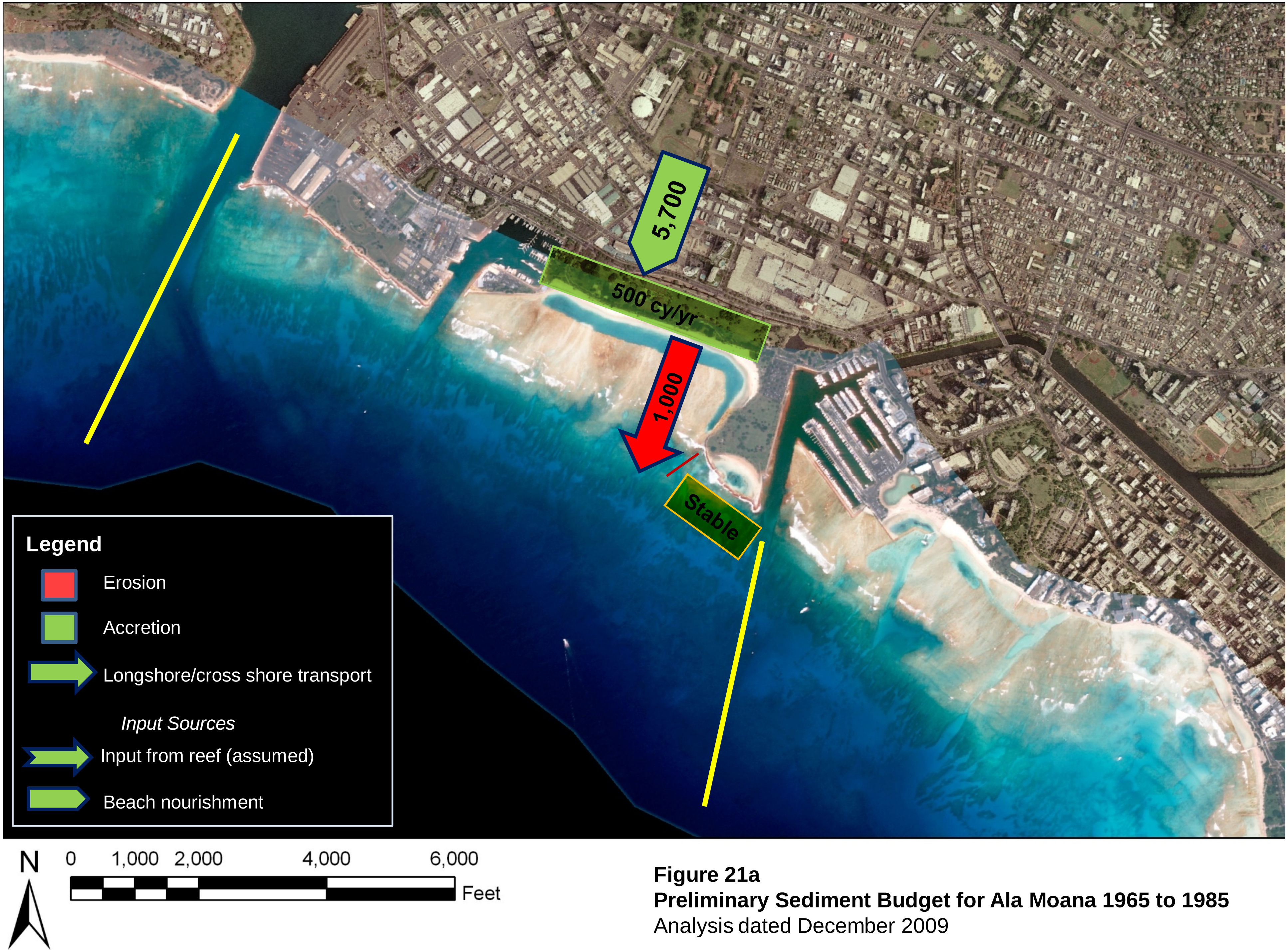


Figure 21a
Preliminary Sediment Budget for Ala Moana 1965 to 1985
Analysis dated December 2009

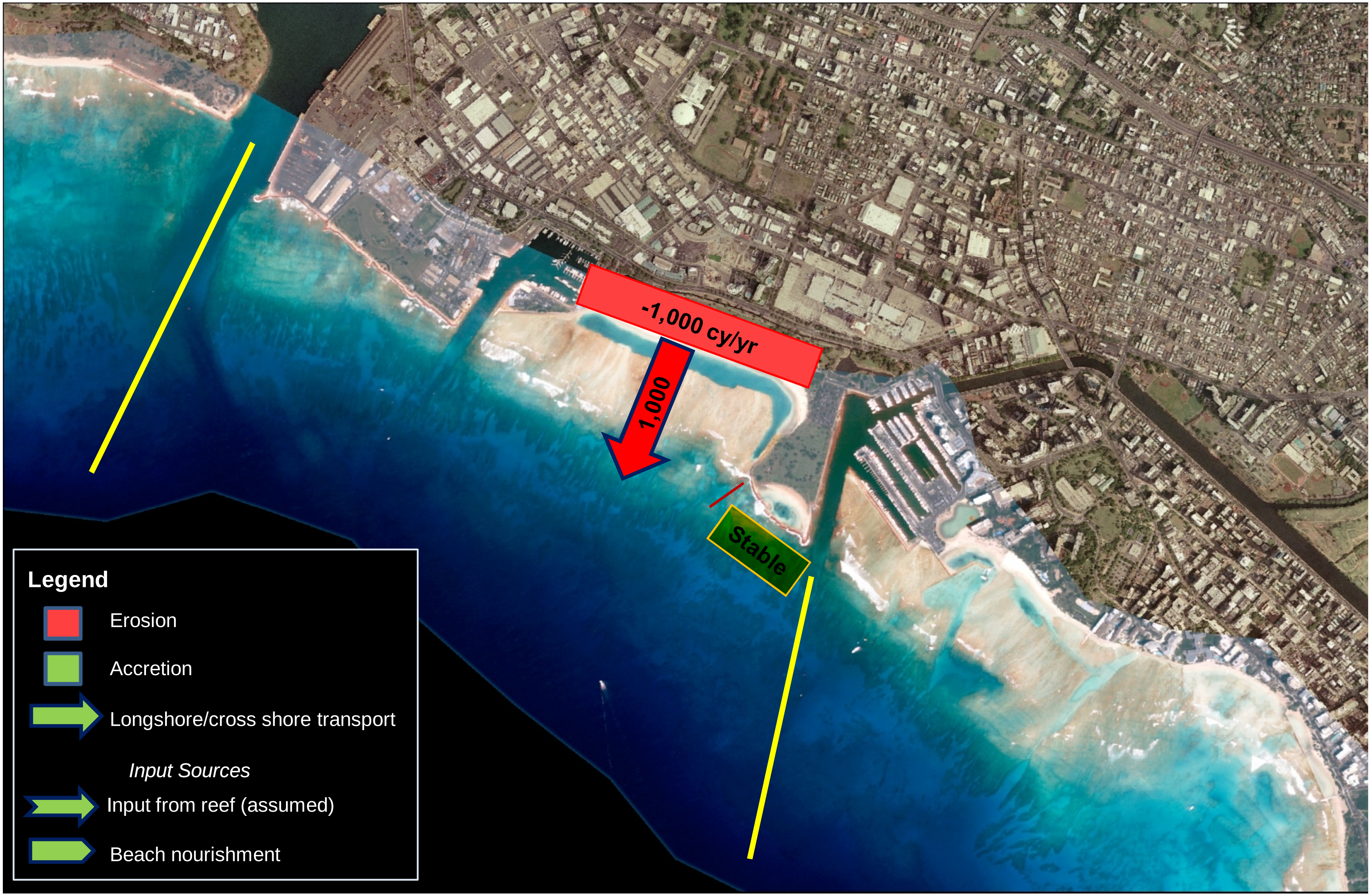


Figure 21b
Preliminary Sediment Budget for Ala Moana 1985 to 2005
Analysis dated December 2009

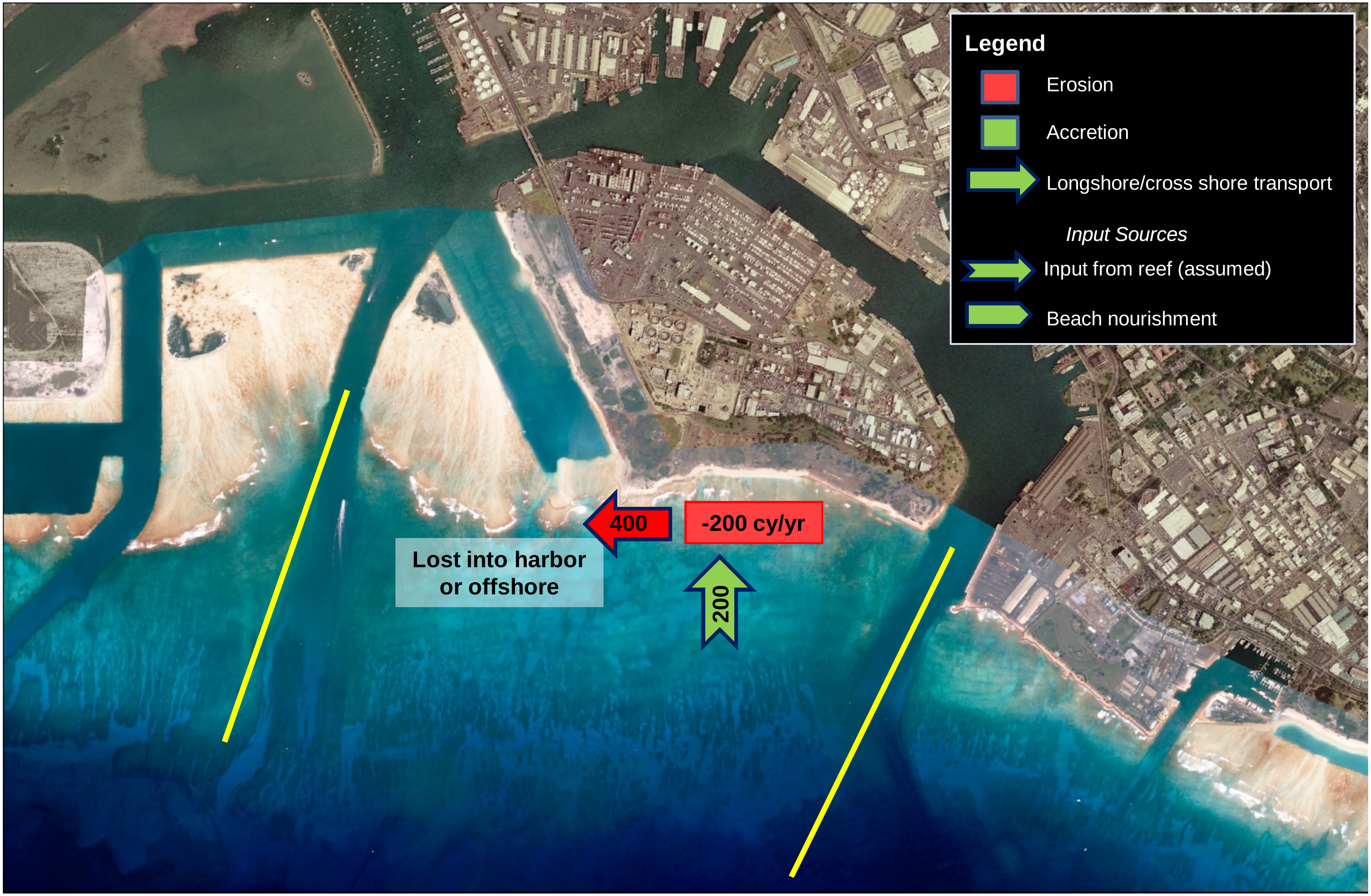


Figure 22
Preliminary Sediment Budget for Sand Island
Analysis dated December 2009

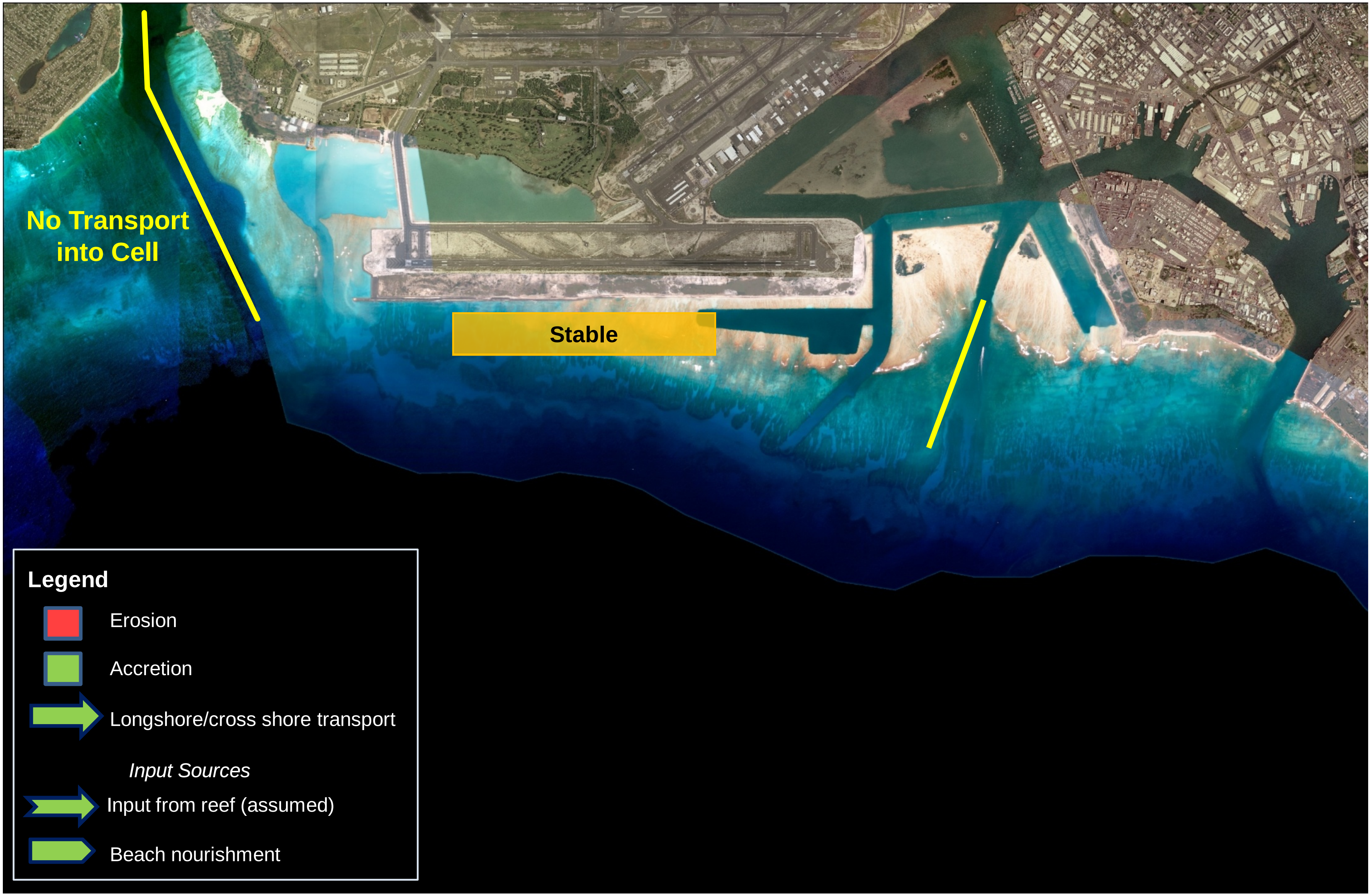


Figure 23
Preliminary Sediment Budget at the Reef Runway
Analysis dated December 2009

Figure 24
Preliminary Sediment Budget for Iroquois Point
Analysis dated December 2009

Results for the six littoral cells include the following:

- **Diamond Head** is a slightly erosional cell. Transport rates in this cell are small – a few hundreds of cubic yards annually. There may be a small modern production of sand by the nearshore reef: this sand would be transported north into the Waikiki cell or offshore into deep water.
- The heavily engineered **Waikiki** cell is generally erosional at present, with sand moving from the beaches to the reef and further offshore. Between 1965 and 1985, beach nourishment at an average rate of approximately 10,000 cubic yards annually led to an accretion of the beach along the central and ‘Ewa portions of the Waikiki cell. However, this reversed between 1985 and 2005, when almost no beach nourishment took place. The 2006 nourishment at Kuhio Beach, if it is not an isolated event, may halt the ongoing erosion.
- The **Ala Moana** cell is similar in behavior to Waikiki. The beach at Magic Island is protected by three detached breakwaters, and is generally stable. The beach at Ala Moana Park is losing sand at a rate of about 1000 cubic yards per year. While 30,000 cubic yards of sand was placed in 1976, this has since been lost offshore.
- The **Sand Island** cell contains little sand. Transport rates are low – a few hundreds of cubic yards annually.
- The **Iroquois Point** cell, ‘Ewa of Pearl Harbor, contains a combination of erosional and accretional areas. Most of the south-facing shoreline of this cell, along ‘Ewa Beach, is slightly accretional. This may result from reef production or longshore sand transport from the ‘Ewa side. Keahi Point is extremely erosional, likely because of loss into the dredged channel at Pearl Harbor: some of the 3,800 cubic yards lost annually from this part of the littoral cell is transported to the beach within Pearl Harbor, just south of Iroquois Lagoon.

XI. Ocean Sand Source Inventory

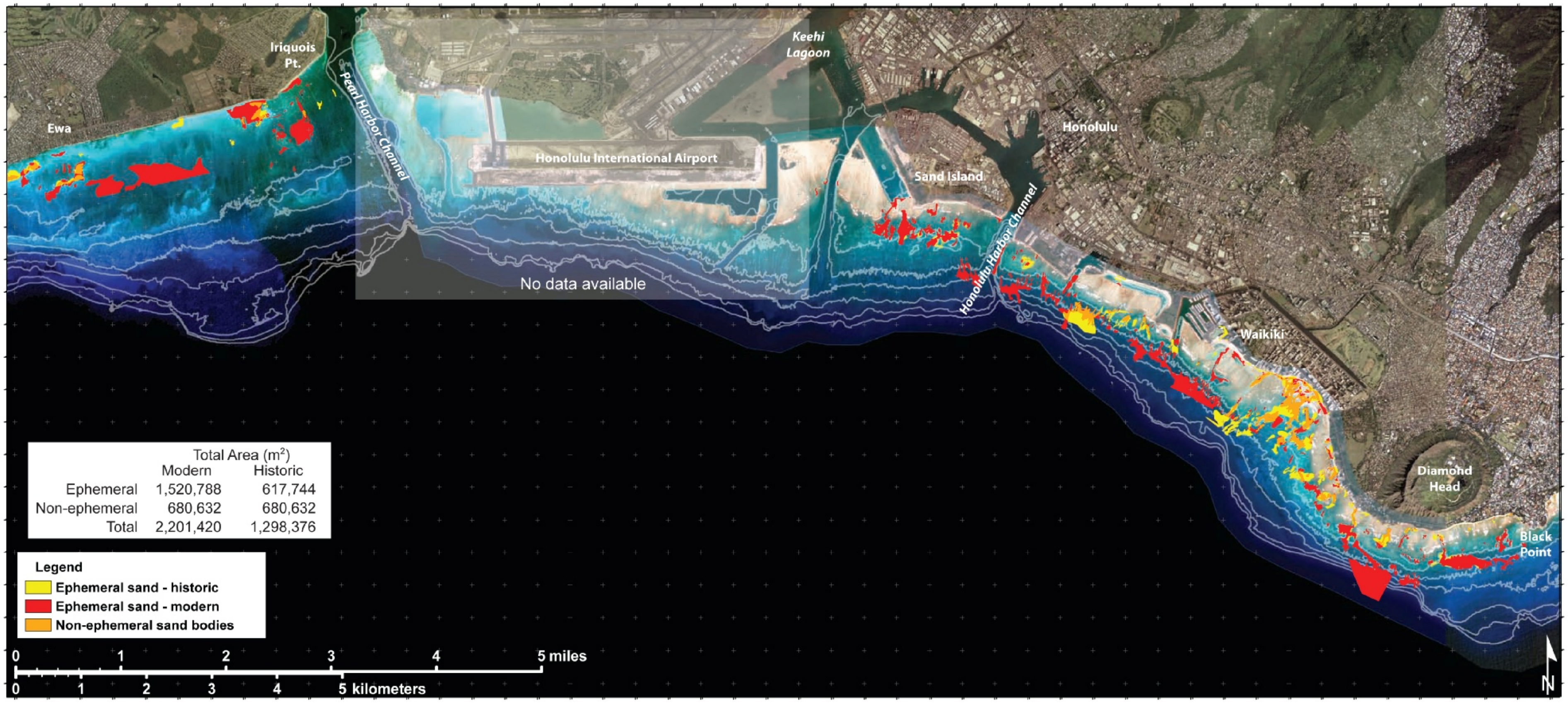
There are believed to be significant sources of sand offshore of the study area, held in low spots and channels on the reef (e.g., Hampton, Blay, and Murray 2004). The University of Hawai‘i, Coastal Geology Group, used high-resolution (0.5 m) orthorectified photomosaics to examine nearshore submarine sand fields (USACE Honolulu District 2010). Changes in the extent of these sand bodies over time help differentiate ephemeral and stable sand volumes that may indicate potential sand resources. Mosaics from 1949, 1950, 1967, and 1970 were selected as base maps to quantify historical sand body extent. Mosaic coverage from 2005 was chosen for the modern base map.

Continuous sand bodies visible in each mosaic were manually digitized. Sandy areas that overlap between historical and modern datasets are inferred to represent relatively stable areas of sand that may be of potentially significant volume. Sandy areas with no spatial overlap indicate sand that has been transported within the past 50 years (the temporal extent of map coverage) and is not likely to be of sufficient thickness for use as a resource. Some areas could not be mapped conclusively, either because of surface glint (water surface reflectance) or due to suspended sediments in shallower water less than 15 feet deep) that obscure potential sandy substrate identification. These two sources of uncertainty affect sand body identification offshore of ‘Ewa Beach to the west of Pearl Harbor Channel. The 2005 coverage in these areas indicates significant sand coverage – 3,800,000 square feet (350,000 square meters). However, no apparent bottom is visible in historic imagery due to significant suspended sediment.

Sand body analysis of the south shore of O‘ahu within the study area indicates approximately 7,300,000 square feet (680,000 m^2) of apparent stable sand.

- The western portion of the study area between the entrance to Pearl Harbor and ‘Ewa Beach contains approximately 1,100,000 square feet (100,000 m^2) of stable sand. The nearshore area is characterized by shallow reef flat within the extents of available base map data.
- The central portion of the study area between the Honolulu Reef Runway and Diamond Head contains approximately 5,300,000 square feet (490,000 m^2) of apparent stable sand. The near shore area is characterized by reef and rock bottom interspersed with sand pockets.
- The remaining section of the study area between Black Point and Diamond Head contains approximately 900,000 square feet (87,000 m^2) of apparent stable sand. The majority of this sand is a single sand body between 15 and 30 feet water depth.

Figure 25 shows the sand bodies identified and classified in this way. The results are summarized in Table 2. Sub-bottom investigations will be required to quantify sand thickness and volumes.



	Total Area (m^2) Modern	Total Area (m^2) Historic
Ephemeral	1,520,788	617,744
Non-ephemeral	680,632	680,632
Total	2,201,420	1,298,376

Figure 25. Digitized modern sand bodies (red) and historic (yellow) with intersecting bodies, presumed stable, in orange

Table 2: Results of Sand Body Surface Analysis

Coverage	Modern	Historic
Total coverage (sq. ft. x1000)	23,700	14,000
Ephemeral coverage (sq. ft. x1000)	16,400	6,700
Non-ephemeral coverage (sq. ft. x1000)	7,300	7,300

Note: Modern Total and Modern Ephemeral Total includes sand bodies offshore of ‘Ewa Beach that are not visible in historic data likely due to obscured water column

XII. O‘ahu Stream Sediment Management

In some areas of O‘ahu, sediment management at stream mouths could be greatly improved. For example, the M2M RSM Plan identified Ka‘elepulu Stream as a potential area for improvement (Oceanit Laboratories 2006). At present, approximately 36,000 cubic yards per year of sand is removed from the stream mouth and, in large part, pushed up on to the banks of the stream. This sand is effectively lost to the littoral zone. The RSM Plan recommends that the sand removed from the stream mouth should be placed at other locations on the adjacent Kailua Beach.

To assist in the development of appropriate stream mouth sediment management practices along the entire coastal zone of O‘ahu, a Stream Mouth Map Book has been prepared (USACE 2010). The map book presents 62 stream mouths that empty into the ocean on O‘ahu. It devotes one page to each stream mouth including a description of the littoral setting, a rectified vertical aerial photograph, ground level photographs, a description of current management practices, and recommendations for management.

A workshop on the topic of O‘ahu Stream Sediment Management was hosted by the State DLNR Office of Conservation and Coastal Lands (OCCL) on December 15, 2009. Attendees were present from the City and County of Honolulu, DLNR-OCCL, POH, and the University of Hawai‘i. Current management practices by the City and County of Honolulu, regulatory issues, and pilot stream mouth sediment management projects were among the topics discussed. None of the proposed pilot projects were within the D2P study region, and at present no recommendations for stream mouth management within this region have been put forward.

XIII. Potential RSM Projects

A. Waikiki Beach Potential RSM Project

Goals of the Waikiki Beach Potential RSM Project (PRP) include the coordination of Federal, State and local efforts to nourish and maintain the beaches in this highly utilized urban setting. Federal interest in the area involves the Waikiki Area Erosion project and the Ala Wai Watershed study. The State of Hawai‘i is currently studying the sustainability of utilizing offshore sediment resources to nourish the Waikiki shoreline. The City and County of Honolulu is recommending the creation of a recreational beach within the footprint of the Natatorium War Memorial. Private property owners have also proposed shore protection projects within the area. D2P/RSM studies are focused on facilitating the efficient and effective use of these resources toward the common goal of improving the quality of beaches throughout the entire region.

Federal Interest: The Waikiki Area Erosion project was authorized under the River and Harbor Act of 1965. The goal of the project is to provide for a stable protective beach that is both publicly and environmentally acceptable. The authorized plan includes restoring and protecting approximately 10,800 feet of shoreline along Waikiki Beach from Duke Kahanamoku Beach to the Elks Club. Two of the eight project reaches authorized for construction in 1965 have been implemented to date. The Fort DeRussy reach was completed in 1971 with non-appropriated military funds. Construction of the Kuhio Beach sector was completed by the State of Hawaiʻi in 1972. Construction of the uncompleted portions of the authorized project is currently estimated at $24,000,000.

The Federally authorized Waikiki Area Erosion project is currently in the Preconstruction and Engineering (PED) phase. However, because of a lack of funds the project has been suspended. The project sponsor, State DLNR, has solicited assistance from the Hawaiʻi delegation in the project implementation process. A study recommending Federal participation in the PED phase was submitted to Headquarters, U.S. Army Corps of Engineers (HQ USACE) in November 2002. The study concluded that the project, as authorized, fulfills the current day needs at Waikiki Beach and is economically justified based on estimated National Economic Development (NED) benefits exceeding project costs. However, the economic justification was based on recreation benefits, considered a low administration budget priority, and visitor expenditures which are not recognized as a NED benefits. Subsequently, the State has decided to pursue design and construction of a locally funded Waikiki Beach shore protection project.

State Of Hawaiʻi Interest: There are two main State concerns regarding ongoing erosion of the beach at Waikiki. In addition to the loss of beach width, and associated effects on tourism, the process of offshore sand migration may have environmental impacts on benthic flora and fauna, the filling of holes on the reef top, changes to bottom feeding fish habitats, and its impact on wave breaks and surf sites

Beach restoration using nearshore sand sources will minimize the environmental impact of onshore and offshore sand transport. However, a single restoration is not considered a permanent solution because of the ongoing erosion.

The State Office of Conservation and Coastal .Lands (OCCL) desires to replenish sand that has been lost from the beach to the nearshore area through an ongoing sand maintenance effort. This “recycling” strategy can be an efficient method of maintaining a recreational beach in Waikiki as well as minimizing the environmental effects of sediment brought into the Waikiki marine ecosystem over the last 50 years. Measures to improve sand management will include, but not be limited to, the periodic identification, mapping, and analysis of offshore sand deposits, extraction of this material, and periodic beach restoration.

Two primary objectives for this work are: 1) obtaining an approved environmental impact statement for periodic beach restoration and maintenance of Waikiki Beach and its supporting activities, and 2) design, permitting, and the preparation of construction documents for beach restoration and maintenance at Waikiki Beach.

City and County of Honolulu Interests: The City and County of Honolulu currently plans to demolish the derelict Natatorium pool and bleachers, while relocating the historic entryway arches inland. Approximately 330 feet of beach will be restored in the pool location. Based on the need for an Environmental Impact Statement and the level of public interest involved, the process is likely to take several years.

Private Interests: Kyo-Ya Hotels and Resorts, owners of the Sheraton Waikiki Hotel, plans to restore and stabilize Gray's Beach. The planned project would place 15,000 cubic yards of sand on the beach, adding 75 feet of beach width along the 500-foot shoreline fronting the Sheraton Waikiki. Nearshore sand sources would be dredged and placed on the beach, and low-profile rock T-groins would be constructed to retain the sand.

Waikiki Beach PRP: The following activities are being pursued in association with the Waikiki Beach PRP. These activities will be developed contingent upon the receipt of additional funding.

- Offshore Geophysical Sand Source Investigations:

  University of Hawai'i Offshore Sand Source Investigations
  State of Hawai'i Proposed Borrow Areas

- D2P Regional Sediment Budget (RSB):

  A RSB has been developed that incorporates the Waikiki Beach littoral cell. Further development of the D2P RSB will help identify problem areas and sustainable offshore sand sources.

- D2P/RSM Workshops:

  A series of workshops will be conducted to facilitate development of RSM strategies to nourish the beaches in the Waikiki area.

- Fort DeRussy Sand Backpassing:

  Erosion along the Fort DeRussy Beach shoreline currently threatens to expose the seawall facing the sidewalk which extends along the full length of this Federally owned parcel. Beach width are narrow (on the order of 30 feet) at the Diamond Head side of the reach. Wave overwash and sedimentation on the landward side of the beach are problematic where beach widths are narrow. In contrast, at the Ewa side of the reach, beach widths are as great as 270 feet. Since the predominant sediment transport direction is from east to west along this portion of the Waikiki Beach shoreline, sand backpassing is proposed to provide a more even distribution of sediment and uniform protection of upland development at the Fort DeRussy parcel.

  Figure 26 shows the various components of a recent shoreline inventory conducted between the Sheraton Waikiki Hotel and the Ala Wai Yacht Harbor. The red line depicts the approximate location of the mean high water shoreline during the time of the inventory. The black line shows the location of the sidewalk that demarks the limit of the sandy beach. At Fort DeRussy Beach, the sidewalk is fronted by a low crested seawall. The seawall provides protection against undermining of the sidewalk, but wave frequently overwash the structure and inundate upland areas. Figure 27 shows the extremes in beach width from the western limit to the eastern limit of the shoreline reach (left and right photographs). These figures show that beach width varies dramatically along the Fort DeRussy Beach shoreline.

  Facilitation of sand backpassing from west to east at Fort DeRussy Beach is a component of the Waikiki Beach PRP. Partners in this effort will include the U.S. Army's Hale Koa Hotel, Hilton Hawaiian Hotel, Federal and State resource agencies, POH as well as other stakeholders.

Figure 26. Shoreline inventory for the D2P shoreline between the Sheraton Waikiki Hotel to the east and the Ala Wai Yacht Harbor to the west

Figure 27. Looking west from the eastern limit of the Fort DeRussy reach (left photograph) and east from the western limit (right photograph)
Photograph orientation represented by blue and orange arrows, respectively, in Figure 26.

B. Honolulu Harbor Potential RSM Project

Goals of the Honolulu Harbor PRP would include maximizing beneficial use of beach quality material that is dredged from the harbor. Given the low dredging quantities in Honolulu Harbor, this project is not considered a high priority.

C. Pearl Harbor Potential RSM Project

Goals of the Pearl Harbor PRP include maximizing beneficial use of beach quality material that is dredged from the harbor. The project also investigates the potential for reducing the amount of littoral material that currently shoals within the entrance and main channels. The Diamond Head to Pearl Harbor regional sediment budget indicates that at least 3,000 cubic yards per year of littoral sediment is transported into the Pearl Harbor entrance channel. The majority of this material comes from the west. In 2004, approximately 143,000 cubic yards of material was dredged from the entrance channel through Nevada Point on the interior of the harbor. In 2006, about 25,000 cubic yards total was removed from Bishop Point, Hospital Point and the at the entrance of the Submarine Base. Another 23,000 cubic yards was dredged that same year from the western bank of the main channel near Iroquois Point.

Historically, the sediment dredged from Pearl Harbor entrance and main channels has been a combination of sand and silt. Generally, contractors have been responsible for disposal of the dredged material. No beach disposal areas are currently permitted for the placement of the suitable fraction of the sediment. RSM opportunities are being sought that would enable direct placement of beach quality dredge material back into the littoral system. Processing of the marginal quality portion of the dredged sediment is also being considered to facilitate beneficial use activities.

Private Interests: The Iroquois Point housing area is located on the central south shore of Oah‘u, immediately west of the Pearl Harbor entrance channel and adjacent to the community of ‘Ewa Beach. The project area extends along 4,200 feet of shoreline.

In 2003, the Iroquois Point housing area was leased by the U.S. Navy to Ford Island Housing, LLC, to maintain and operate for 65 years. This lease has recently been extended to 99 years. The chronic shoreline erosion problem was noted during the lease negotiations, and a lease “credit” was given by the Navy to Ford Island Housing in recognition of the erosion problem. The Navy has granted Ford Island Housing the requisite property interest and accompanying authority to undertake the proposed beach restoration and stabilization project and to maintain it for the duration of the lease.

The existing ground elevation at the housing area is +5 to +7 feet above MLLW. The shoreline consists of a sandy beach. Chronic erosion and shoreline recession, coupled with backshore flooding due to wave overtopping of the low-lying shore, have resulted in the abandonment and demolition of 16 shoreline homes to date. Several more homes are threatened by shoreline recession, and emergency shore protection for these homes was constructed in February 2004. Sewer lines running along the shore were abandoned and relocated in the 1980’s, and now the old concrete sewer pipe lies exposed and broken on the beach. Sand berms, wooden walls, and concrete walls have been constructed behind the beach crest to prevent flooding. All of these measures have ultimately failed, some failing almost immediately, because of the on-going erosion. The project proponent believes that eroded sand is transported to the east and into the Pearl Harbor entrance channel.

The Ford Island Housing proposed beach restoration plan consists of nine T-head groin structures extending along the 4,200-foot project reach. Approximately 97,000 cubic yards of sand would be placed on the beach. The sand will be obtained by maintenance dredging of accreted sand along the west side of the Pearl Harbor entrance channel in the vicinity of the Iroquois Lagoon entrance.

Pearl Harbor PRP: The following activities are being pursued in association with the Pearl Harbor PRP. These activities will be developed contingent upon the receipt of additional funding.

- Reduce Entrance Channel Shoaling:

  Identify Sources of Shoaling
  Intercept Material Before it Reaches the Channel
  Investigate Feasibility of Constructing Deposition Basin

- Identify Dredge Material Stockpile Areas:

  Capacity Requirements
  Land Ownership
  Identify Potential Safety Issues

- Designated Beach Disposal:

  Identify Disposal Area Location
  Quantify Disposal Volumes
  Identify Characteristics of Suitable Material
  Develop Construction Template
  Predict Ultimate Fate of Placed Material

- Investigate Post Processing of Dredged Material:

  Hydrocycloning
  Other Methods

XIV. Conclusions and Recommendations

A. Conclusions

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

- Waikiki Potential RSM Project: There is ongoing erosion in the Waikiki area as a whole. In the 1970s, this was effectively countered by beach nourishment. Between the early 1980s and 2006, almost no beach nourishment occurred, and the beach narrowed significantly. The 2006 nourishment of Kuhio Beach was successful, but ongoing nourishment in the area is needed. Similarly, sand that was placed along Fort DeRussy Beach has partially migrated to the west. This has resulted in narrowing of the beach on the eastern portion of the reach while the western portion of the reach has experienced dramatic accretion. At present, the beach width along the western shoreline of Fort DeRussy Beach is seven times wider than that to the east. One of the components of the Waikiki Beach PRP will be to facilitate and coordinate sand backpassing at Fort DeRussy Beach.

- Pearl Harbor Potential RSM Project: There is ongoing erosion at the Iroquois Point Housing area near Keahi Point, immediately ‘Ewa of the Pearl Harbor entrance. This may be associated with loss of sand into Pearl Harbor – along the beach at Iroquois Point, and in the channel. There may be opportunities to decrease erosion rates, reduce shoaling in the channel entrance, and nourish adjacent beaches.

- In the D2P region, a good degree of localized coordination appears to be in place. The importance of Waikiki’s beaches to the tourist industry has encouraged coordination between the U.S. Army, the hotel industry, and various State of Hawai‘i offices. The existence of a single organization (Ford Housing, LLC) that manages Iroquois Point housing area has led to the pursuit of a single project to manage 4,200 lineal feet of eroding beach. However, ongoing coordination between the Federal interests, the State of Hawai‘i, and the City and County of Honolulu should be furthered.

- Stream mouth management does not appear to be a major issue in the D2P region and no associated Potential RSM Projects have been identified.
- Dune protection does not appear to be a major issue in the D2P region and no associated Potential RSM Projects have been identified.

B. Recommendations

It is recommended that the following products be developed in association with the D2P region of the SEO/RSM Project in FY10.

- Coastal Processes Modeling: Continue water circulation and wave transformation numerical modeling to refine the D2P regional sediment budget. For instance, in the Waikiki Beach littoral cell, there appears to be significant movement of sand between the beaches and the reef. This sediment circulation is not well understood. Given the likely need for ongoing nourishment at Waikiki Beach, these sediment pathways will be investigated further through field work and more detailed coastal processes modeling analyses.
- Regional Sediment Budget: Update the preliminary D2P regional sediment budget based upon the findings of FY10 investigations.
- GIS/IMS: Update the Honolulu District RSM web site to include the D2P region. Similar to the products that are currently available for the M2M region, the D2P products will be ported to the web site. Historical aerial photography, digitized shorelines, ground photography, coastal structure inventory, regional sediment budget, reports and other D2P products will be available to the public on the web site. An Internet Map Server will provide real-time mapping capabilities to enhance the utility of the information compiled for the region.
- Potential RSM Projects: Develop details for potential RSM projects identified in FY09 to improve sediment management strategies in the region. Activities to reduce project costs and increase beneficial use of sediments on a regional scale at Pearl Harbor, Waikiki Beach and Iroquois Point will be investigated and coordinated with various stakeholders. For instance, backpassing of sand at the eastern limit of Iroquois Point to beaches to the west could significantly reduce Pearl Harbor dredging requirements. Also, identification of a substantial and sustainable sand source in the vicinity of Waikiki Beach could greatly reduce the cost of restoring its highly utilized urban beaches. Potential backpassing of sand from west to east along the Fort DeRussy shoreline will also be facilitated and coordinated. Due to the limited amount of maintenance dredging that has historically been required at Honolulu Harbor, additional RSM investigations are not recommended for that Federally authorized project at this time.
- RSM Plan Report: Revise preliminary D2P Regional Sediment Management Plan Report to reflect the tasks accomplished in FY10.
- D2P/RSM Workshop: Conduct a series of informational workshops concerning the needs, findings and RSM opportunities within the D2P region. The workshops will

provide an overview of the tasks accomplished in the D2P region and include detailed discussions on the findings presented in the D2P/RSMP.

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Rosati, J.D., B.D. Carlson, J.E. Davis, and T.D. Smith. 2001. The Corps of Engineers National Regional Sediment Management Demonstration Program. CHETN-XIV-1, U.S. Army Engineer Research and Development Center ERDC/CHL, Vicksburg, MS. <http://chl.erdc.usace.army.mil/library/publications/chetn/pdf/chetn-xiv-1.pdf>.

Sea Engineering, Inc. 2008. Waikiki Beach War Memorial Natatorium, Honolulu, Hawaii. Shoreline Restoration Study Conceptual Design Review Report. Prepared for U.S. Army Corps of Engineers, Honolulu District, and City and County of Honolulu, Department of Planning and Construction.

Sea Engineering, Inc., and Group 70 International. 2008. Wave Modeling Comparison: Kaumalapua, Waikiki, and Kikiaola. Islands of Lanai, Oahu, and Kauai.

Tomascik, T. and F. Sander, F. 1985. Effects of eutrophication on reef-building corals. 1. Growth rate of the reef-building coral *Montastrea annularis*. Marine Biology 87, 143-155.

Tracy, B.A. 2009. Wave Transformation of Wave Information Studies Pacific Basin Information for the south shore of Oahu in the Hawaiian Islands (D2P Region from "Diamond Head" to "Pearl Harbor"). Prepared for the U.S. Army Corps of Engineers, Honolulu District.

University of Hawai'i Sea Grant Extension Service and County of Maui Planning Department. 1997. Beach Management Plan for Maui.

United States Army Corps of Engineers (USACE), Honolulu District. 1992. Waikiki Beach Erosion Control: Island of Oahu, Hawaii. Reevaluation Report. January 1992.

U.S. Army Corps of Engineers (USACE), Honolulu District. 2010. Oahu Coastal Stream Mouth Map Book. Prepared by the University of Hawaii Coastal Geology Group for Honolulu Engineering District, 68 p..

U.S. Army Corps of Engineers (USACE). 2009. Water Resource Policies and Authorities: Incorporating Sea-Level Change Considerations in Civil Works Programs. Engineering Circular EC 1165-2-211, dated July 1 2009.

Vitousek, S. and C.H. Fletcher. 2008. Maximum annually recurring wave heights in Hawai'i. Pacific Science 62, No. 4, pp. 541-553. <http://www.soest.hawaii.edu/coasts/publications/Vitousek_SCD08.pdf>

Wang, N. and F.Gerritsen. 1995. Nearshore circulation and dredged material transport at Waikiki Beach. Coastal Engineering 24, pp. 315-341.

Wiegel, R.L. 2002. Waikiki, Oahu, Hawaii, an urban beach: Its history from a coastal engineering perspective. University of California at Berkeley, Report UCB/HEL-2002-1. 15 November 2002.

Wiegel, R.L. 2008. Waikiki Beach, Oahu, Hawaii: History of its transformation from a natural to an urban shore. Shore & Beach 76 No. 2, pp.3-30.

Wolanski, E., J.A. Martinez, and R.H. Richmond. 2009. Quantifying the impact of watershed urbanization on a coral reef: Maunalua Bay, Hawaii. Estuarine, Coastal and Shelf Science, 84, pp. 259-268.

APPENDIX A : LITERATURE SEARCH

Documents Prepared in Support of this RSM Plan

Moffatt & Nichol. 2009. Regional Sediment Budget for O'ahu, D2P Region. Prepared for the U.S. Army Corps of Engineers, Honolulu District.

Provides a preliminary sediment budget for the D2P study area.

Tracy, B.A. 2009. Wave Transformation of Wave Information Studies Pacific Basin Information for the south shore of Oahu in the Hawaiian Islands (D2P Region from "Diamond Head" to "Pearl Harbor"). Prepared for the U.S. Army Corps of Engineers, Honolulu District.

Describes wave transformation modeling work. The STWAVE model is used to transform waves from an offshore WIS hindcast station to the D2P study area. The model setup, validation, and results are shown.

U.S. Army Corps of Engineers (USACE), Honolulu District. 2009. Oahu Coastal Stream Mouth Map Book. Draft, November 2009.

Provides aerial photography and descriptions of stream mouths for the entire coastline of O'ahu. As an addendum, this document also describes a photogrammetric analysis leading to the identification of stable areas of sand offshore of the D2P study area.

Winds, Waves, Tides, and Currents

Bathen, K.H. 1978. Circulation Atlas for Oahu, Hawaii. Sea Grant Miscellaneous Report UNIHI-SEAGRANT-MR-78-05.

Gives seasonal patterns of tidal and wind influenced current patterns based on reports of in situ current meter observations, drogue, drift card and dye studies; as well as visual observations of flotsam and shoreline sediment discharges.

Edward K. Noda and Associates, Inc. 1991. Current Measurement Program, Offshore Waikiki Beach. Waikiki Beach Improvement Project. Prepared for State of Hawaii, Department of Transportation, Harbors Division.

This report was prepared as background to restoration of the Waikiki Beach. The field work included deployment of in-situ current meter and a second wave/current/tide meter, both deployed for 3 months in deep water, seaward of the reef; and drogue measurements within the bay. The work focuses on currents and circulation patterns seaward of the breaker zone.

Hearn, C.J. 1999. Wave-breaking hydrodynamics within coral reef systems and the effect of changing relative sea level. Journal of Geophysical Research, 104 No.C12, pp. 30,007-30,019.

Develops a model to describe the hydrodynamics of wave-driven flow across a coral reef and the resultant flushing of its lagoon. The model requires a current depth coefficient that is sensitive to the form of the frictional law on the reef flat.

Houston, J.R. 1978. Interaction of Tsunamis with the Hawaiian Islands Calculated by a Finite-Element Numerical Model. Journal of Physical Oceanography 8, pp. 93-102.

Describes a finite-element numerical model that determines the interaction of tsunamis with the Hawaiian Islands, and shows good agreement with tide gauge recordings of the 1964 Alaskan tsunami and the 1960 Chilean Tsunami.

Intergovernmental Panel on Climate Change (IPCC). 2007. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Solomon S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (eds.). Cambridge University Press. Also available online at <http://www.ipcc.ch/>.

A very detailed synthesis of accepted science with predictions of possible future climate change, including sea level rise. Provides projections for sea level rise out to 2100.

National Oceanic and Atmospheric Administration (NOAA). 2009a. Datums for Honolulu, HI. Also available online at <http://tidesandcurrents.noaa.gov/data_menu.shtml?stn=1612340 Honolulu, HI&type=Datums>

Provides tidal elevations and other information for the Honolulu tide gauge station.

National Oceanic and Atmospheric Administration (NOAA). 2009b. Mean Sea Level Trend: 1612340, Honolulu, Hawaii. Also available online at < http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=1612340>

Plots the monthly mean sea level without the regular seasonal fluctuations due to coastal ocean temperatures, salinities, winds, atmospheric pressures, and ocean currents. The long-term linear trend is also shown, including its 95% confidence interval.

Sea Engineering, Inc. 2008. Waikiki Beach War Memorial Natatorium, Honolulu, Hawaii. Shoreline Restoration Study Conceptual Design Review Report. Prepared for U.S. Army Corps of Engineers, Honolulu District, and City and County of Honolulu, Department of Planning and Construction.

This study is an evaluation of beach configurations for a number of conceptual designs for restoration of the Natatorium. Specifically, it uses Boussinesq Wave propagation modeling to investigate the effect of those alternatives that include modifying or removing the Natatorium, and evaluates typical current patterns resulting from tides and waves. Given the direction (northward) of littoral drift in the area, removal of the Natatorium would likely cause erosion at San Souci Beach.

Sea Engineering, Inc., and Group 70 International. 2008. Wave Modeling Comparison: Kaumalapua, Waikiki, and Kikiaola. Islands of Lanai, Oahu, and Kauai.

This report examines the suitability of measurements obtained from a wave buoy at Kaumalapau, Lanai, (NDBC 51203) as a proxy for conditions at Waikiki (O‘ahu) and Kikiaola (Kauai). Measurements from the wave buoy were compared to model results obtained from both “deep” and “shallow” locations just offshore of these sites. The report found that wave heights and periods at Kikiaola and Waikiki can be reasonably approximated by NDBC 51203, however direction can often be highly erroneous.

Smith, E.R., B.A. Ebersole, and Ping Wang, 2004. Dependence of Total Longshore Sediment Transport Rates on Incident Wave Parameters and Breaker Type. United States Army Corps of Engineers ERDC/CHL CHETN-IV-62.

Tested the CERC formula for longshore transport, in particular the coefficient K, against laboratory experiments. The CERC formula, which is not sensitive to breaker types, overestimated measurements by a factor of 7 to 8 for spilling breakers, and more than a factor of 3 for plunging breakers. Swash zone transport accounts for a third of total transport for the higher energy cases, and 40 to 60 percent for the lower energy cases.

Storlazzi, C.D. and B.E. Jaffe. 2008. The relative contribution of processes driving variability in flow, shear, and turbidity over a fringing coral reef: West Maui, Hawai'i. Estuarine, Coastal and Shelf Science 77, pp.549-564.

High-frequency measurements of waves, currents and water column properties were made on a fringing coral reef off northwest Maui, Hawai'i, for 15 months between 2001 and 2003 to aid in understanding the processes governing flow and turbidity over a range of time scales and their contributions to annual budgets.

U.S. Army Corps of Engineers (USACE). 2009. Water Resource Policies and Authorities: Incorporating Sea-Level Change Considerations in Civil Works Programs. Engineering Circular EC 1165-2-211, dated July 1 2009.

Gives guidance for incorporating future sea level change into Civil Works projects. The general approach is to consider a low future rate (based on present day trends), and medium and high rates based on defined curves. The high rate corresponds to an increase of approximately 1.5 meters over 100 years.

Vitousek, S. and C.H. Fletcher. 2008. Maximum annually recurring wave heights in Hawai'i. Pacific Science 62, No. 4, pp. 541-553. <http://www.soest.hawaii.edu/coasts/publications/Vitousek_SCD08.pdf>

The goal of this study was to determine the maximum annually recurring wave height approaching Hawai'i. The annual recurring significant wave height was found to be (25 ft± 0.9 ft) for open north Pacific swell. Directional annual wave heights were obtained by applying hindcast swell direction to observed nondirectional buoy data.

Reef Ecology

Edinger, E.N., Jompa, J., Limmon, G.V., Widjatmoko, W. and M. J. Risk. 1998. Reef degradation and coral biodiversity in Indonesia: Effects of land-based pollution, destructive fishing practices and changes over time. Marine Pollution Bulletin 36, pp. 617-630.

Uses transect surveys on 15 reefs in three regions of Indonesia to estimate the relative decrease in within-habitat coral species diversity associated with different types of reef degradation. Reefs subject to land-based pollution (sewage, sedimentation, and/or industrial pollution) show 30% to 60% reduced diversity. Bombed or anchor damaged reefs are approximately 50% less diverse in shallow water (3 m depth) than are undamaged reefs, but at 10 m depth the relative decrease is only 10%. The results found a 25% decrease in generic diversity of corals on two reefs resampled after 15 years.

Halley, R.B. 2000. 11 things a geologist thinks an engineer should know about carbonate beaches. In L.L. Robbins, O.T. Magoon, and L. Ewing (eds.), Carbonate Beaches 2000, American Society of Civil Engineers.

This conference paper provides a general overview of carbonate beach sand characteristics and reef production.

Rogers, C.S. 1990. Responses of coral reefs and reef organisms to sedimentation. Marine Ecology Progress Series, 62, No. 1-2, pp.185-202.

Unprecedented development along tropical shorelines is causing severe degradation of coral reefs primarily from increases in sedimentation. Sediment particles smother reef organisms and reduce light available for photosynthesis. Heavy sedimentation is associated with fewer coral species, decreased net productivity of corals, and slower rates of reef accretion. Sedimentation can also alter the complex interactions between fish and their reef habitat. Long-term data sets describing these reef responses are critically needed.

Tomascik, T. and F. Sander, F. 1985. Effects of eutrophication on reef-building corals. 1. Growth rate of the reef-building coral Montastrea annularis. Marine Biology 87, pp.143-155.

Fourteen environmental variables were monitored at seven locations along the west coast of Barbados on a weekly basis over a one-year period, 1981 to 1982. The physicochemical and biological data indicate that an environmental gradient exists because of increased eutrophication of coastal waters. Growth rates measured of Montastrea annularis along the environmental gradient exhibit high correlation with a number of water quality variables. Concentration of suspended particulate matter is the best univariate estimator of skeletal extension rates, suggesting such matter may be an energy source for reef corals, increasing growth up to a certain maximum concentration. After this, reduction of growth occurs due to smothering and reduced light levels.

Wolanski, E., J.A. Martinez, and R.H. Richmond. 2009. Quantifying the impact of watershed urbanization on a coral reef: Maunalua Bay, Hawaii. Estuarine, Coastal and Shelf Science, 84, pp. 259-268.

Human activities in the watersheds surrounding Maunalua Bay, O‘ahu, Hawai‘i, east of Diamond Head, have led to the degradation of coastal coral reefs. The ecosystem collapse on the east side of the bay and the prevailing westward longshore current have resulted in the collapse of the coral and coralline algae population on the west side of the bay. In turn this has led to a decrease in carbonate sediment production through bio-erosion as well as a disintegration of the dead coral and coralline algae, leading to increased coastal erosion.

Coastal Geomorphology of the Hawaiian Islands

Dickinson, W.R. 2001. Paleoshoreline record of relative Holocene sea levels on Pacific islands. Earth-Science Reviews 55, pp.191-234.

Gives a history of Holocene sea levels throughout the tropical Pacific Ocean, with particular emphasis on the mid-Holocene highstand that affected the development of shoreline morphology throughout the tropical Pacific Ocean.

Feirstein, E.J., and C.H. Fletcher. 2004. Hawai'i's Coastline. In: The World's Coastline, Bird, E. (Ed.). <http://www.soest.hawaii.edu/coasts/publications/hawaiiCoastline/HawaiisCoastline.pdf>

Gives a very general introduction to the geology of Hawai'i, and then discusses each island in turn.

Fletcher, C.H., and others. 2008. Geology of Hawaii Reefs. Chapter 11 in B.M. Riegl and R.E. Dodge (eds.), Coral Reefs of the USA. Springer Science+Business Media. <http://www.soest.hawaii.edu/coasts/publications/GeologyofHawaiiReefs.pdf>

This chapter contains a detailed geological description of Hawai'i, with particular emphasis on its reefs.

Fletcher, C.H., and E.J. Feirstein. 2009. Hawaii. Chapter 1.16 in The World's Coastal Landforms, Bird, E.C.F. (Ed.), Springer-Verlag, Heidelberg. <http://www.soest.hawaii.edu/coasts/publications/FletcherFiersten_Hawaiichaptercoasts.pdf>

Gives a broad introduction to the geology and coastal processes in Hawai'i.

Gerritsen, F. 1978. Beach and Surf Parameters in Hawaii. University of Hawaii Sea Grant Technical Report UNIHI-SEAGRANT-TR-78-02.

Describes the results of a three-year study of beach and surf parameters in Hawai'i, primarily O'ahu. The study objectives were: to identify dominant coastal parameters and their effect on beach stability; to determine general aspects of sand transport for selected beach areas; to evaluate beach cusp behavior for selected beaches; and to study the influence of headlands on beach stability. At Waikiki, the most intensively studied area, waves (offshore and breakers), tides, surface, and subsurface currents were measured. The study also collected sand samples at Waikiki, and included a modest program of fluorescent tracing of sediment. A detailed description of the beach and reef morphology and its effects on wave transformation and sediment transport are included.

Moberly, R. 1963. Coastal Geology of Hawaii. Hawaii Institute of Geophysics Report No. 41. Prepared for Department of Planning and Economic Development, State of Hawaii.

The bulk of this report is an inventory of 90 beaches in Hawai'i, including Waikiki and 'Ewa in the study area. The report also provides a general geological and coastal process description of the beaches.

Moberly, R., and T. Chamberlain. 1964. Hawaiian Beach Systems. Hawaii Institute of Geophysics Report HIG-64-2. Prepared for Harbors Division, Department of Transportation, State of Hawaii.

Provides a general geomorphic description of the Hawaiian beaches; seasonal rates of erosion and accretion of beach sand reservoirs; and grain size parameters. Gives a basic overview of coastal processes, including different wind and wave conditions. Discussions conditions and seasonal beach variations at 112 beaches in Hawai'i, including four in the D2P study area.

Rooney, J., C. Fletcher, E. Grossman, M. Engels, and M. Field. 2004. El Niño influence on Holocene reef accretion in Hawai'i. Pacific Science 58, No. 2, pp. 305-324.

In Hawai'i, accretion occurred during early to middle Holocene time in areas where today it is precluded by the wave regime, suggesting an increase in wave energy.

This may be associated with changes in strength of the El Nino Southern Oscillation (ENSO) during the Holocene period.

Coastal Erosion in the Hawaiian Islands

Fletcher, C.H., et al. 2008. On the Shores of Paradise. Chapter 9: Coastal Erosion and Beach Loss. <http://www.soest.hawaii.edu/coasts/publications/shores/index.html>.

Gives a general description of coastal erosion; the tension between preserving coasts and preserving upland infrastructure; and of specific regulatory issues in Hawaiʻi.

Fletcher, C.H., E.E. Grossman, B.M. Richmond, and A.E. Gibbs. 2002. Atlas of Natural Hazards in the Hawaiian Coastal Zone. United States Geological Survey Geological Investigations Series I-2761. <http://pubs.usgs.gov/imap/i2761/>

Provides maps of coastal hazard levels along the shoreline of each island. The documented and ranked hazards include: coastal erosion, sea-level rise, major storms, volcanic and seismic activity, tsunami inundation, coastal stream flooding, and extreme seasonal high wave events.

Fletcher, C.H., J.J.B. Rooney, M. Barbee, S.-C. Lim and B.M. Richmond. 2003. Mapping Shoreline Change using Digital Orthophotogrammetry on Maui, Hawaii. Journal of Coastal Research, Special Issue 38: 106-124.

Describes the basis for the shoreline change rates prepared by the University of Hawaiʻi. Digital, aerial orthophotomosaics, used with NOAA topographic maps (T-sheets), document past shoreline positions on Maui Island, Hawaiʻi. A least squares linear regression (outliers excluded and weighted by intrinsic errors) is used to determine a shoreline trend termed the reweighted linear squares (RLS). To determine the annual erosion hazard rate (AEHR) for use by shoreline managers the RLS data is smoothed in the longshore direction using a weighted moving average five transects wide with the smoothed rate applied to the center transect. The paper discusses specific areas in Maui.

Hawaiʻi Coastal Geology Group. 2009. Oʻahu Shoreline Study Erosion Maps. <http://www.soest.hawaii.edu/asp/coasts/oahu/index.asp>.

Provides rectified aerial photography, draft erosion hazard maps, and a description of methods used in developing shoreline retreat rates for the sandy shorelines of Oʻahu. Note that numerical data were provided directly to Moffatt & Nichol by Matt Barbee, Coastal Geology Group.

Hwang, D. 1981. Beach Changes on Oahu as Revealed by Aerial Photographs. Technical Supplement Number 22, Coastal Zone Management Project, Urban and Regional Planning Program. Technical Report HIG-81-3, Hawaii Institute of Geophysics. Cooperative Report UNIHI-SEAGRANT-CR-81-07, UH Sea Grant Collect Program.

Gives a shoreline retreat analysis based on aerial photography for much of Oʻahu. The different beaches are classified into five classes: hazard areas; chronic erosion areas; unstable, stable, and accreting beaches. Based on the results, the report proposes a management strategy including the establishment of setbacks for each beach class and ongoing monitoring.

Richmond, B.M., C.H.Fletcher, E.E.Grossman, and A.E. Gibbs. 2001. Islands at risk: Coastal hazard assessment and mapping in the Hawaiian Islands. Environmental Geosciences 8, No.1, pp. 21-37.

Describes the development of the coastal hazard database and atlas, *Atlas of Natural Hazards in the Hawaiian Coastal Zone*.

O‘ahu – General

City and County of Honolulu, Department of Planning and Permitting. 2009. Development Plan and Sustainable Communities Plan Revision Program.

O‘ahu is divided into eight planning areas. Each area has a Development Plan adopted by City Council ordinance and administered by the Department of Planning and Permitting. The plans are reviewed periodically. The adopted Plans and two Draft Revised Plans can be found at <http://www.honoluludpp.org/Planning>

Fletcher, C.H., Mullane, R.A. and Richmond, B.M. 1997. Beach loss along armored shorelines on Oahu, Hawaiian Islands, Journal of Coastal Research 13 No.1, pp. 209-215.

An analysis of an aerial photographic time series of O‘ahu's shoreline reveals that historical seawall and revetment construction (coastal armoring) to protect eroding lands has caused the narrowing of 17.3 ± 1.5 km and loss of 10.4 ± 0.9 km of sandy beach over the period 1928 or 1949 to 1995. This is ~24% of the 115.6 ± 9.8 km of originally sandy shoreline of O‘ahu.

Gibbs, A.E., B.M. Richmond, and C.H. Fletcher. 2000. Beach Profile Variation on Hawaiian Carbonate Beaches. In L.L. Robbins, O.T. Magoon, and L. Ewing (eds.), Carbonate Beaches 2000, American Society of Civil Engineers.

Discusses the USGS measurements of beach profiles in Maui and O‘ahu. Notes seasonal variation in many of the beaches, however excluding the D2P study area. There was little net gain or loss of beach volume during the study period (1994 to 1999); however, this period also did not include any extreme events such as tropical storms or hurricanes.

Hawaii Department of Transportation. 2009. Hawaii Aviation: An Archive of Historic Photos and Facts. <http://hawaii.gov/hawaiiaviation>

Contains a description of aviation history in Hawai‘i. More than 4,000 annotated historical photographs include the construction of the Honolulu Reef Runway.

Hwang, D.J., and Fletcher, C.H. 1992. Beach Management Plan with Beach Management Districts. Prepared for Hawaii Coastal Zone Management Program.

Gives a reconnaissance-level overview of beach retreat in O‘ahu, including ‘Ewa Beach as one example, and outlines the physical processes involved. Discusses structural and regulatory options for beach management, and proposes Beach Management Districts that would be used to pay for the design, analyses, and capitalization of erosion-control measures. Funding options, and the experience in other states, is also discussed.

Smith, D.A. and K.F. Cheung. 2002. Empirical relationships for grain size parameters of calcareous sand on Oahu, Hawai'i. Journal of Coastal Research, 18, No. 1, pp. 82-93.

Develops a relationship between sieve size and other grain size parameters based on 11 medium to very coarse calcareous sand samples collected on O'ahu, Hawai'i, including one site at Diamond Head.

O'ahu – D2P Region

American Marine Corporation. 2007. Kuhio Beach small-scale beach nourishment, Waikiki Beach, Oahu, Hawaii – After action report. Prepared for Hawaii Department of Land and Natural Resources.

In December 2006, Hawai'i DLNR carried out a project to replenish sand at Kuhio Beach, using 10,000 cubic yards sand pumped onto the beach from offshore. This after-action report summarizes environmental data collected during construction.

Crane, J.K. 1972. History of the marine structures of Waikiki Beach and their effects upon the beach. University of Hawaii, Department of Ocean Engineering.

Reconstructs the history of structures built on Waikiki Beach. This study provides much of the basis for Wiegel's historical papers.

Eversole, D. 2004. Results from Current Study Research, September 2004, Nearshore Kuhio Beach, Oahu. State of Hawaii, Department of Land and Natural Resources. <http://www6.hawaii.gov/dlnr/occl/files/waikiki/results.pdf>

Describes a one-day dye tracer study at Kuhio to explore the general direction of current transport. At all tides, the dye transport was generally to the northwest until it reached the Royal Hawaiian Hotel at which point it moved out through a fixed rip current at that location.

Hawaii Department of Land and Natural Resources. 2005. Kuhio Beach improvements – facts on beach history and engineering design.

Provides a history of development at Kuhio Beach, describes a concept using T-head groins.

Miller, T.L. 2002. Waikiki: Analysis of an engineered shoreline. Thesis submitted to the graduate division of the University of Hawaii in partial fulfillment of the requirements for the degree of Master of Science.

Gives a detailed description of short-term and long-term shoreline change at Waikiki Beach, with the beach divided into seven littoral sub-cells. Short-term changes are based on bi-monthly beach profiles measured at 22 sites. Early volume fluctuations are traced to beach nourishment, typically with subsequent beach loss. Volume gains are documented across the entire shoreline between 1975 and 1985, suggesting that Hurricane Iwa may have triggered onshore delivery of sand to Waikiki Beach from deeper offshore regions. Widespread chronic erosion characterizes the years after 1985. Despite frequent beach nourishment, a sediment budget for Waikiki reveals a sand volume deficit of at least 77,000 m^3 for the period 1951 to 2001.

Miller, T.L., and C.H. Fletcher. 2003. Waikiki: Historical Analysis of an Engineered Shoreline. Journal of Coastal Research 19, No. 4, pp. 1026-1043.

This covers much the same material as Miller 2002.

Norcross, Z.M.N., C.H. Fletcher, J.J.R. Rooney, D. Eversole, and T.L. Miller. 2003. Hawaiian Beaches Dominated by Longshore Transport. <http://www.soest.hawaii.edu/coasts/publications/CS2003_Norcross_LongshoreTransport.pdf>

Reviews studies of two beaches on O‘ahu (Kailua and Waikiki) and two beaches on Maui (Ka‘anapali and Kihei) that suggest seasonal sand transport is strongly influenced by longshore movement and limited cross-shore movement. A possible explanation is that water from waves breaking over the reefs builds up landward of the reefs, then travels alongshore along the inside of the reefs, before moving back out to sea through a channel.

OI Consultants, Inc. 1991. Baseline surveys of nearshore water quality and coral reef communities at Waikiki, Oahu, Hawaii. Prepared for Edward K Noda and Associates.

This is primarily a biological and water quality study. However, it also contains a physical description of the reef offshore of Waikiki Beach.

Schroeder, P.R. and M.R. Pelermo. 2000. Long-term management strategy for dredged material disposal for naval facilities at Pearl Harbor, Hawaii. Phase I – formulation of preferred disposal and management alternatives. U.S. Army Research and Development Center Report ERDC/EL SR-00-3, dated February 2000.

Elements of this Long Term Management Strategy relevant to the SEO/RSM study include a summary of the history of dredging and disposal at Pearl Harbor and a general description of the physical and chemical characteristics of the dredge spoils.

Sea Engineering, Inc. 2008. Draft Environmental Assessment: Iroquois Point Restoration.

Environmental Assessment for a proposed project to restore 4,200 lineal feet of beach at the Iroquois Point housing area. The project would involve nine (9) T-head groins and approximately 97,000 cubic yards of sand for beach nourishment, to be dredged from an accretional area of the Pearl Harbor channel, immediately south of the Iroquois Lagoon entrance. Other project alternatives reviewed are: no action; five longer groins with beach nourishment; beach nourishment alone; and a revetment to protect the upland infrastructure.

United States Army Corps of Engineers. 1992. Waikiki Beach Erosion Control: Island of Oahu, Hawaii. Reevaluation Report. January 1992.

This reevaluation report covers: the history of the Corps project, initiated in 1948 and with construction starting in 1951; and economic, cultural, and marine resource analyses. Based on recreational benefits not being allowable as benefits at the time, only the shoreline from the Fort DeRussy Groin to Kuhio Beach warranted continued Federal interest at the time, and the State was unwilling to proceed until all relevant littoral rights belonged to the State.

United States Army Corps of Engineers. 2002. Honolulu Harbor: Honolulu, Island of Oahu.

Fact sheet regarding authorization, completed work, and project status of Honolulu Harbor.

United States Army Corps of Engineers. 2009. Public Notice POH-2005-552. Iroquois Point Beach Restoration and Stabilization: Ford Housing LLC.

Public notice for a proposed project to restore 4,200 lineal feet of beach at the Iroquois Point housing area. The project would involve nine (9) T-head groins and

approximately 97,000 cubic yards of sand for beach restoration, to be dredged from an accretional area of the Pearl Harbor channel, immediately south of the Iroquois Lagoon entrance. The present erosion rate in the area equates to approximately 6,700 cubic yards per year.

Wiegel, R.L. 2002. Waikiki, Oahu, Hawaii, an urban beach: Its history from a coastal engineering perspective. University of California at Berkeley, Report UCB/HEL-2002-1. 15 November 2002.

Gives a wide-ranging history of the Waikiki beach area, in more detail than the later Shore & Beach articles mentioned below. This report also contains information that is not strictly historical: a discussion of the health of the reef offshore from Waikiki, wave and current climate, and sand production and loss and transport pathways. Waikiki Beach is complicated by channels that have been dredged in the reef, as well as by the structures on the beach (including fill).

Wiegel, R.L. 2005. Waikiki, Oahu, Hawaii – An urban beach chronology of significant events, 1825-2005. Shore & Beach 73 No. 4, pp. 30-32.

Gives a chronology of the main events at the beach. Notes that it is important to consider the full area from Diamond Head to Kewalo Basin, immediately west of Ala Moana Park – not just the relatively small stretch traditionally referred to as Waikiki Beach. This can be considered superseded by Wiegel 2008.

Wiegel, R.S. 2006. Letter from Robert Wiegel, UC Berkeley, to Harry Yeh, Oregon State University, dated 12 September 2006. <http://tsunami.oregonstate.edu/workshop/2006/doc/premeeting/Wiegel_9-12-06.pdf>

Describes three tsunami drawdown events at Waikiki in which much of the reef became bare, and requests any information regarding scour caused during such events.

Wiegel, R.L. 2008. Waikiki Beach, Oahu, Hawaii: History of its transformation from a natural to an urban shore. Shore & Beach 76 No. 2, pp.3-30.

Describes the history of Waikiki Beach, including the area from Diamond Head to Kewalo Basin (west of Ala Moana Beach). Notes that very little of the sand on the beach is from its stream sources, or even local carbonate sources: sand mining removed much of the sand in the early 20th century, and subsequent nourishment has brought in other sand. Numerous channels, basins, and ponds have been dredged in the reef. A specific case is dredging around 1909-1913 to provide fill for construction of Fort DeRussy, as well as access for transport of gun emplacements, including significant shore-parallel as well as shore-perpendicular channels and apparently causing significant erosion. A chronology of significant events is provided.

O'ahu – Windward

Harney, J.N., E.E. Grossman, B.M. Richmond, and C.H. Fletcher III. 2000. Age and composition of carbonate shoreface sediments, Kailua Bay, Oahu, Hawaii. Coral Reefs (2000), No. 19, pp. 141-154.

The origin, age, and dynamics of carbonate sediments in Kailua Bay on Oahu, Hawai'i, are described. Despite an apparently healthy modern coral ecosystem, the surficial sand pool of Kailua Bay is dominated by sand reflecting an antecedent system, possibly one that existed under a +1-2 m sea-level high stand during the mid- to late Holocene. Sand composition and age across the shoreface are correlated to carbonate production. Of 20 calibrated radiocarbon dates on skeletal constituents of sand, only three are younger than 500 years B.P.; six are 500-1000 years B.P.; six are 1000-2000 years B.P.; and five are 2000-5000 years B.P. Dominance of fossiliferous sand indicates long storage times for carbonate grains, which tend to decrease in size with age, such that the entire period of relative sea-level inundation (~5000 years) is represented in the sediment.

Harney, J.N., and C.H. Fletcher. 2003. A budget of carbonate framework and sediment production, Kailua Bay, Oahu, Hawaii. Journal of Sedimentary Research, 73, No. 6, pp.856-868.

Constructs a field-based, biogeological sediment budget for windward Kailua Bay on the island of O‘ahu, Hawai‘i. The model of calcareous sediment production considers details of benthic community structure, physiographic setting, biogenic carbonate production by framebuilding and reef-dwelling organisms, and erosion of carbonate facies by biological and mechanical means. The gross production of calcareous material averages 1.22 (± 0.36) kg m^{-1} y^{-1} in Kailua Bay; sediment production through bioerosion and mechanical averages 0.33 (± 0.13) kg m^{-1} y^{-1}. The difference between these is the net production, corresponding to reef accretion.

Oceanit Laboratories, Inc. 2006. Southeast Oahu Regional Sediment Management Demonstration Project: Regional Sediment Management Plan. Prepared for the U.S. Army Corps of Engineers, Honolulu District, and the State of Hawaii Department of Land and Natural Resources.

Regional Sediment Management Plan for the area Mokapu Point to Makapu‘u Point. This report represents the first demonstration within the SEO/RSM project; the present report, covering the area Diamond Head to Pearl Harbor, is the second.

Other Islands

Calhoun, R.S., C.H. Fletcher, and J.N. Harney. 2002. A budget of marine and terrigenous sediments, Hanalei Bay, Kauai, Hawaiian Islands. Sedimentary Geology 150, pp. 61-87.

Develops a sediment budget for Hanalei Bay on the north shore of Kauai. There are significant terrigenous (siliciclastic) sediment components from the Hanalei River watershed, in addition to the carbonate components. Excess carbonate sediment is estimated based on published production rates for different.

Eversole, D. and Fletcher, C.H. 2003. Longshore sediment transport rates on a reef-fronted beach: field data and empirical models, Kaanapali Beach, Hawaii. Journal of Coastal Research 19 No. 3, pp. 649-663.

Longshore sediment transport (LST) measured at monthly beach profiles on Kaanapali Beach, on the leeward coast of Maui, is compared to three predictive models. The presence of fringing reef significantly affects the ability of LST models to accurately predict sediment transport: the functional beach profile area available for sediment transport is assumed much larger than actually exists in Kaanapali; wave parameters are also important.

Storlazzi, C.D., A.S. Ogston, M.H. Bothner, M.E. Field, and M.K. Presto. 2004. Wave- and tidally-driven flow and sediment flux across a fringing coral reef: Southern Molokai, Hawaii. Continental Shelf Research 24, pp. 1397-1419.

Deployed instrumentation across the fringing coral reef off the south coast of Molokaʻi to understand the processes governing fine-grained terrestrial sediment suspension on the shallow reef flat and its advection across the reef crest and onto the deeper fore reef. Relatively clear water flows up onto the reef flat during flooding tides. At high tide, more wave energy is able to propagate onto the reef flat and sediment suspension is increased. During ebb tide, the water and associated suspended sediment drains off the reef flat and is advected offshore and to the west by trade wind and tidally driven currents. There is relatively high turbidity on the fore reef during ebb tide.

University of Hawaii Sea Grant Extension Service and County of Maui Planning Department. 1997. Beach Management Plan for Maui.

This report makes recommendations on how Maui County can better address beach management issues. It is intended to be a guiding policy document, rather than be adopted in its entirety as formal law. Issues include: Where and why coastal erosion and beach loss have occurred; Recommendations for more effective management of shoreline areas; and the development of increased options for resource conservation and erosion mitigation.

Offshore Sand Sources

Hampton, M.A., C.T. Blay and C.J. Murray. 2004. Carbonate sediment deposits on the reef front around Oahu, Hawaii. Marine Georesources and Geotechnology 88, No.1, pp. 65-102.

Describes the state of knowledge regarding sediment deposits on the reef front around Oʻahu, which are a possible resource for replenishing eroded beaches. High-resolution sub-bottom profiles clearly depict the deposits in three study areas: Kailua Bay off the windward coast, Makua to Kahe Point off the leeward coast, and Camp Erdman to Waimea off the north coast. Previous literature showed that there are analogous deposits around Oʻahu, essentially encircling the entire island.

Hampton, M.A., C.H. Fletcher, J.H. Barry, and S.J. Lemmo. 2000. The Halekulani Sand Channel and Makua Shelf Sediment Deposits: Are they a sand resource for replenishing Waikiki's beaches? In L.L. Robbins, O.T. Magoon, and L. Ewing (eds.), Carbonate Beaches 2000, American Society of Civil Engineers.

The Halekulani Sand Channel and the Makua Shelf off the south shore of Oʻahu contain at least 1.3×10^6 m^3 of sediment that is a possible resource for nourishing Waikiki Beach. A sidescan sonar survey indicates continuous sediment cover within the channel and on the shelf, and vibracore samples indicate that 29% to 77% of grains have the appropriate size for Waikiki Beach. The color (gray) and mechanical characteristics (relatively easily abraded) of this sediment may be a drawback.

Marine Advisers, Inc. 1968. Sand Survey at Waikiki and at the Honolulu Harbor Entrance, Oahu. Prepared for State of Hawaii, Department of Transportation, Harbors Division,

This sand survey was performed in order to find an adequate volume of sand which could be used for rebuilding Kuhio Beach. Several areas in the Halekulani Sand Channel were found with good quality sand, although much of this sand was rather fine. In the Honolulu Harbor entrance channel, there was an acceptable sand grain size and sorting, and probably enough volume. However, the sand was very dark in color, due to a high percent of detrital volcanic grains and contained organic and other undesirable material. Based on this initial survey, a more detailed assessment of the Halekulani channel was performed.

Wang, N. and F.Gerritsen. 1995. Nearshore circulation and dredged material transport at Waikiki Beach. Coastal Engineering 24, pp. 315-341.

Describes a study of the effects of using offshore sand deposits as a source of material, considered as part of a beach nourishment project at Waikiki Beach, Hawaiʻi. The borrow site is located approximately 1100 meters off the beach. Modeling the influence of the dredging pit at the borrow site on the stability of the nearshore ocean bottom and on the beach shows that effects on the beach would be negligible.

Regional Sediment Management – General

Hawaii Department of Land and Natural Resources. November 2006. Report to the Twenty-Fourth Legislature Regular Session of 2007 – 3-year plan for beach restoration studies and projects.

Provides an overview of the Department's efforts to implement beach restoration projects and studies to support such efforts. Includes a discussion of the Department's efforts to create a comprehensive management plan (Hawaiʻi Beach Management Plan) to conserve and restore Hawaiʻi's important beaches; and a discussion of existing and proposed studies and beach restoration projects being conducted by the Department.

Rosati, J.D., B.D. Carlson, J.E. Davis, and T.D. Smith. 2001. The Corps of Engineers National Regional Sediment Management Demonstration Program. CHETN-XIV-1, U.S. Army Engineer Research and Development Center ERDC/CHL, Vicksburg, MS. <http://chl.erdc.usace.army.mil/library/publications/chetn/pdf/chetn-xiv-1.pdf>.

Gives a general introduction to Regional Sediment Management and discusses ongoing demonstrations by the U.S. Army Corps of Engineers.

United States Army Corps of Engineers, 2005. Army Corps, State DLNR announce implementation of programmatic general permit for beach nourishment, restoration and enhancement for Hawaii. Public Affairs Office, Honolulu Engineer District, and DLNR Public Information Office.

The USACE and the State DLNR announce the issuance of a State Programmatic General Permit (SPGP) for Beach Nourishment and Restoration in the State of Hawaiʻi. This is an expedited permit for beach nourishment, allowing replenishment of up to 10,000 cubic yards of sand as an alternative to shoreline hardening and beach loss.

APPENDIX B : WAVE TRANSFORMATION MODELING

Wave Transformation of Wave Information Studies Pacific Basin Information for the south shore of Oahu in the Hawaiian Islands (D2P Region from "Diamond Head" to "Pearl Harbor")

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Preface

Wave Information Studies (WIS) has produced a 1981-2004 Pacific Basin (PACBAS) numerical wave hindcast that includes output stations with hourly bulk wave parameter and spectral information around the Hawaiian Islands. These stations reside in very deep water about 1 degree offshore, and wave information is needed for coastal projects, coastal model applications and analysis closer to the shore. The Honolulu District (POH) is interested in transforming wave conditions from the PACBAS WIS Station 116 to save locations closer to the south shore of Oahu in increments along and within the 30-m contour and have asked ERDC/CHL to do this transformation project. Since nearshore bathymetry within the 30-m contour contains reef conditions, wave transformation will include reef bathymetry. Three representative years are selected from the PACBAS hindcast to use in the wave transformation process, and selected wave cases from the representative years are transformed using the half-plane Steady-State Spectral Wave Model (STWAVE) nearshore model (Smith et al. 2001). This report describes the details of the wave transformation process for three selected years of WIS PACBAS Station 116 information. Appendix I contains the scope of work for this project.

Introduction

The project area for this wave study is located along the south shore of the island of Oahu, Hawaii, from the eastern side of Diamond Head to three miles west of Pearl Harbor (see Figure 1 for a map of the project area and Figure 2 for a map of the Hawaiian Islands noting the island of Oahu). The wave climate is dominated by the arrival of swell from the south during the summer. Kona storms also produce energy that arrives from the southwest, and the south shore of Oahu also receives swell from Kona storms that impact the islands to the southeast. The summer season can include possible tropical storm waves or swell from events that track near the area. This area is also influenced by the tradewinds but is sheltered from the waves of north Pacific winter storms. See http://www.wrcc.dri.edu/narratives/HAWAII.htm for information on the wave climate.

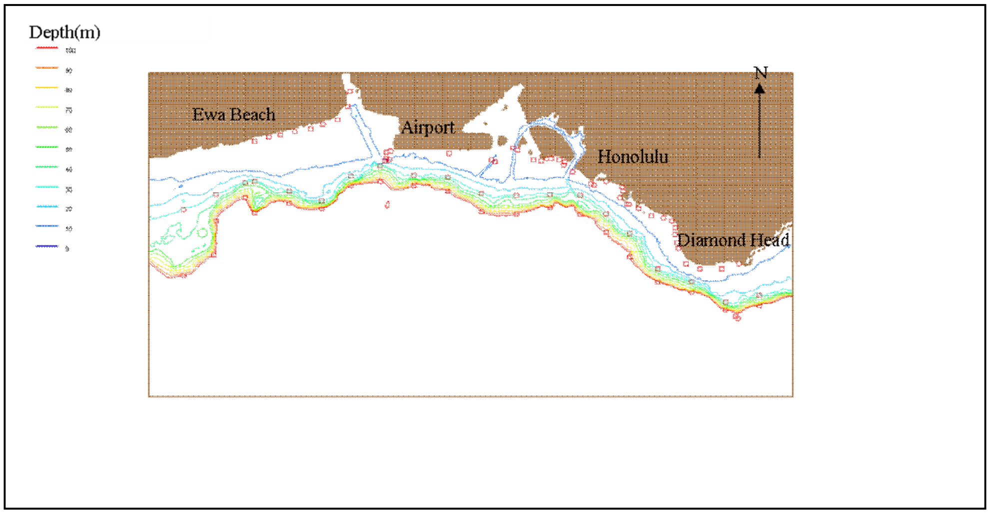


Figure 1. South shore of Oahu that was included in project STWAVE wave grid. Contour lines show depths 100m and below. Red squares indicate locations where output information was saved.

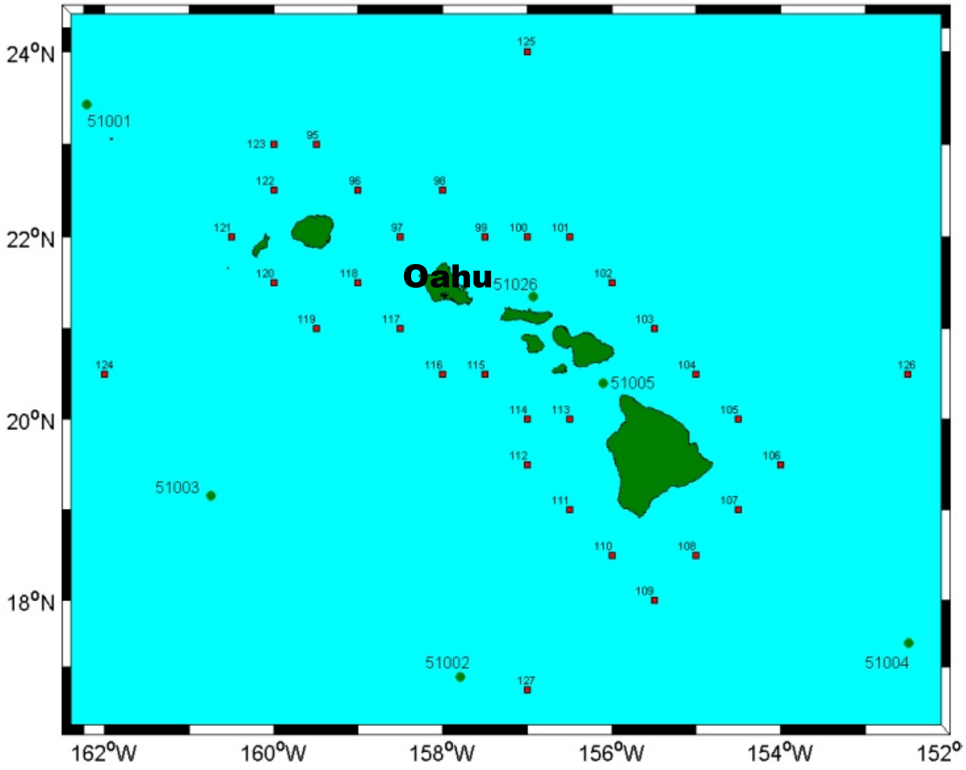


Figure 2. Map showing WIS PACBAS stations in the Hawaiian Islands. Note that WIS PACBAS Station 116 is due south of the island of Oahu.

WIS Hindcast

Wave Information Studies (WIS) created the 1981-2004 PACBAS wave information by using a 0.5-degree grid covering the Pacific Ocean from Latitude -64 to 64 degrees and E. Longitude 110 to 300 degrees. This grid requires bathymetry for each of the grid points and an obstruction grid to simulate the effects of small islands in the 0.5-degree grid setup. Input wind fields from Oceanweather, Inc. (OWI) were used to drive the hindcast simulations. OWI used their meteorological expertise to produce wind input that accurately represents the wind field over the Pacific basin. WIS has relied on OWI wind fields for past hindcasts in the Atlantic and Gulf of Mexico. PACBAS wind fields are based on National Center for Atmospheric Prediction-National Center for Atmospheric Research (NCEP/NCAR) global reanalysis 6-hourly 10-m surface winds. These wind fields are adjusted using QuikSCAT scatterometer winds based on quantile-quantile plots. Tropical cyclone winds from OWI's Planetary Boundary Layer Model are blended in to simulate the tropical events. The original Pacific basin hindcast used the fully spectral third-generation wind-wave model WAVEWATCH III version 2.22 (Tolman 2002a). Since that release, many upgrades and code changes have been made to the WAVEWATCH III model, and WIS has rerun PACBAS using the new WAVEWATCH III version 3.12 (Tolman 2007). The PACBAS rerun coincided with the need to run a Pacific regional hindcast for the US west coast as a nested grid system. WAVEWATCH III version 3.12 model upgrades include the ability to use a nested grid system to move energy back and forth through the grid boundaries, the addition of depth-limited breaking for shallow areas, and the addition of a cap to the drag coefficient in the wind input term. Both versions of WAVEWATCH III have been coded with MPI to utilize parallel computer resources available at the ERDC High Performance Computing Center. Details of the model selection and validation of the PACBAS numerical wave hindcast can be found in Hanson et al (2009).

The PACBAS hindcast is currently undergoing a reanalysis to check if a new set of input wind fields will correct the problem of excess swell energy from the storms in the North Pacific during the winter. Since the south shore of Oahu is sheltered from the wave energy from the North Pacific winter storms and comparisons of wave energy coming from the south at Christmas Island (NDBC 51028) do not show this excess swell bias during the summer months, wave results at PACBAS station 116 should provide a good starting point for the wave transformation into the south shore of Oahu.

PACBAS Station 116 is located at Latitude 20.5 degrees, Longitude -158.0 degrees at a depth of 4394m. POH requested the selection of three years that were representative of the wave climate at this location. A low wave condition (1984), a medium wave condition (1992) and a high wave condition year (1994) were selected. The medium wave condition year also included Hurricane Iniki in September, 1992. Hurricane Iniki produced the largest waves at this station during the period of the hindcast. One of the tools used to select the three years was the WIS table product that shows the maximum significant wave heights for all the months and years of the hindcast. This portion of the WIS Station 116 table is shown in Table 1.

TABLE 1. WIS Maximum Height for Station 116

STATION: 116 PAC
MAX Hmo(m) WITH ASSOCIATED Tp(sec) AND Dm(deg) BY MONTH AND YEAR

YEAR	JAN	FEB	MAR	APR	MAY	JUN
1981	5.3 18 319	4.3 16 296	3.5 16 331	2.1 14 67	2.3 15 320	1.7 13 13
1982	4.2 14 285	4.9 13 281	2.8 18 320	2.3 10 21	1.9 12 20	1.5 10 82
1983	4.2 18 315	5.2 18 317	3.9 16 308	2.3 13 310	2.0 12 74	1.9 15 137
1984	3.3 15 293	3.5 16 321	4.0 19 306	2.4 12 38	2.1 15 67	1.6 16 155
1985	5.7 16 309	3.2 14 305	3.6 11 58	2.4 12 24	2.0 13 8	1.8 13 329
1986	3.2 16 308	6.5 19 301	4.6 18 307	3.3 7 57	2.0 15 120	2.0 14 41
1987	5.3 18 317	3.8 16 329	3.6 13 326	3.8 14 21	2.6 10 14	2.2 16 116
1988	3.4 16 311	3.2 15 302	3.3 17 319	2.4 12 50	1.9 15 179	2.0 15 208
1989	4.4 18 307	3.7 15 306	3.1 9 216	2.4 12 5	2.2 14 301	1.8 13 89
1990	3.2 19 322	3.5 9 69	3.0 10 74	2.2 15 335	2.3 11 37	2.1 15 114
1991	4.5 13 290	4.1 16 308	3.8 16 328	2.6 16 1	2.1 17 124	2.0 14 123
1992	4.3 17 311	3.8 16 302	3.3 16 305	2.1 12 15	2.6 15 57	1.9 10 78
1993	4.5 13 296	4.3 15 321	3.4 13 310	2.9 16 324	2.1 16 17	2.2 15 91
1994	4.2 16 306	3.3 16 320	3.8 11 59	2.6 14 326	2.2 6 72	1.8 5 94
1995	5.2 15 298	4.6 15 304	3.7 15 303	3.5 16 48	2.5 14 340	2.4 16 142
1996	5.1 17 301	4.2 17 306	3.4 15 244	2.6 16 332	2.5 12 333	1.7 13 60
1997	3.7 14 301	4.0 18 311	2.6 15 322	3.3 16 321	2.0 13 3	2.2 6 84
1998	5.2 20 321	4.8 18 300	3.8 18 309	2.8 11 64	2.2 10 85	2.1 16 146
1999	3.3 17 319	3.6 18 325	3.9 19 353	2.4 6 80	2.0 5 67	1.9 11 156
2000	2.7 7 45	3.7 18 313	3.5 18 318	3.2 10 57	2.0 18 121	2.0 14 144
2001	4.1 18 311	3.0 17 320	3.4 16 320	2.6 7 88	2.3 17 109	1.6 12 106
2002	4.6 16 311	3.3 14 19	3.0 11 22	2.5 13 329	1.8 14 163	2.1 15 132
2003	5.2 17 309	3.2 15 313	3.1 16 304	2.5 15 182	2.2 16 199	1.9 15 129
2004	6.2 17 290	4.2 16 295	3.2 17 317	2.8 17 326	2.0 12 66	1.7 18 102
MAX	6.2 17 290	6.5 19 301	4.6 18 307	3.8 14 21	2.6 10 14	2.4 16 142

YEAR	JUL	AUG	SEP	OCT	NOV	DEC	MAX
1981	1.8 14 94	1.7 5 65	1.7 15 330	2.1 14 312	3.3 10 63	3.3 17 320	5.3 18 32
1982	1.9 11 86	3.0 10 155	2.3 13 315	2.1 15 334	5.7 11 227	3.6 14 320	5.7 11 23
1983	1.9 10 75	1.8 11 80	1.8 11 78	2.3 10 37	3.2 16 327	3.3 13 295	5.2 18 32
1984	1.6 13 136	1.6 13 107	1.6 13 1	2.2 16 335	2.7 16 353	3.0 11 66	4.0 19 31
1985	1.9 6 74	1.8 13 127	1.9 14 27	2.2 11 203	3.5 13 304	4.8 18 321	5.7 16 31
1986	2.7 12 96	2.3 13 261	1.6 12 86	3.0 17 326	3.4 16 333	4.0 18 318	6.5 19 31
1987	1.9 15 172	1.7 20 180	2.1 15 338	2.3 14 36	3.5 16 4	3.6 17 351	5.3 18 32
1988	2.0 12 80	1.9 17 141	3.2 11 178	2.0 12 346	3.7 7 179	4.0 14 302	4.0 14 31
1989	6.0 10 110	1.6 12 112	1.9 15 327	1.9 12 347	3.2 15 334	3.8 16 302	6.0 10 12
1990	1.9 5 74	1.7 5 60	1.8 13 318	2.0 6 61	3.3 15 346	3.0 16 308	3.5 9 7
1991	1.7 5 77	2.1 6 90	2.0 14 324	2.3 14 321	2.5 15 330	3.9 15 329	4.5 13 29
1992	1.9 13 75	1.8 15 101	8.0 12 182	2.6 13 40	3.2 15 336	2.9 18 54	8.0 12 19
1993	2.1 6 69	1.9 13 72	1.8 12 335	2.5 13 327	2.9 15 323	3.0 15 360	4.5 13 30
1994	4.1 12 134	2.9 10 132	1.6 11 68	2.2 15 318	2.7 11 88	3.3 17 336	4.2 16 31
1995	2.0 13 296	1.8 5 78	3.1 18 330	2.0 13 60	3.5 18 335	4.0 18 306	5.2 15 30
1996	1.8 16 158	1.7 15 180	2.6 16 310	2.6 15 318	3.6 15 7	3.8 15 333	5.1 17 31
1997	2.2 6 82	1.9 15 142	3.1 17 332	2.4 16 343	2.9 15 27	3.3 17 308	4.0 18 32
1998	2.0 14 96	2.2 15 113	2.1 15 134	2.6 18 325	3.2 16 329	4.0 11 87	5.2 20 33
1999	2.1 6 84	2.5 12 105	2.4 16 118	2.4 15 119	2.6 6 54	3.4 18 352	3.9 19 36
2000	2.0 6 88	2.3 15 129	2.0 15 318	2.2 16 332	2.9 18 341	3.4 17 321	3.7 18 32
2001	2.1 10 67	2.1 10 67	2.0 14 76	2.5 11 29	3.4 7 176	3.6 18 328	4.1 18 32
2002	1.8 16 91	1.9 12 173	1.9 15 121	3.1 17 342	3.5 17 320	2.9 17 332	4.6 16 32
2003	1.9 15 132	1.9 6 87	2.2 11 85	2.2 15 315	3.6 15 25	2.7 13 349	5.2 17 31
2004	1.7 11 116	1.7 13 350	1.7 12 227	1.9 14 124	2.5 11 29	4.3 18 300	6.2 17 30
MAX	6.0 10 110	3.0 10 155	8.0 12 182	3.1 17 342	5.7 11 227	4.8 18 321	

MAX Hmo(m): 8.0 MAX Tp(sec): 12. MAX Dp(deg): 182. DATE(gmt):1992091201

MAX WIND SPEED(m/sec): 22. MAX WIND DIRECTION(deg): 134. DATE(gmt):1992091121

MEAN Hmo(m): 1.7 MEAN Tp(sec): 12.

STANDARD DEVIATION Hmo(m): 0.6 STANDARD DEVIATION Tp(sec): 2.6

Wave Component Analysis at Station 116

Hourly output information for PACBAS Station 116 includes the bulk wave parameters consisting of the energy-based significant wave height, the peak and mean period, and the mean and peak wave direction. Since PACBAS Station 116 is capable of receiving energy from the northwest, the bulk wave parameters are dominated by the swell from Pacific storms to the northwest, and the contributions of smaller energy swell trains from other directions that may be important for the wave climate at the south shore of Oahu are masked. The latest version of the WAVEWATCH III numerical wave model includes an option to output the various partitioned wave components that are included in the bulk wave parameters. This partitioning analysis was developed at CHL in connection with the WaveMEDS analysis used to analyze the Pacific wave model hindcast performance, and this technology was transferred to NOAA for use in the WAVEWATCH III model (Tracy et al. 2007). Output consists of the bulk wave parameters and parameters relating to each of the partitioned components within the spectra. Each partitioned component is checked to see if it is being forced by the prevailing wind direction, and a wind-sea percentage coefficient gives information on whether the component is wind sea or swell. This partitioned information is invaluable for determining the actual wave climate that should be transformed into the south shore of Oahu. The Station 116 partitioned files ("parts" files) were analyzed for the three selected years (1984, 1992, and 1994) of the hindcast. Figure 3 shows the wave rose produced by the bulk wave parameters for Station 116 for 1992. This is the usual wave rose product that is available on the WIS website. Figures 4, 5, and 6 show swell wave roses that were produced from the Station 116 partitioned wave results for 1992, 1984 and 1994. Note the differences between Figure 3 and Figure 4 and how Figure 4 shows a better display of the contributions of swell components that are heading into the Oahu south shore. Note that the primary swell energy directions that would impact the south shore of Oahu in Figures 4, 5 and 6 are 202.5deg, 180deg, and 135deg. Figure 4 shows that the large waves from Iniki (> 5m) approached from 202.5 deg. Figure 7 shows the track of Hurricane Iniki (September, 1992).

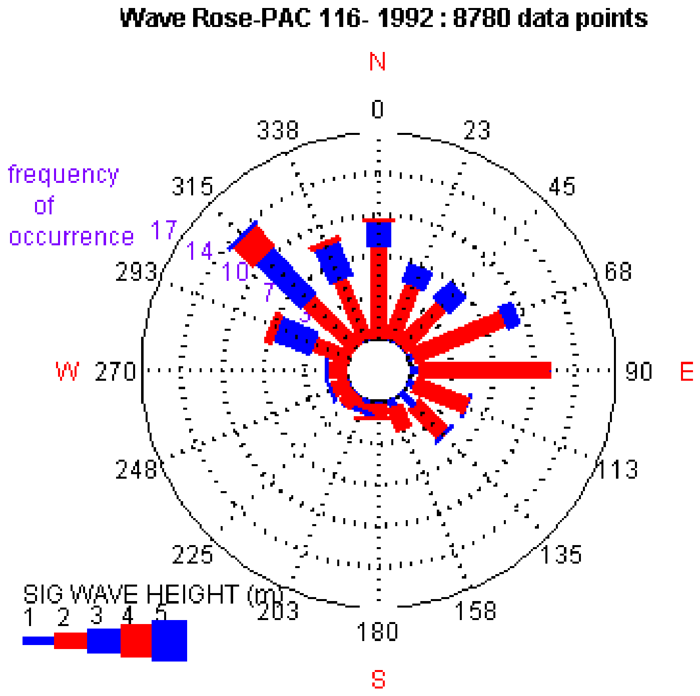


Figure 3. Wave rose showing the bulk wave parameters for PACBAS Station 116 for 1992.

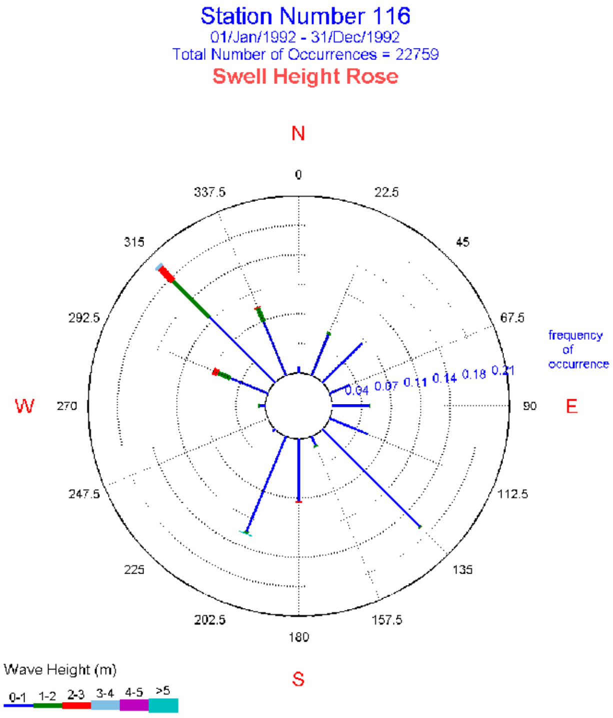


Figure 4. Swell contributions for PACBAS Station 116 for 1992.

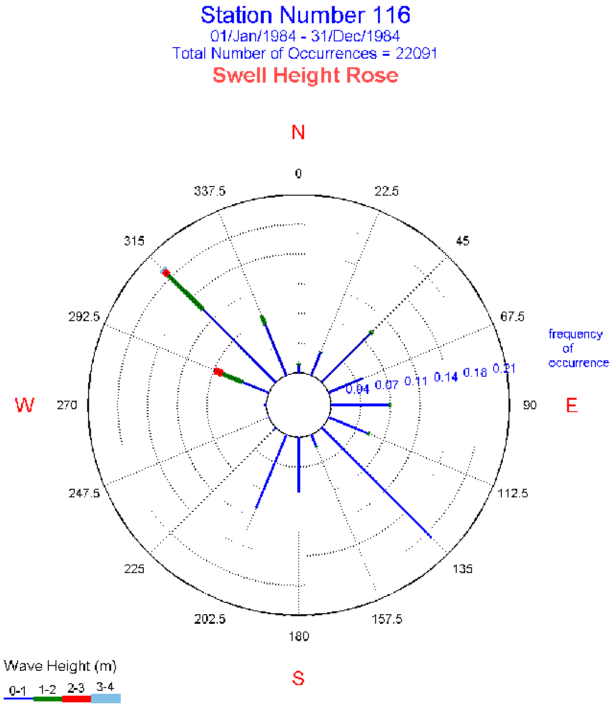


Figure 5. Swell contributions for PACBAS Station 116 for 1984.

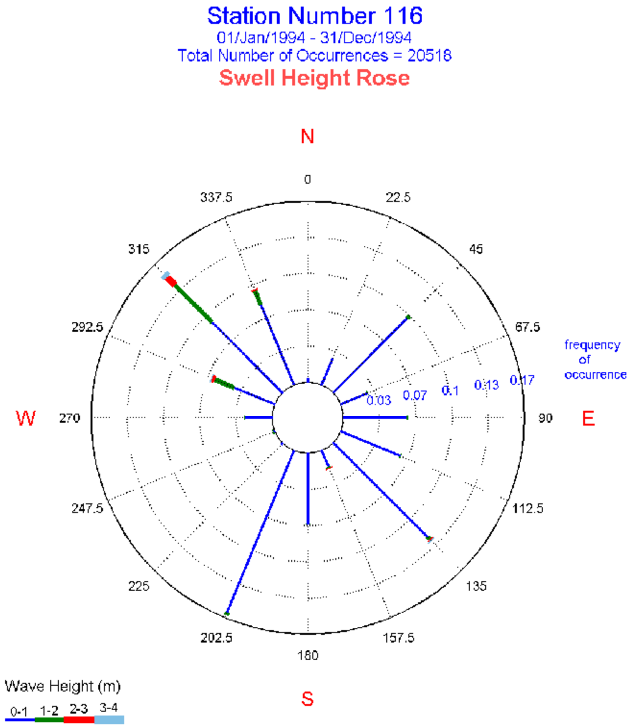


Figure 6. Swell contributions for PACBAS Station 116 for 1994.

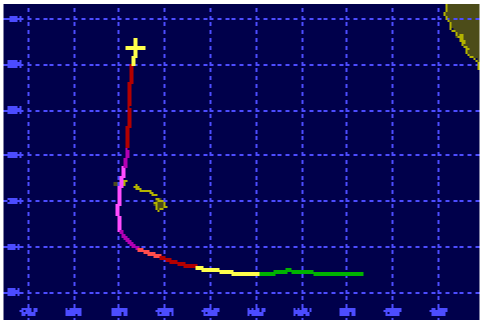


Figure 7. Path of Hurricane Iniki, 5-13 September, 1992. Maximum wind speed was 125 knots; minimum pressure was 935 mb. The storm's maximum strength was Category 4 (Saffir-Simpson scale). Figure from Unisys web resources.

Spectral Analysis

Hourly spectral information in a frequency-direction matrix from the PACBAS WAVEWATCH III hindcast was available for PACBAS Station 116. The swell wave roses in Figures 4, 5, and 6 indicated that only wave energy coming from MET direction 95 (5 deg below due east) through 265 (5 degrees below due west) would move in to impact the south shore of Oahu. An STWAVE half-plane application was planned using the half-plane spectral input from PACBAS Station 116. STWAVE hourly spectral input files were prepared from PACBAS Station 116 spectra for 1984, 1992 and 1994. PACBAS Station 116 spectral files contain 25 frequencies and 24 direction bands. The half-plane STWAVE input spectra contains 30 frequencies and 35 directions so interpolation was also accomplished within the spectral transformation process.

PACBAS Station 116 resides in approximately 4000 m of water and is located approximately 0.7 degrees south of the edge of the STWAVE grid where the water depth is approximately 300-400m. Figure 8 shows PACBAS Station 116 in relation to Oahu and the STWAVE grid. A 1-d wave transformation code was run to check if there would be significant spectral changes from PACBAS Station 116 to the STWAVE ocean boundary. Figure 8 shows the line that was used in the transformation. No significant changes in the spectral output were noted after transformation across the bathymetry shown in Figure 8. All points on the 1-d line remain in deep water so significant changes were not expected. Half-plane spectra from PACBAS Station 116 could be used as input on the boundary of the STWAVE simulation.

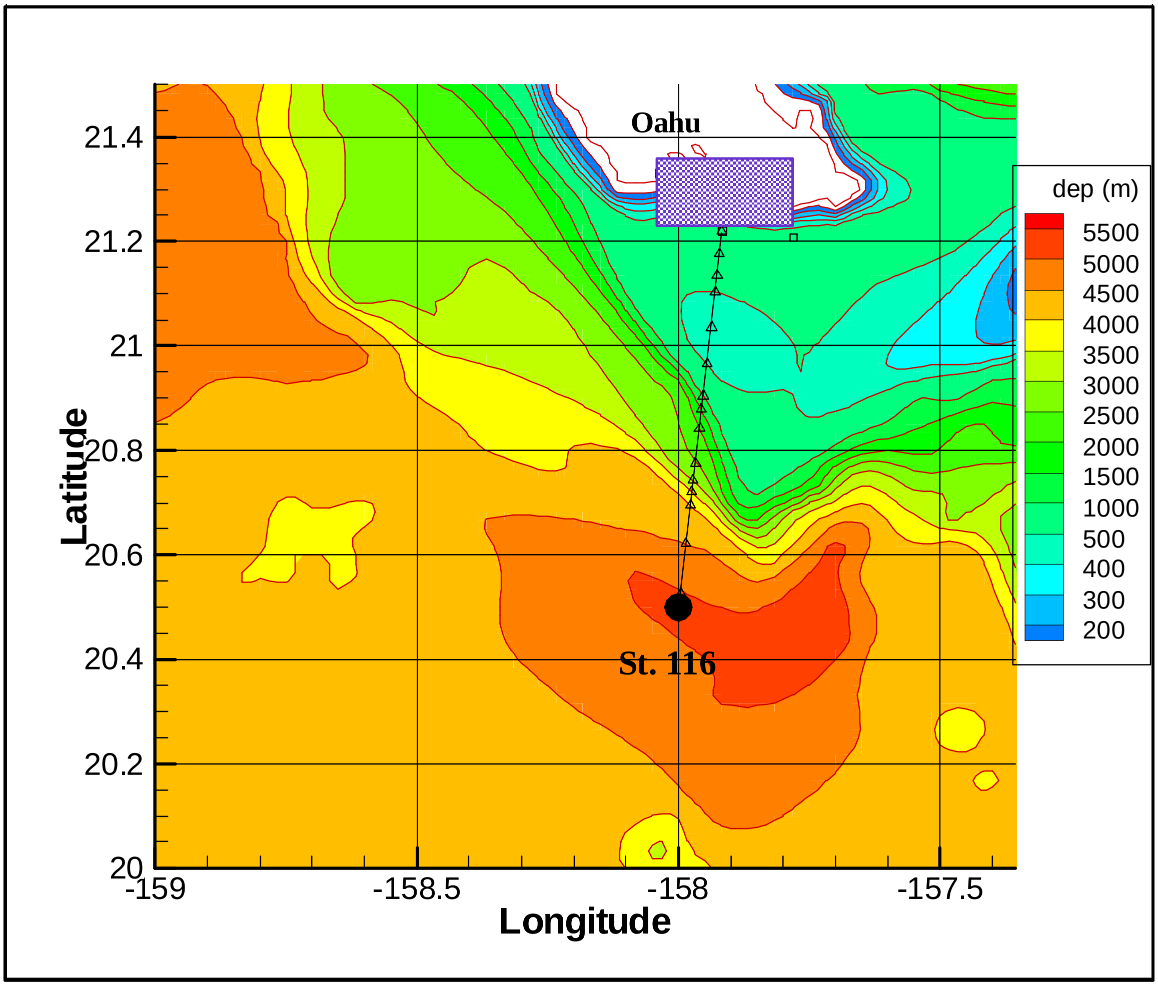


Figure 8. Bathymetry contours (in meters) south of the island of Oahu. STWAVE grid shown in purple.

Wave Case Selection

Wave parameters (significant wave height, peak period, and mean direction) were defined for each of the hourly half-plane spectral files available for 1984, 1992, and 1994. The resulting wave parameters were plotted using the WSAV section of the Coastal Engineering Design and Analysis System (CEDAS, http://chl.erdc.usace.army.mil/cedas) software to produce percentage analysis, wave roses and table files. Figures 9-17 show the percent occurrence tables for wave height, wave period and wave direction for 1984, 1992, and 1994. The wave direction uses the STWAVE convention such that 0 degrees is a wave moving from due south toward north. A direction of -45 degree indicates a wave moving toward the northeast and +45 degrees indicates a wave moving toward the northwest. A set of STWAVE input wave cases was developed from the CEDAS analysis. Tables 2 and 3 list the wave conditions that were selected. Table 2 defines the normal or moderate wave conditions and Table 3 adds some of the extreme or more unusual wave conditions. Table 2 lists 441 conditions, and Table 3 lists 63 conditions for a total of 504 wave conditions. Wave conditions are identified with a 3-digit number using the numbers in parenthesis in the Tables. The first digit represents the wave height, the second the wave period, and the third the wave direction. A wave condition with significant wave height = 2m, period =16sec, and direction =-15deg would be 764.

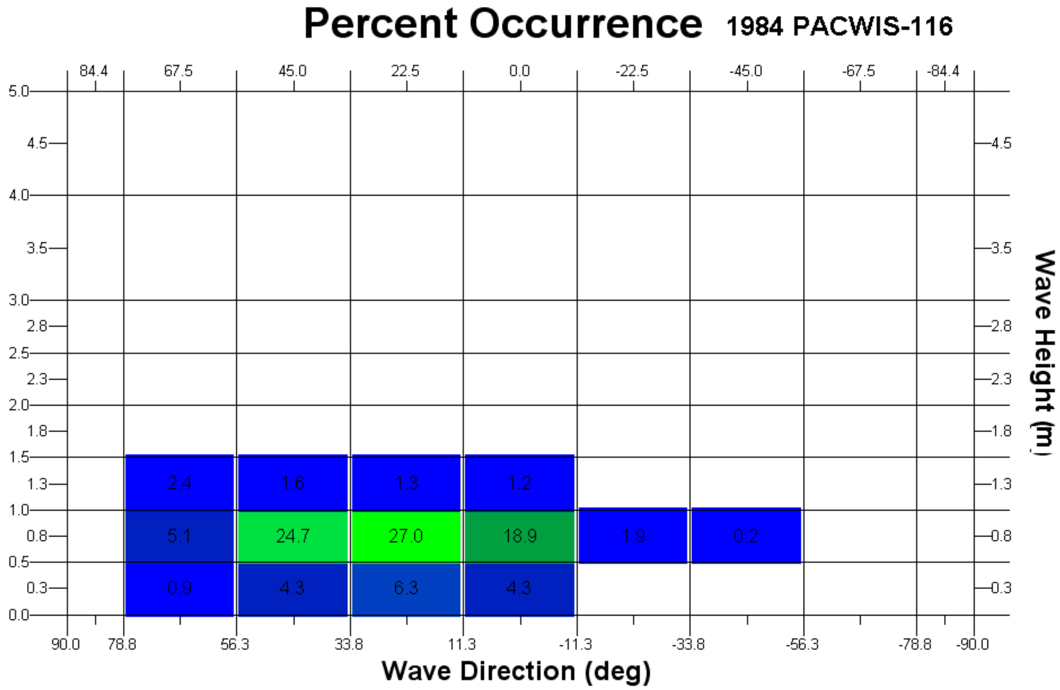


Figure 9. 1984 percent occurrence table for wave height and direction.

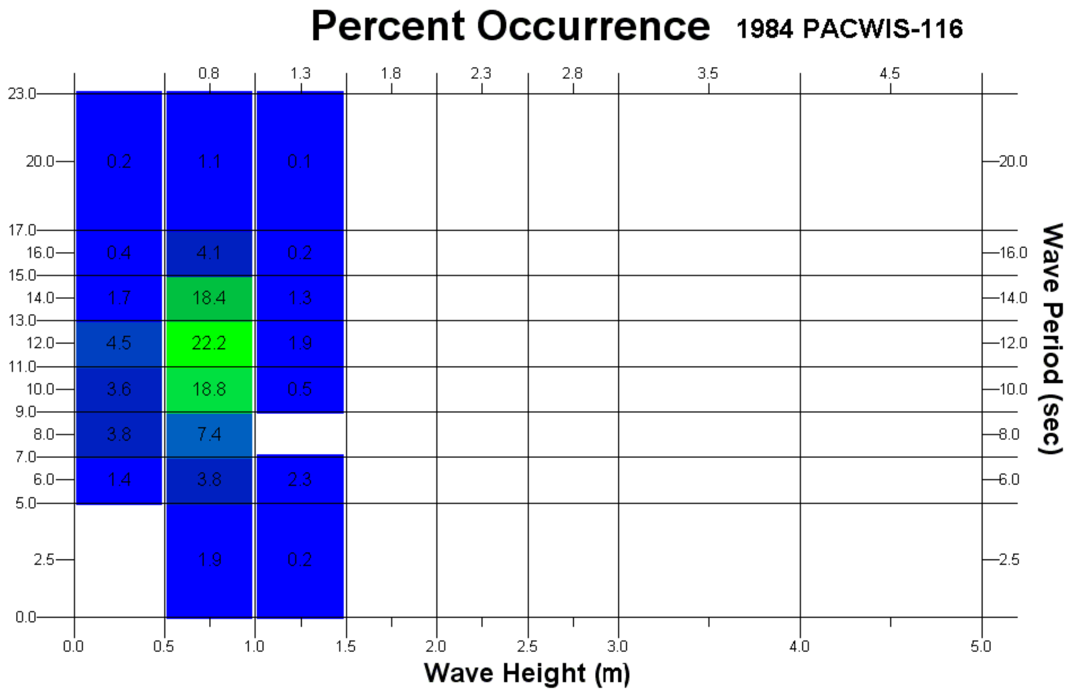


Figure 10. 1984 percent occurrence table for wave height and wave period.

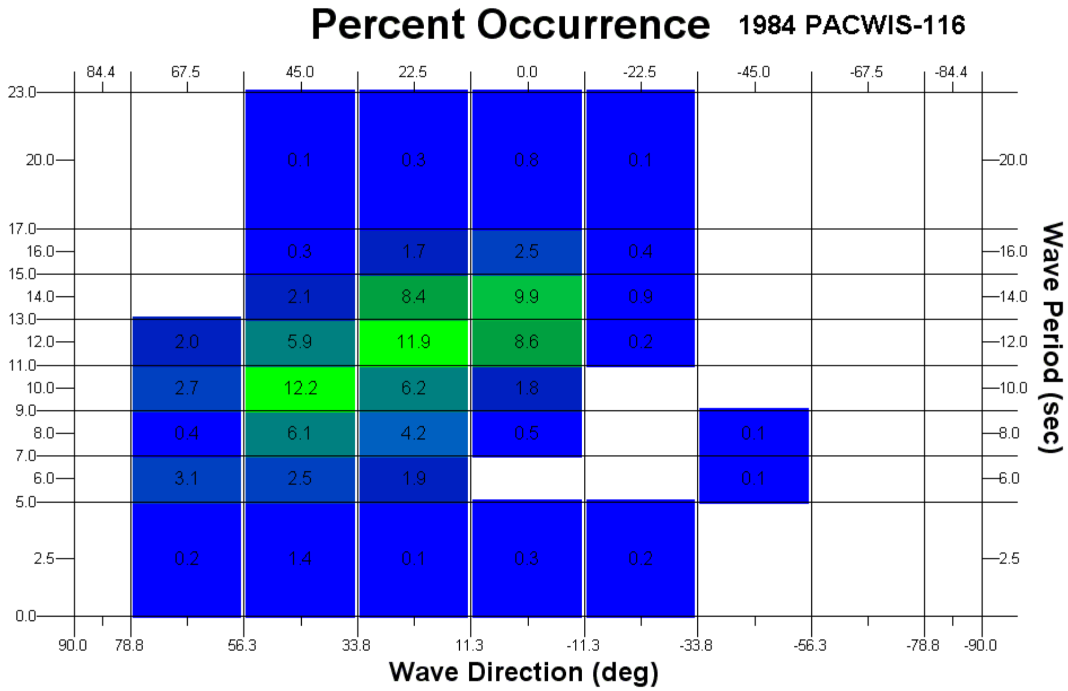


Figure 11. 1984 percent occurrence for wave period and direction.

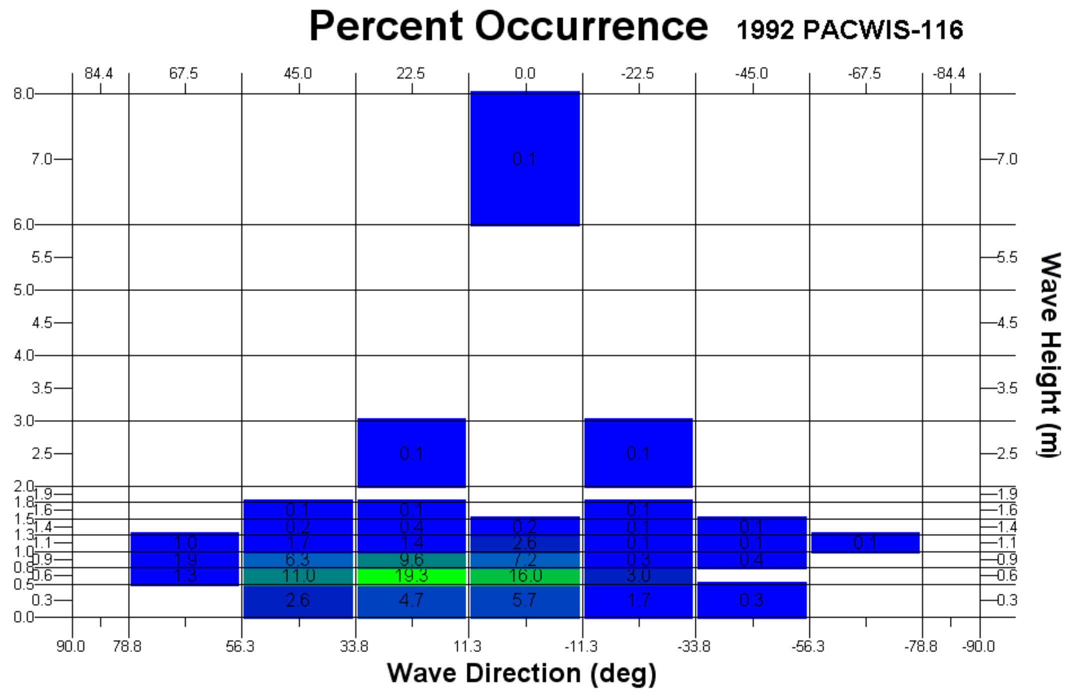


Figure 12. 1992 percent occurrence for wave height and direction.

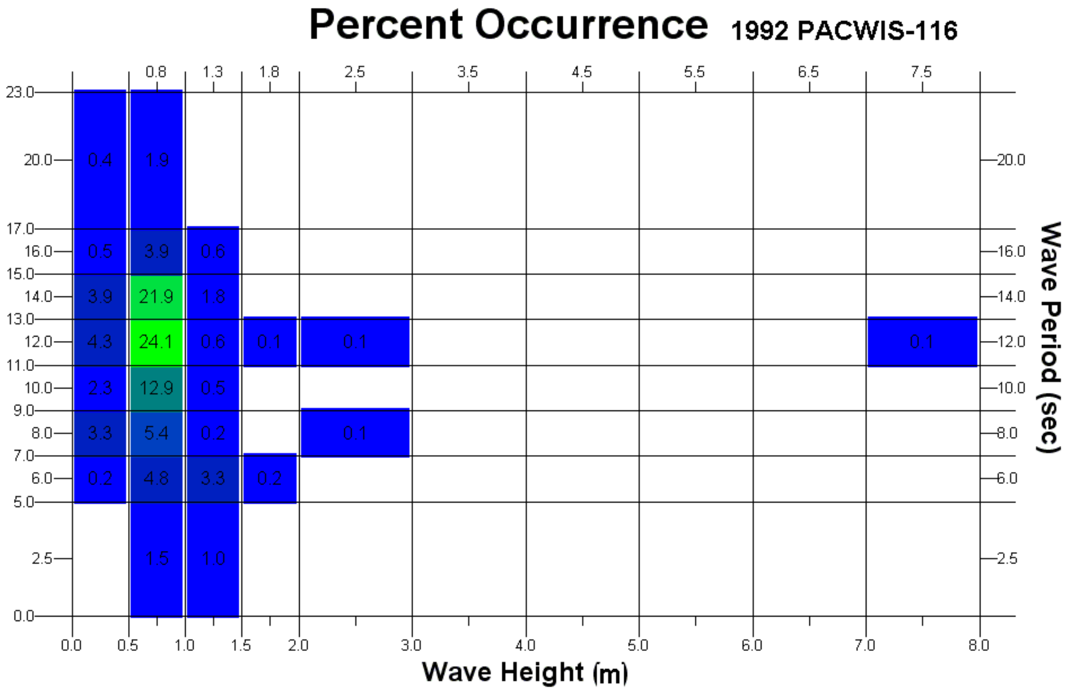


Figure 13. 1992 percent occurrence for wave height and period.

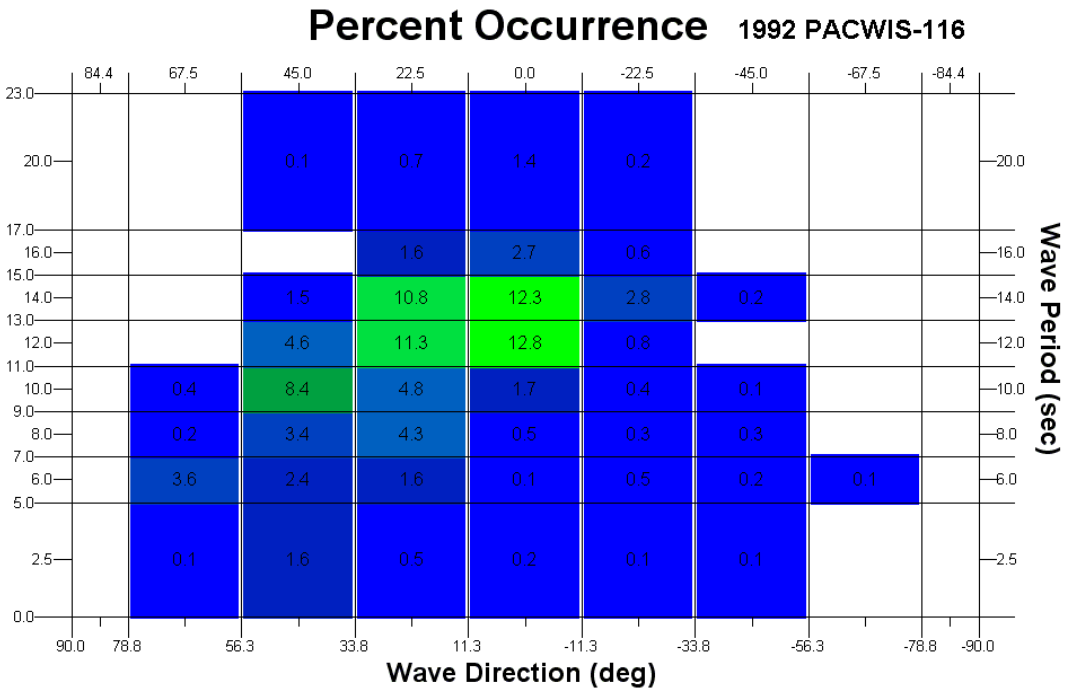


Figure 14. 1992 percent occurrence for wave period and direction.

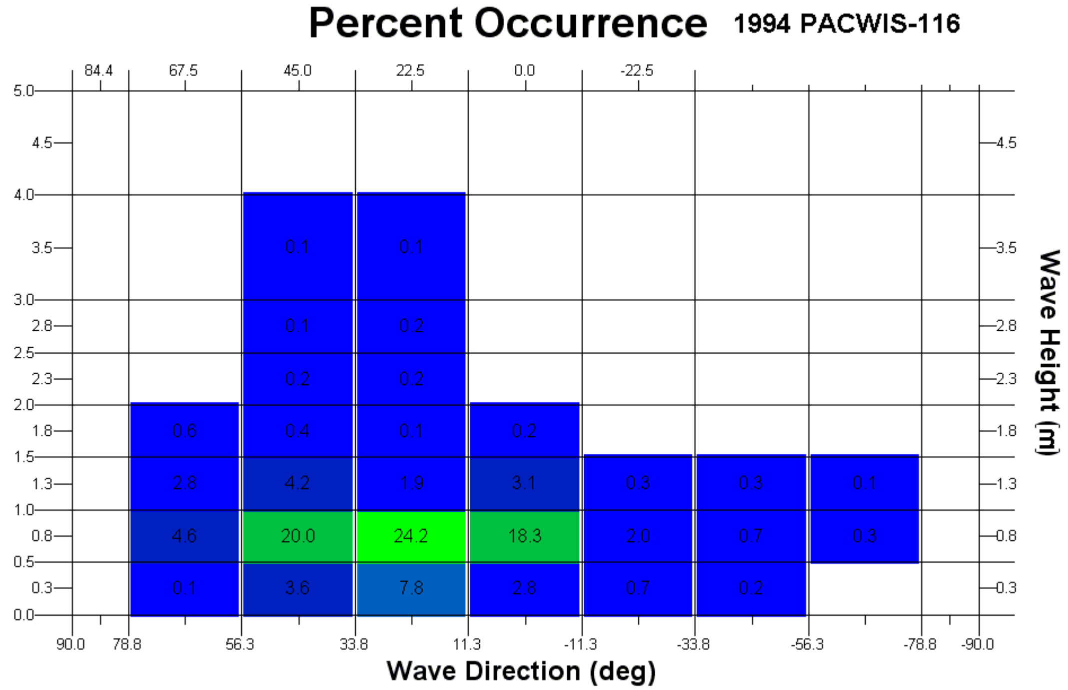


Figure 15. 1994 percent occurrence for wave height and direction.

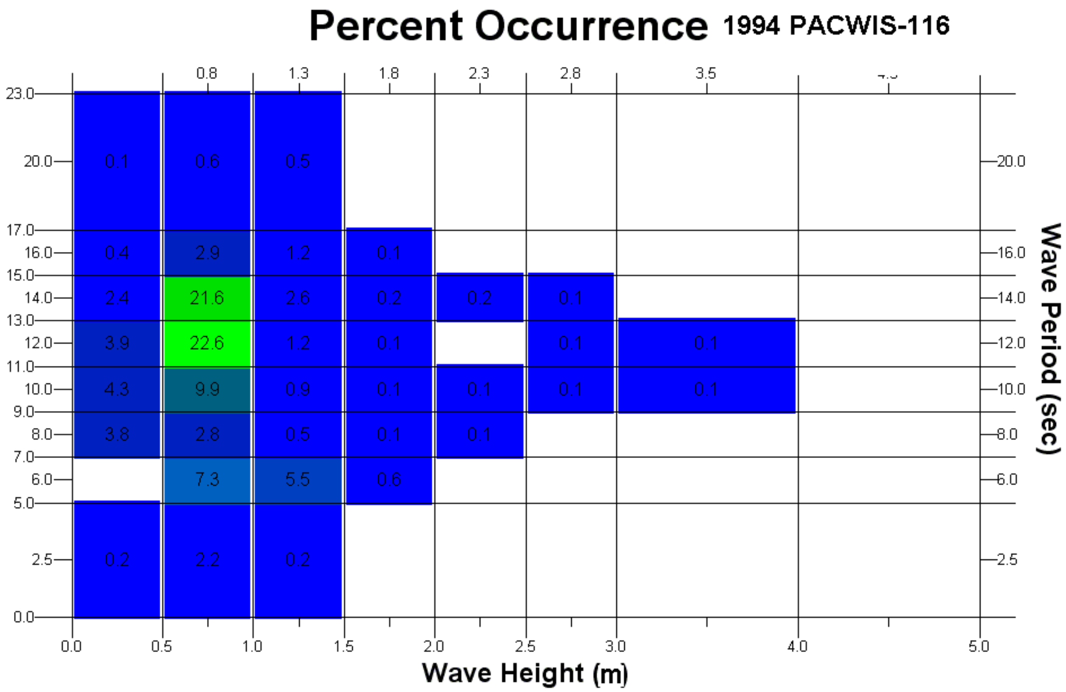


Figure 16. 1994 percent occurrence for wave period and wave height.

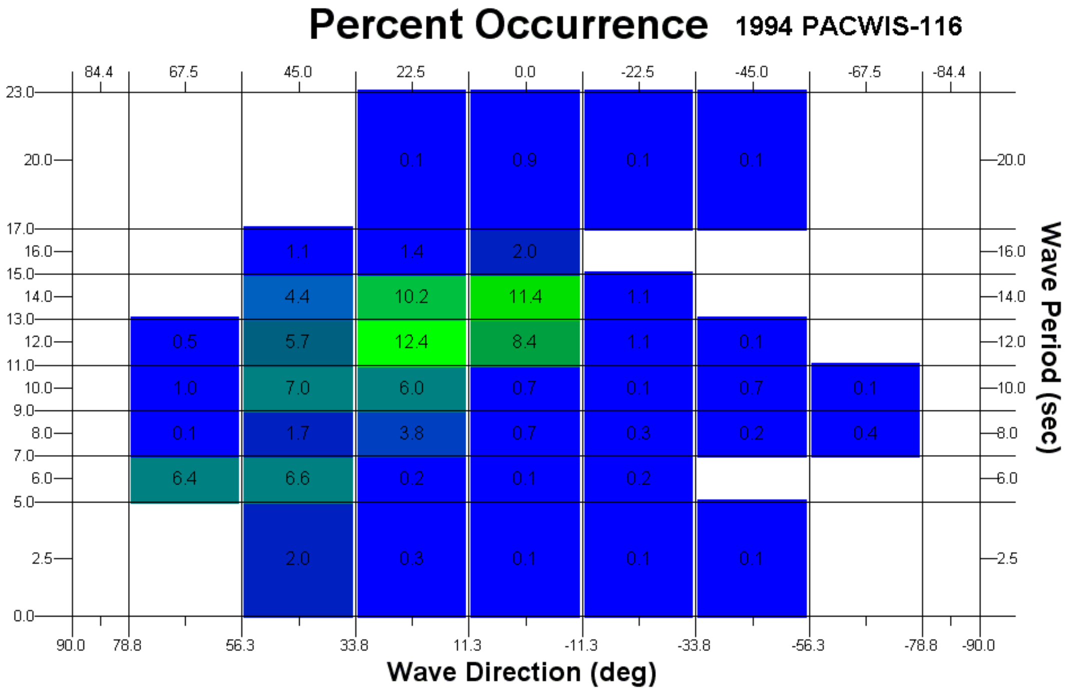


Figure 17. 1994 percent occurrence for wave period and direction.

TABLE 2: Initial Conditions (441 conditions)			
Significant Wave height, m	Wave period, sec	Wave Direction, deg from STWAVE axis	
.5 (1)	6 (1)	-60 (1)	
.75 (2)	8 (2)	-45 (2)	
1.0 (3)	10 (3)	-30 (3)	
1.25 (4)	12 (4)	-15 (4)	
1.50 (5)	14 (5)	0 (5)	From south
1.75 (6)	16 (6)	15 (6)	
2.00 (7)	20 (7)	30 (7)	
		45 (8)	
		60 (9)	

TABLE 3: Extreme Conditions (63 conditions)			
Significant Wave height, m	Wave period, sec	Wave Direction, deg from STWAVE axis	
2.5 (8)	8 (2)	-60 (1)	
	10 (3)	-45 (2)	
	12 (4)	-30 (3)	
	16 (6)	-15 (4)	
3.5 (9)	10 (3)	0 (5)	From south
	12 (4)	15 (6)	
7.5 (10)	12 (4)	30 (7)	
		45 (8)	
		60 (9)	

It was decided that selected cases of parameter input into STWAVE from the half-plane spectral information would provide a definable estimate of the wave response close the south shore of Oahu. Real spectral situations could have been selected from the available hourly spectral files but STWAVE has the option of creating input TMA one-dimensional shallow-water spectral shape input (named for TEXEL, MARSEN and ARSLOE storm data sets, Bouws et al. 1985) from a set of wave parameters. The parameter cases were used with suggested spreading coefficients and gamma values noted in Smith et al. 2001 to produce the STWAVE input spectral files. Several of the input spectral files were compared with plots of the actual hourly spectra and they looked very similar. Using the parameter input makes sure that only one wave train is being considered at a time, and real hourly spectral input files could contain traces of several wave trains in addition to the primary one being considered.

STWAVE Application

The bathymetry for the STWAVE grid shown in Figure 1 was developed by Mitchell Brown for a concurrent Regional Sediment Management application on the south shore of Oahu. All coordinates in the grid correspond to State Plane, NAD83, Hawaii Zone 3, meters. The STWAVE wave grid shown in Figure 1 has an origin at x = 523640. m, y = 3740. m with angle = 90 degrees. The cell size was set to 50 m and there are 300 columns and 595 rows. The grid size is 15000m in the x-direction 9cross shore) and 29750m in the y-direction (long shore). Surface Modeling System (SMS 9.0) was used for the STWAVE simulations. Figure 18 shows a picture of the coastline in the Diamond Head area and gives a sense of the Oahu south shore coastline.

Figure 18. Photo from Mitchel Brown showing the Oahu south shore coastline in the Diamond Head area. Note the wave breaking on the reefs just offshore from the coast.

Forty-four points were selected as output save locations. Output information was also saved at regular intervals along both the 30-m and 100-m depth contours. There were two measurement locations available (CDIP Pearl Harbor and CDIP Diamond Head) for a short time during the hindcast period and several points were saved at these measurement sites. Table 4 lists the 44 output save locations that were selected for wave output. Coordinates are in State Plane, NAD83, Hawaii Zone 3, meters. All the saved locations are shown as red squares in Figure 1.

TABLE 4: State Plane locations of save points
XYZ (44 points)

1.	511683.45080	14700.26712
2.	510904.94260	15153.68209
3.	510693.71580	15275.33477
4.	504855.85550	15073.26495
5.	505063.39510	15095.47183
6.	507761.15380	14996.88101
7.	509701.61410	14710.04436
8.	509888.44350	14610.50819
9.	521159.00000	9908.10000
10.	520344.10000	9670.00000
11.	519382.90000	9670.00000
12.	518731.80000	9930.00000
13.	518386.70000	10602.90000
14.	518327.70000	10841.00000
15.	518194.40000	11561.90000
16.	518201.00000	11280.10000
17.	518041.50000	11885.20000
18.	517654.80000	12022.90000
19.	517119.60000	12127.70000
20.	516525.00000	12473.00000
21.	515956.00000	12682.00000
22.	516074.00000	12649.00000
23.	515650.00000	12979.00000
24.	515801.00000	13248.00000
25.	515771.00000	13450.00000
26.	515033.00000	13713.00000
27.	514309.00000	13639.00000
28.	514484.00000	13555.00000
29.	513457.00000	14183.00000
30.	513127.90000	14599.70000
31.	513043.70000	14488.20000
32.	512850.30000	14736.20000
33.	512445.30000	14777.20000
34.	512274.60000	14745.30000
35.	511992.50000	14670.20000
36.	502596.10000	16548.00000
37.	501910.70000	16368.70000
38.	503064.00000	17166.00000
39.	503176.00000	17872.00000
40.	501352.70000	16165.20000
41.	500598.80000	16024.50000
42.	499942.90000	15876.20000
43.	498750.00000	15566.00000
44.	499415.00000	15755.00000

The STWAVE simulations were run with no wind input and no tide input. Tests were made using both tide and wind input and output results between the two simulations were almost identical indicating that wind and tide input would not change results. STWAVE was run within the framework of SMS 9.0 using the TMA spectral input option described previously using the source term and propagation options available for STWAVE. Wave breaking was included in the runs. Spectral input was provided on all points on the southern ocean boundary. One typical wave simulation case required about 5 minutes on a Dell Precision PWS 380 Personal Computer.

Result Validation

Measurements in this area were limited to two CDIP sites, one at CDIP 075 Pearl Harbor, HI (21.3N,-157.9533, depth = 14m) and one at CDIP 097 Diamond Head (21.23N, -157.79, depth=120m).   Figure 19 shows the location of these measurement devices. CDIP 075 was a directional array, and CDIP 097 was a Datawell directional buoy.   The Pearl Harbor site was up from February 1993 through July 1994. Diamond Head was up from March to April 2000. Initial comparisons for the STWAVE setup were done using June 1994 at Pearl Harbor and all the available 2000 measurements at Diamond Head. STWAVE was run using the same setup described previously under the wave cases and STWAVE application.

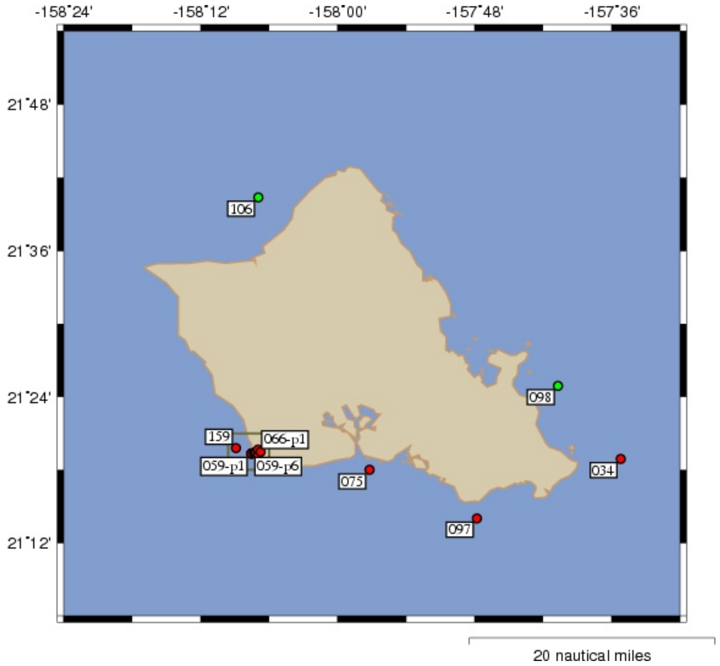
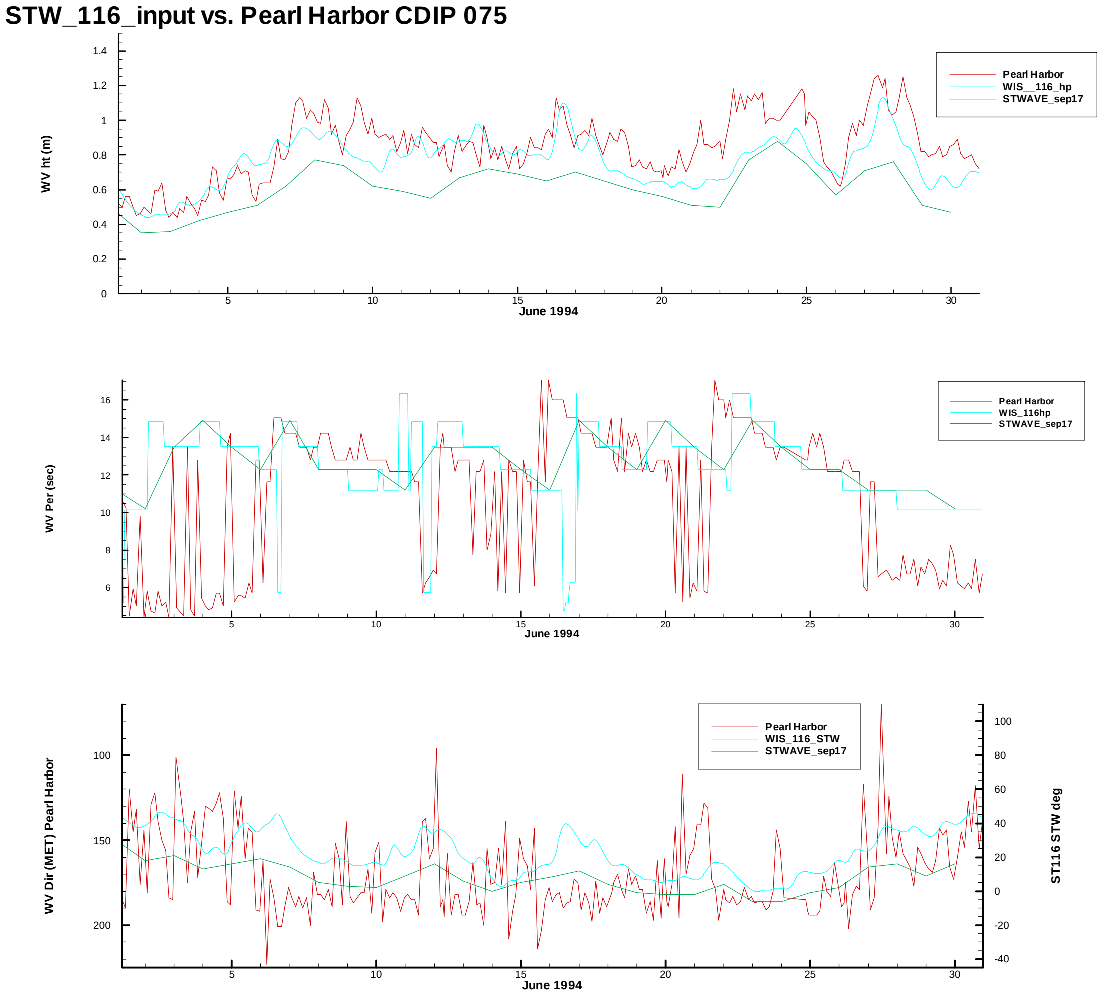


Figure 19. CDIP map of the island of Oahu showing measurment locations. Pearl Harbor is 075 and Diamond Head is 097.

The comparisons for CDIP 075 Pearl Harbor for June 1994 are shown in Figure 20. STWAVE simulations were run for each day of the hindcast since there was very little hourly change in the wave input. Wave direction shows a good general comparison but does not pick up some of the local directional fluctuations. Wave period results also show a good comparison although the swell period dominates in the simulated wave results rather than the wind sea period at several periods during the month. The significant wave height comparisons are most interesting since it looks like the input wave conditions make a closer match than the STWAVE simulations. The wave conditions are fairly low to start with maximum differences between the simulations and measurements only about 0.4m. The shape of the simulated results appears to make a very good match but is slightly low. Wind speeds during the month of June 1994 varied between 4 and 8 m/sec coming from the northeast, and local wind generation does not appear to be significant. Energy input is only available from the half-plane to the south of the shoreline but significant additional energy coming from other directions does not appear to be possible because of the orientation of the island and the shoreline. Figure 21



STW_116_input vs. Pearl Harbor CDIP 075

Figure 20. Comparisons of significant wave height, peak period, and wave direction for June 1994 at CDIP 075 Pearl Harbor. Measurements are shown by a red line, half-plane input wave conditions from WIS Station 116 are shown by a cyan line, and the STWAVE simulated results are shown by a green line. Wave direction axes are shown in both MET convention and the local STWAVE convention.

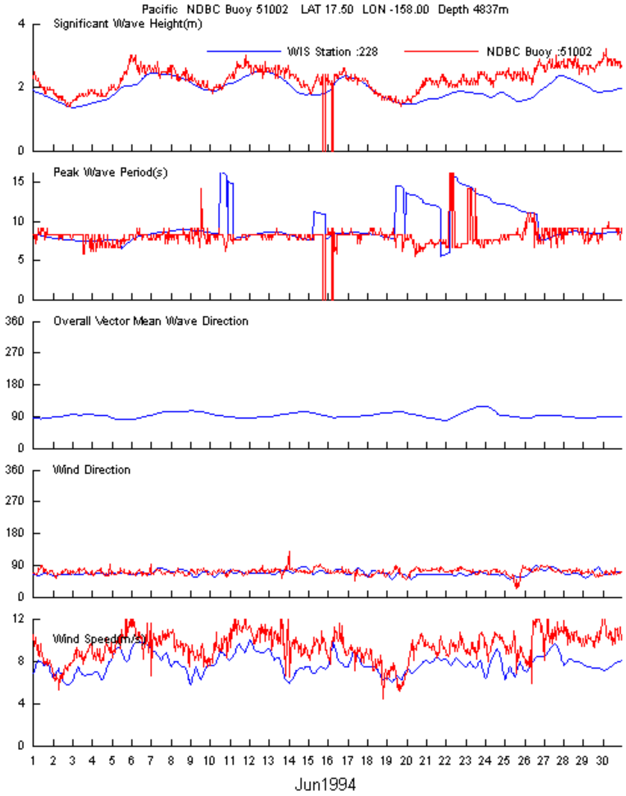


Figure 21. Plot showing wave hindcast results at NDBC 51002 for June 1994. The plot at the top of the page shows the significant wave height comparison and note that WIS results shown in blue tend to be lower than measured results in red. The wind speed plot at the bottom of the figure shows that the WIS hindcast wind fields are typically lower than the measured wind fields.

shows a plot of WIS June 1994 hindcast results at NDBC 51002, located south of WIS station 116 (see location in Figure 2). This plot indicates that the WIS input wind fields and the WIS hindcasted wave results for this month are slightly lower than the measurements. The significant wave height bias for this month is -.34m (WIS – measurement) and the wind bias is -1.66m/sec. This means that the wave energy at WIS Station 116 is probably slightly low for June 1994. A slight increase in energy for the input wave conditions would make the simulated STWAVE results match very well.

Measurements at the CDIP Diamond Head site were available for only a few days. Figures 22, 23, and 24 show the measurements for April 1-5, 2000. Figure 25 shows both the bulk significant wave height at Station 116 and the half-plane parameters at Station 116 for this same time period. The maximum half-plane input wave height for the STWAVE simulation (1.22m, 6.28sec, 64 deg) occurred on April 5, 2000. Since there was not much variation in the input conditions, only the maximum wave condition was run in an STWAVE simulation. Figure 26 shows a contour plot of the wave results for this condition. Note that wave results at the Diamond Head site (noted by a black dot) reached about 1.4m, which is about 0.5m lower than the measured value in Figure 22. Figure 27 shows the breaking dissipation for the same case as Figure 26. Note the breaking similarities between Figure 27 and the photo in Figure 18.

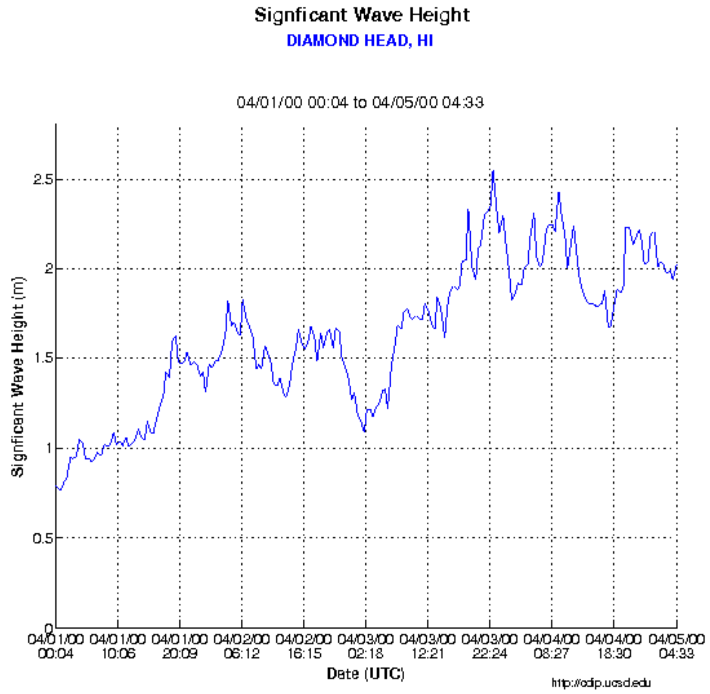


Figure 22

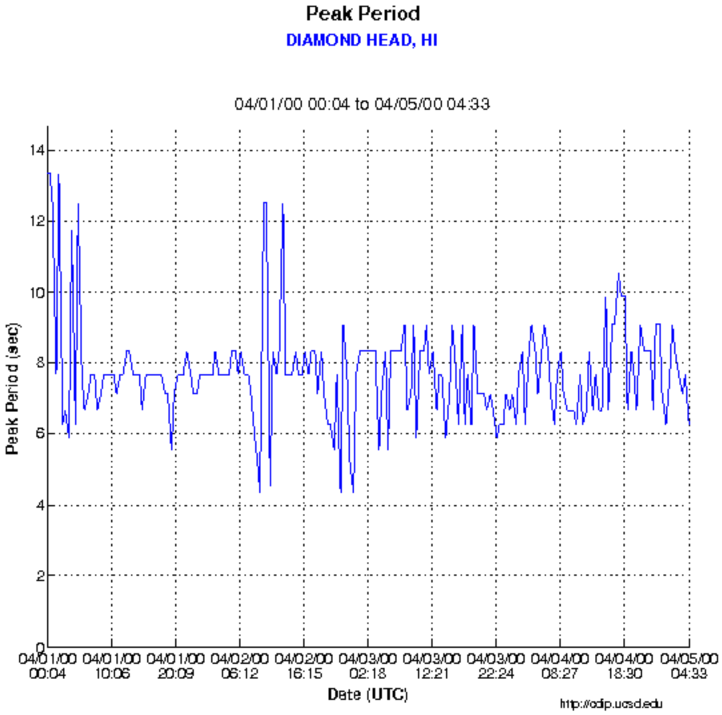


Figure 23

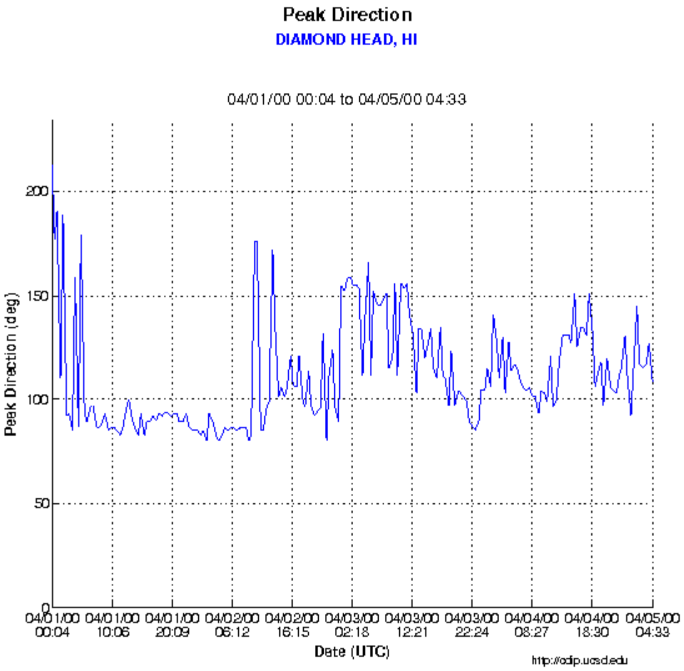


Figure 24

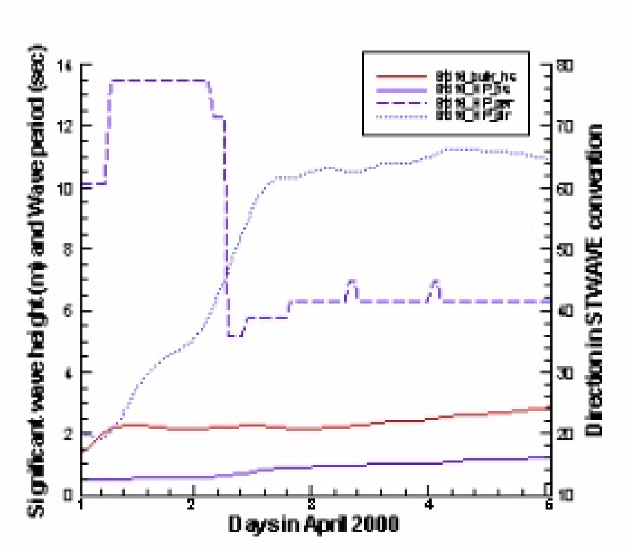


Figure 25. Plot of Station 116 results for April 1-5, 2000. Red line shows bulk significant wave height at Station 116. Blue lines show significant wave height, period and direction after the spectra from Station 116 has been transformed to half-plane. Direction is in the STWAVE convention described previously.

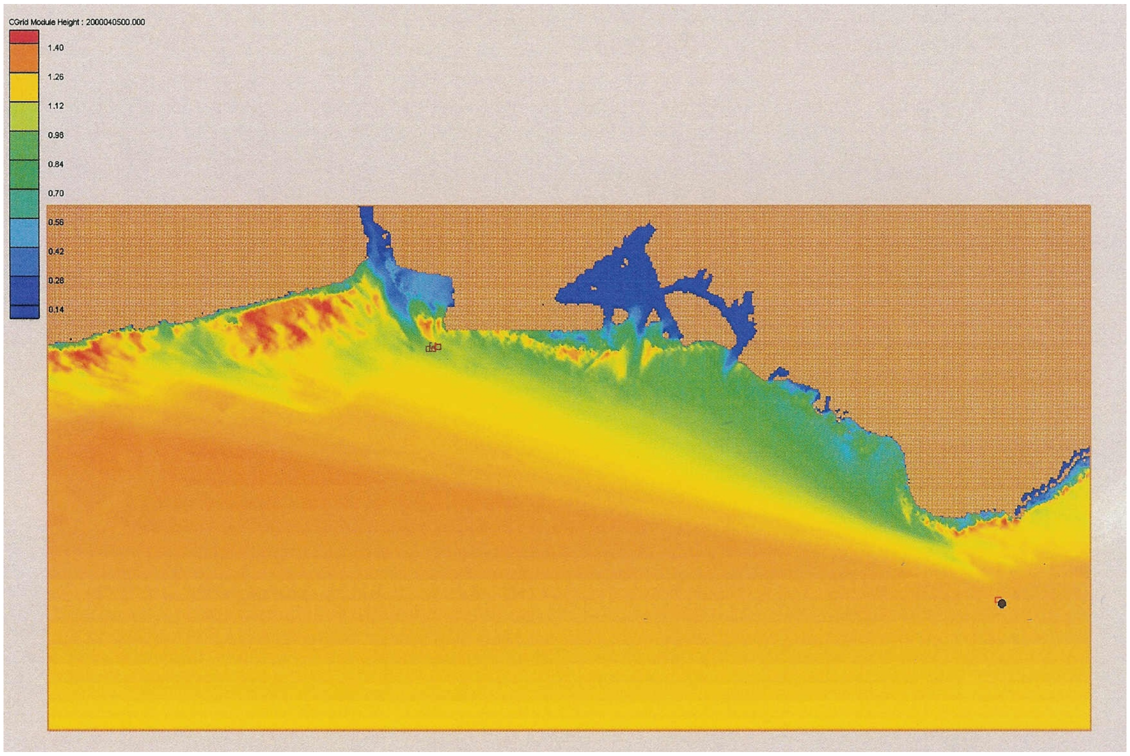


Figure 26. Contour plot of STWAVE wave results for input case (1.22m, 6.28sec, 64deg) corresponding to input conditions for April 5, 2000. Black dot indicates location of Diamond Head CDIP measurement site.

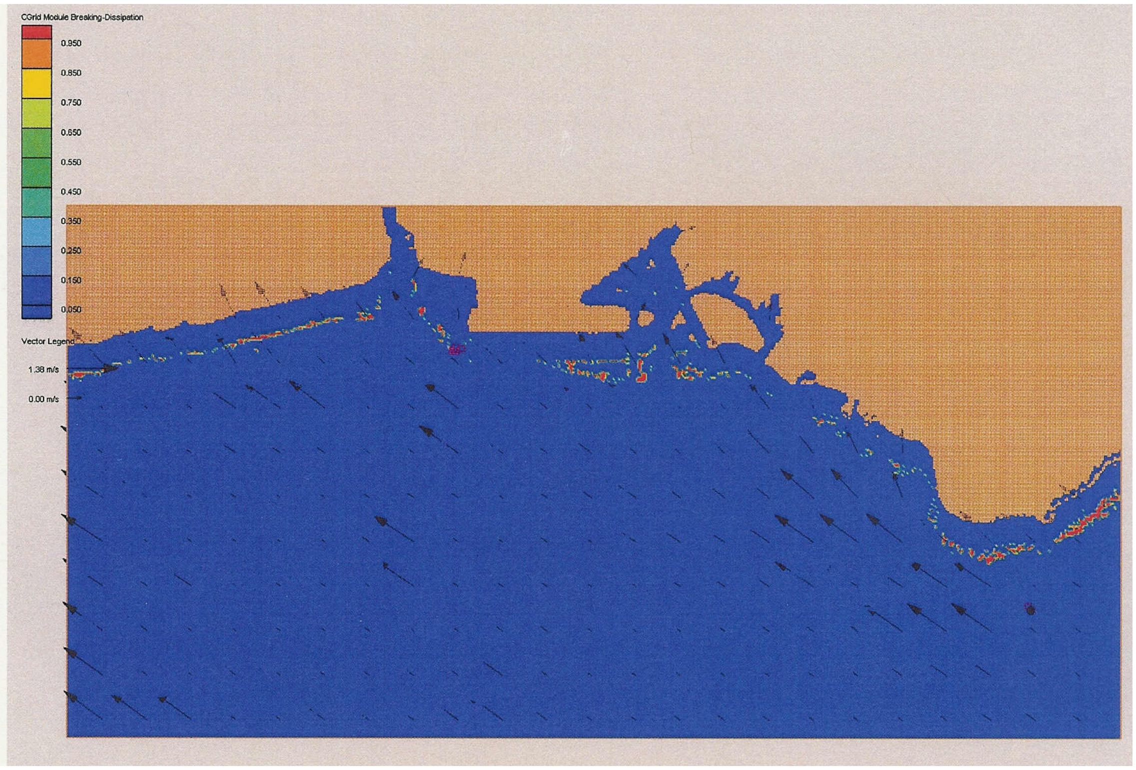


Figure 27. STWAVE breaking dissipation for the STWAVE case shown in Figure 26. Arrows show wave direction. Note the similarities with the breaking in the photo in Figure 18.

Figure 28 shows a comparison of WIS results at NDBC 51002 for April, 2000. Figure 2 shows the location of 51002. WIS wave results look very close to the measurements with a slight tendency to be a little low for April 1-5. Waves for April 5 are coming from the southeast, and it is possible that the 0.5-deg wind fields close to the Hawaiian chain on this date may be a little low. Surf conditions available from the National Weather Service at Diamond Head for April 1-5, 2000, show 1-2 ft surf with only April 5 including 1-2 ft with the occasional 3 ft. This gives credence to the STWAVE results with the caveat that results still may be several tenths of a meter low because the input energy values are low (similar to the case at Pearl Harbor).

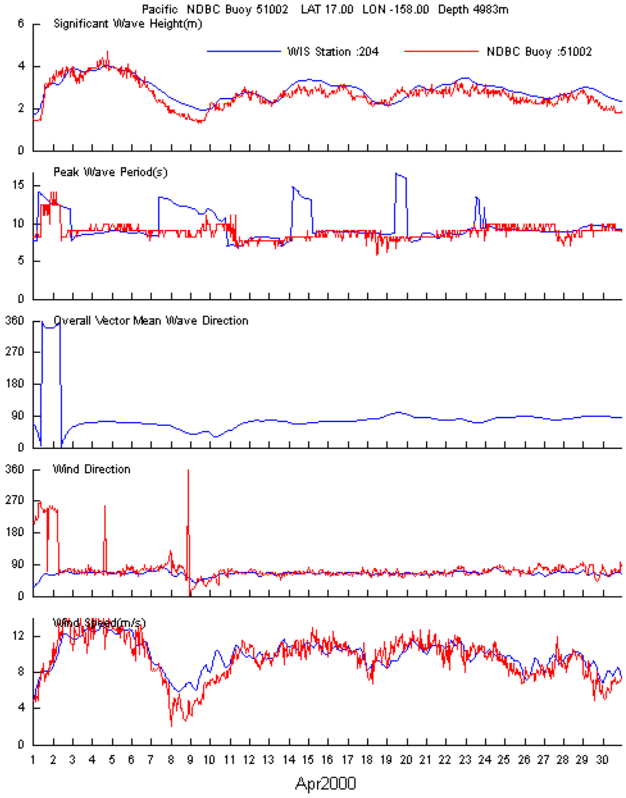


Figure 28. Comparison of WIS results at NDBC 51002 for April 2000.

Output Results

The wave cases were run using the input wave information in Tables 1 and 2. All cases were labeled by the three or four digit code described in the tables. Wave results were processed so each of the 44 stations includes the wave results for the three selected years. This information was saved into three yearly files for the 44 separate stations. Output included the date, input wave height, period, and direction, with the corresponding STWAVE wave height, period, and direction for the input wave case. Output wave conditions that fell outside the conditions that were run show “999.’s” for the output values. Direction is in degrees using the STWAVE convention; wave height is in meters and period is in seconds. Station 17 on the coast between the labels for Honolulu and

Diamond Head in Figure 1 received significant energy from Iniki, and a section of Station 17 wave results are shown in Table 5 for Hurricane Iniki in September, 1992.

TABLE 5: Station 17 Results for a portion of September, 1992, that includes Iniki

	INPUT			STWAVE OUTPUT		
Date	H	T	θ	H	T	θ
1992091100	1.5970	12.29	39.79	1.14	11.50	31.00
1992091101	1.6454	11.17	39.12	1.33	11.50	31.00
1992091102	1.6980	11.17	38.38	1.33	11.50	31.00
1992091103	1.7545	11.17	37.55	1.33	11.50	31.00
1992091104	1.8174	11.17	36.59	1.47	11.50	22.00
1992091105	1.8942	11.17	35.55	1.68	11.50	22.00
1992091106	1.9898	11.17	34.46	1.68	11.50	22.00
1992091107	2.1077	11.17	33.33	1.68	11.50	22.00
1992091108	2.2525	11.17	32.14	2.10	11.50	22.00
1992091109	2.4258	11.17	30.85	2.10	11.50	22.00
1992091110	2.6449	11.17	29.64	2.10	11.50	22.00
1992091111	2.8987	11.17	28.38	999.00	999.00	999.00
1992091112	3.1878	11.17	27.04	999.00	999.00	999.00
1992091113	3.4890	11.17	25.34	2.94	11.50	22.00
1992091114	3.8006	11.17	23.26	999.00	999.00	999.00
1992091115	4.1241	11.17	20.83	999.00	999.00	999.00
1992091116	4.4677	11.17	18.27	999.00	999.00	999.00
1992091117	4.8531	11.17	15.80	999.00	999.00	999.00
1992091118	5.2566	11.17	13.38	999.00	999.00	999.00
1992091119	5.6975	11.17	11.10	999.00	999.00	999.00
1992091120	6.1763	12.29	8.68	999.00	999.00	999.00
1992091121	6.6902	12.29	5.98	999.00	999.00	999.00
1992091122	7.1718	12.29	2.47	999.00	999.00	999.00
1992091123	7.5820	12.29	-1.45	6.25	11.50	0.00
1992091200	7.8853	12.29	-4.97	999.00	999.00	999.00
1992091201	7.9922	12.29	-7.86	999.00	999.00	999.00
1992091202	7.8982	12.29	-10.09	999.00	999.00	999.00
1992091203	7.6637	11.17	-11.89	6.17	11.50	-12.00
1992091204	7.3519	11.17	-13.37	6.17	11.50	-12.00
1992091205	6.9513	11.17	-14.83	999.00	999.00	999.00
1992091206	6.4666	11.17	-16.33	999.00	999.00	999.00
1992091207	5.9481	10.15	-17.70	999.00	999.00	999.00
1992091208	5.4403	10.15	-18.77	999.00	999.00	999.00
1992091209	4.9657	10.15	-19.18	999.00	999.00	999.00
1992091210	4.5345	9.26	-19.22	999.00	999.00	999.00
1992091211	4.1492	9.26	-19.08	999.00	999.00	999.00
1992091212	3.8160	9.26	-18.71	999.00	999.00	999.00

Contoured Output Results

Many times it is helpful to visualize output results over the entire grid. Figures 29 through 38 show wave height contours for cases 771 through 779 (2m, 20sec, -60 through 60 deg at 15 deg intervals). Case 776 exhibits the maximum wave height conditions in this set. Wave focusing varies depending on the direction of the input wave conditions.

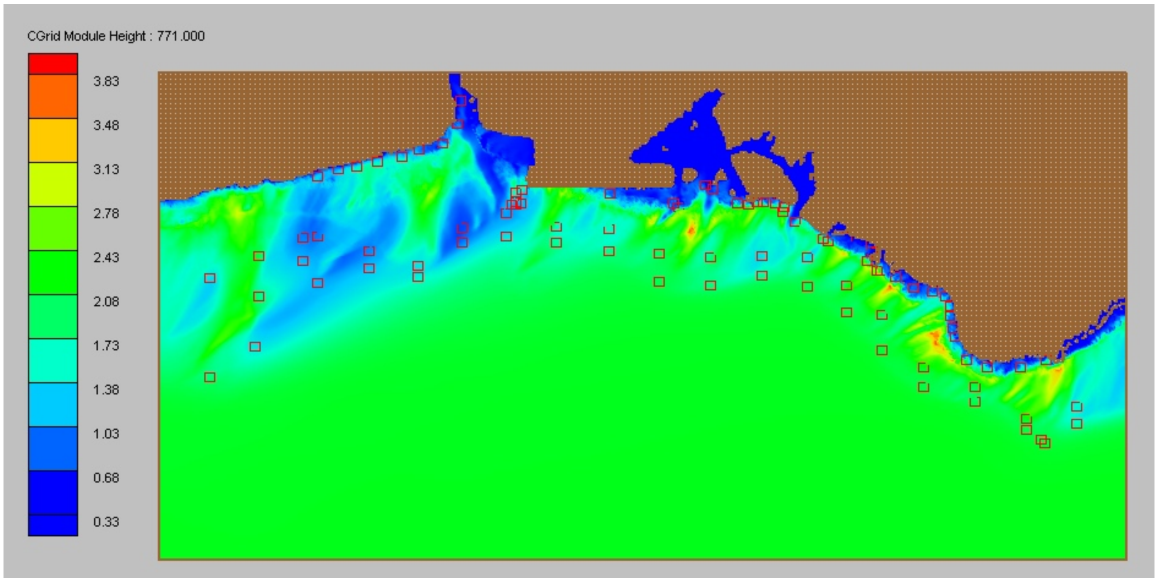


Figure 29. Wave height contours in meters for case 771.

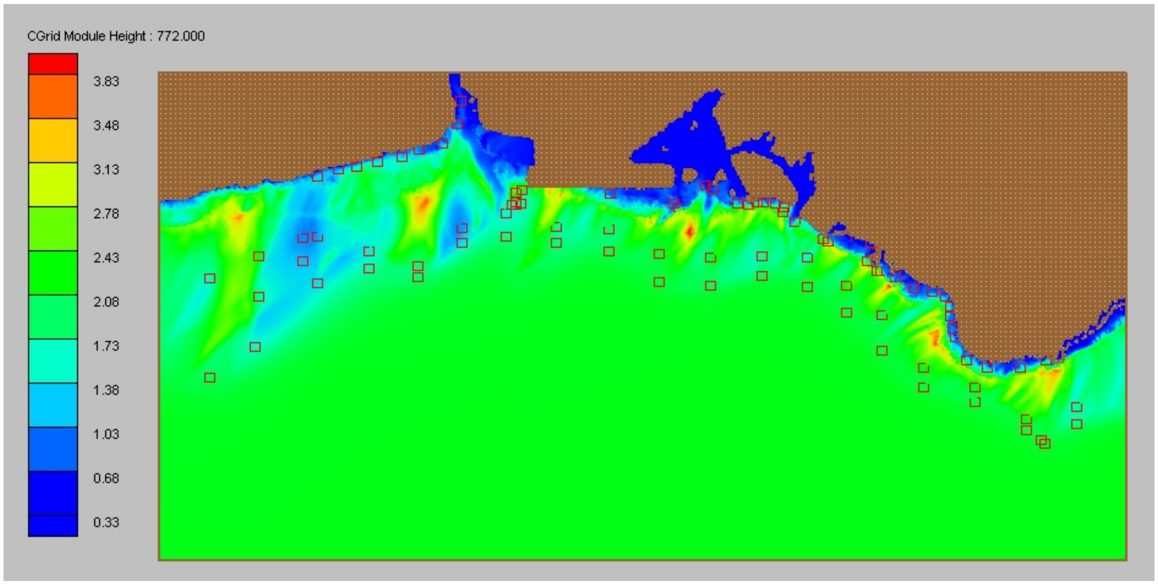


Figure 30. Wave height contours in meters for case 772.

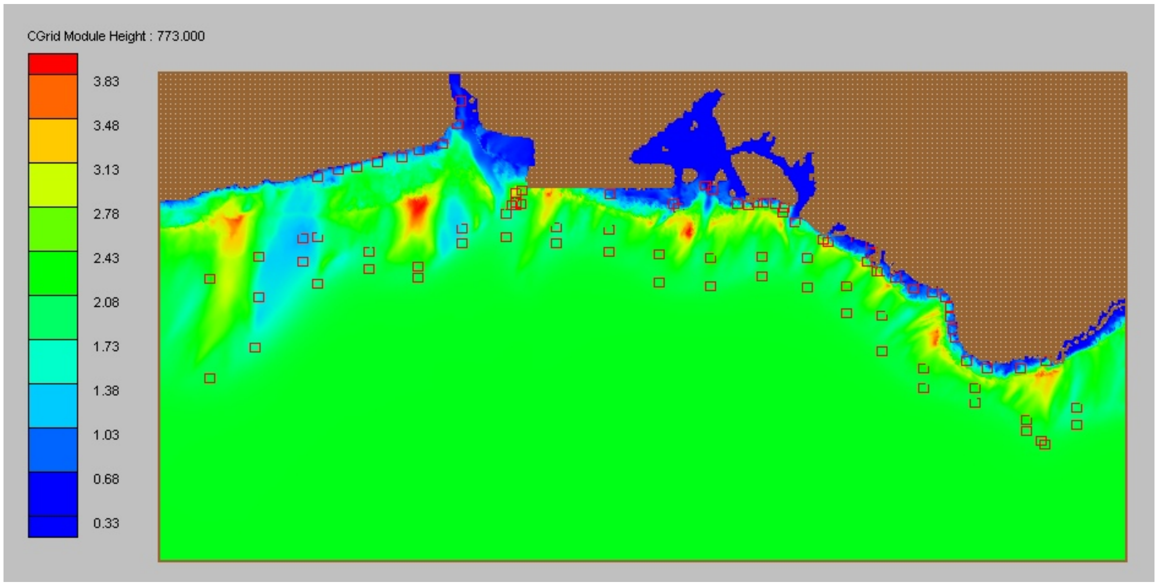


Figure 31. Wave height contours in meters for case 773.

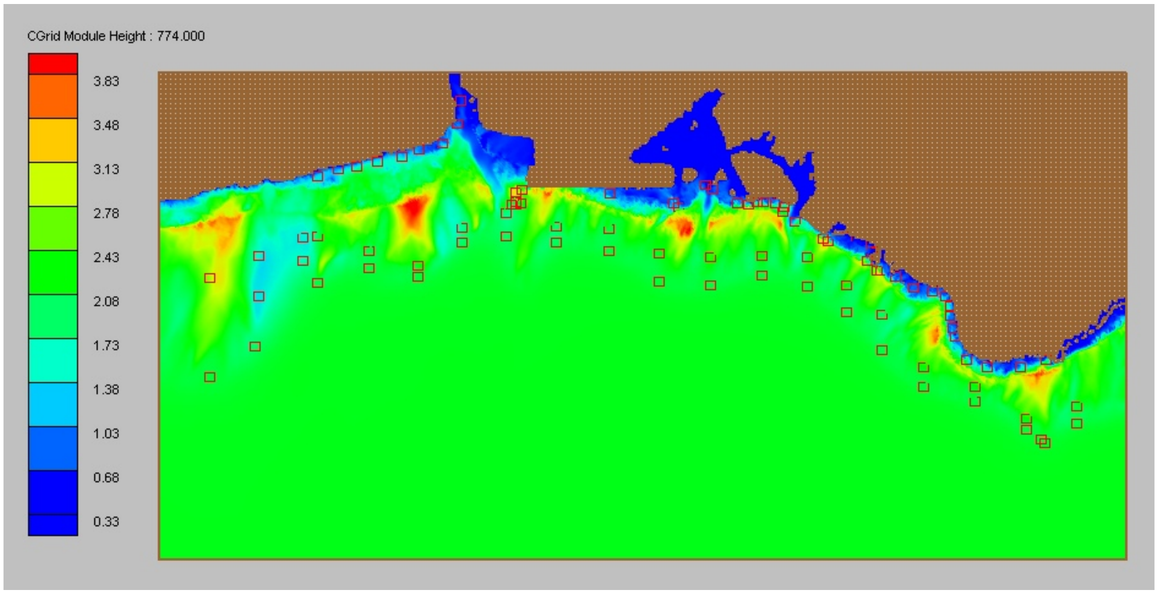


Figure 32. Wave height contours in meters for case 774.

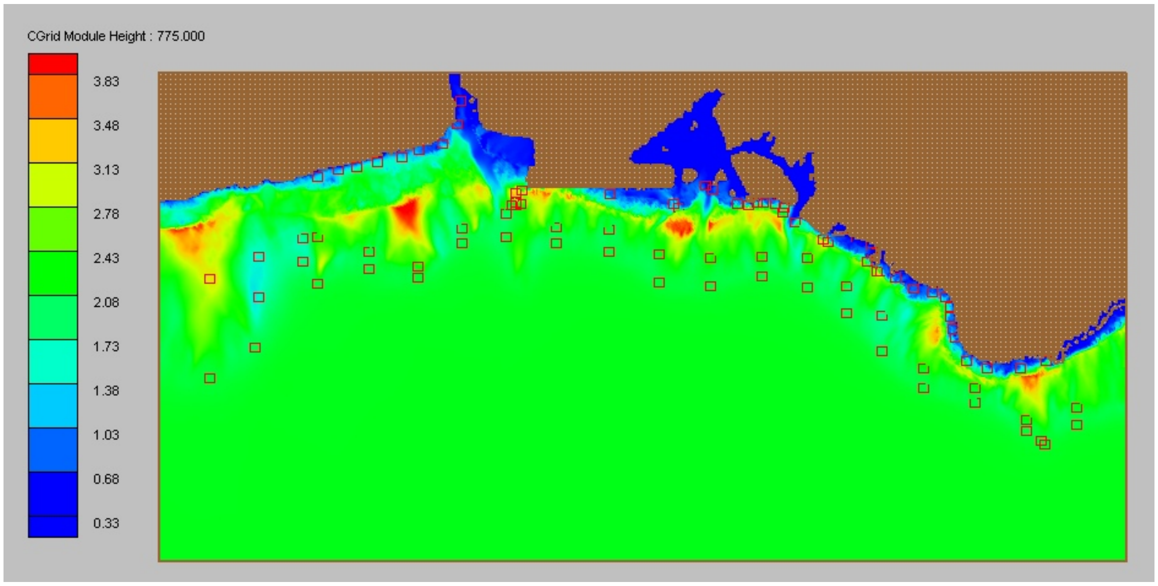


Figure 33. Wave height contours in meters for case 775.

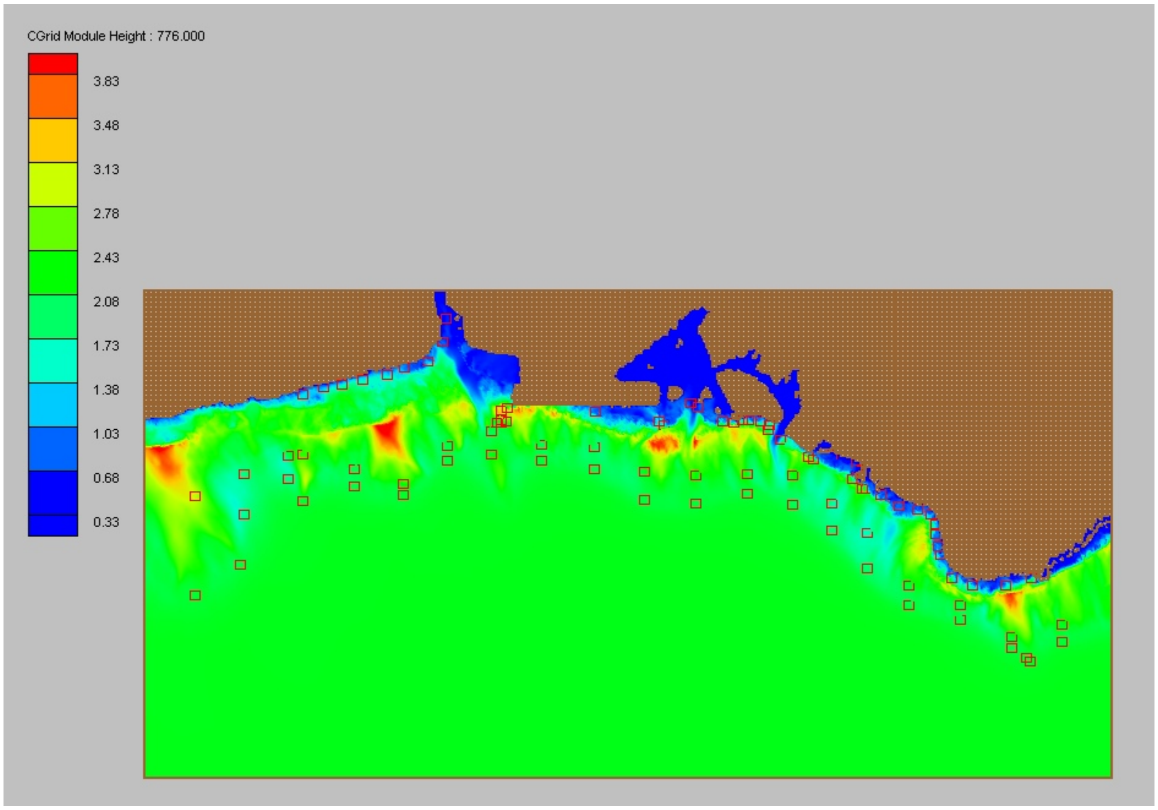


Figure 34. Wave height contours in meters for case 776.

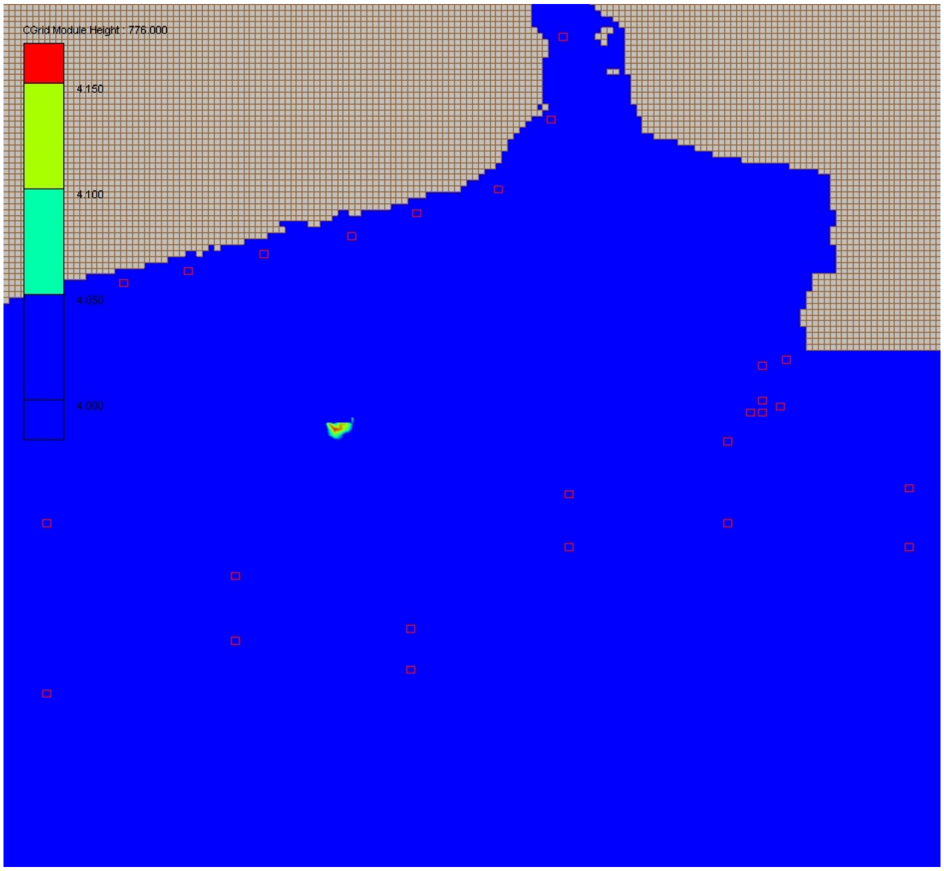


Figure 35. Zoomed wave height contours in meters for case 776.

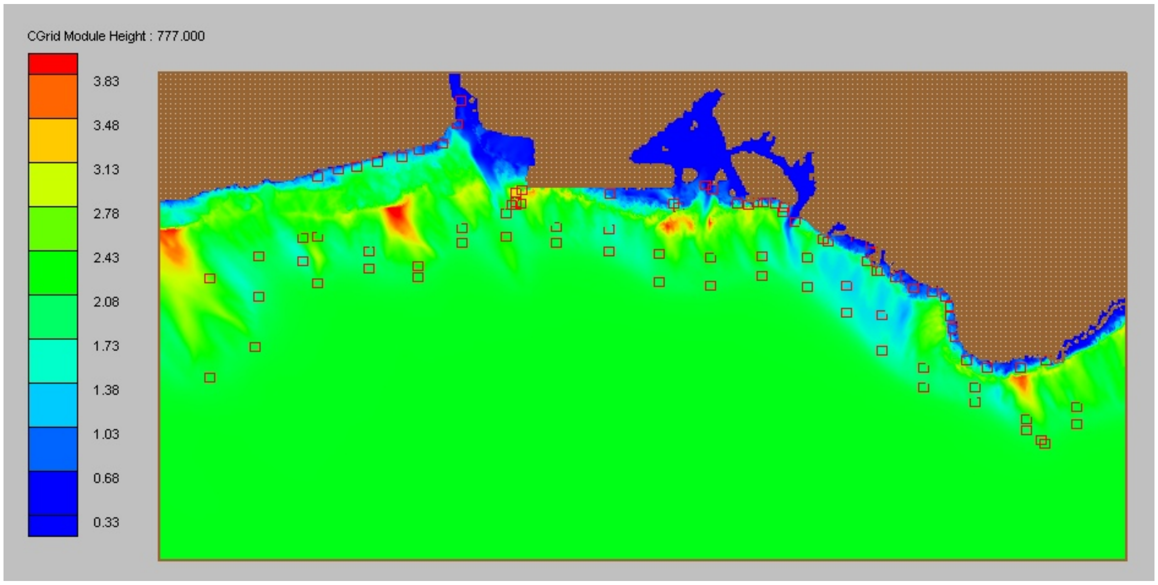


Figure 36. Wave height contours in meters for case 777.

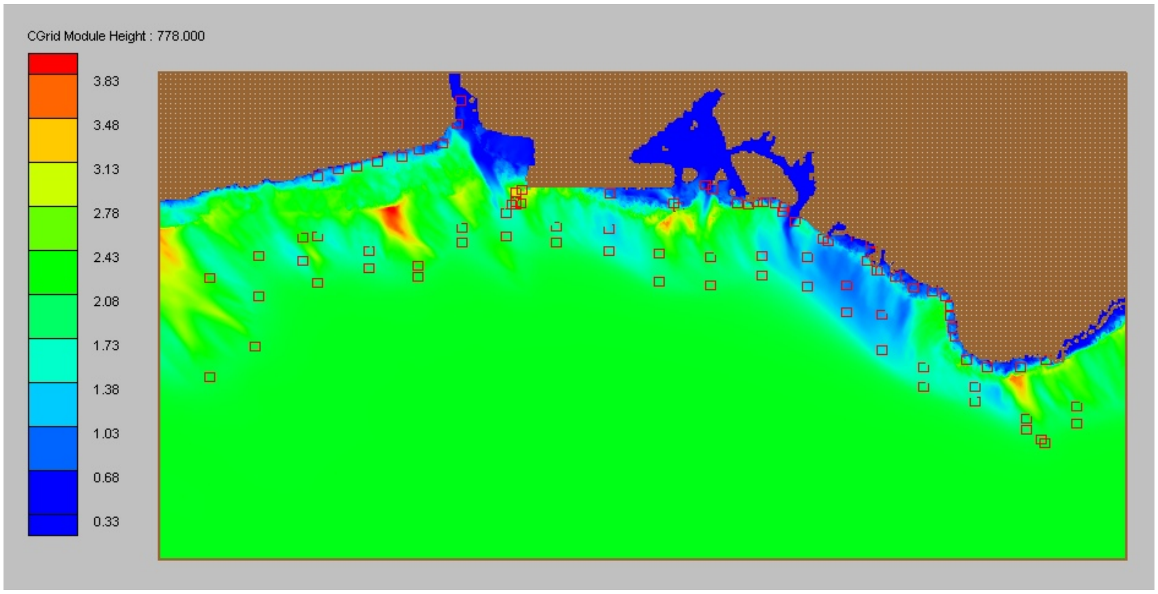


Figure 37. Wave height contours in meters for case 778.

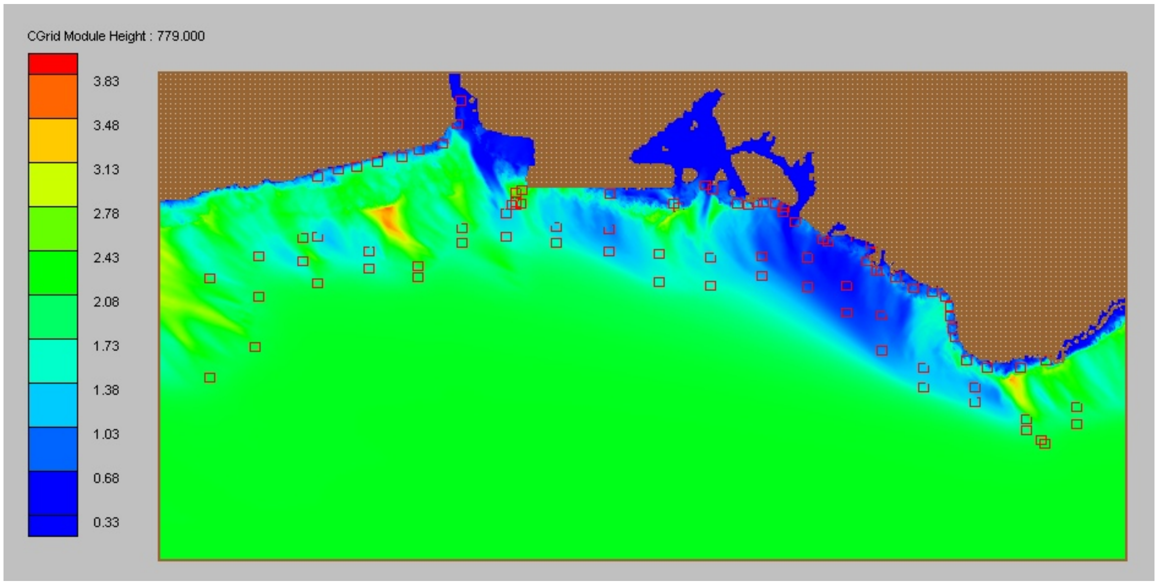


Figure 38. Wave height contours in meters for case 779.

Summary of Output Station Results

Figures 39 through 44 display summary wave roses showing modeling results for selected stations at different sections of the coastline. Each figure shows the wave rose of the incoming wave conditions for the 1984, 1992 and 1994 wave conditions. Note that only selected wave conditions were modeled for 1984, 1992 and 1994, and wave rose results at the coastal stations only show results from the selected wave conditions. The incoming wave rose outer ring corresponds to 35% with each concentric interior ring equal to 5%. Each of the coastal station wave roses uses different values for the rings.

Table 6 lists the % value of the outer ring and the % value of each of concentric interior rings by station number.

TABLE 6: Wave rose % information for figures 39 through 44		
Station number	Outer ring %	Interior ring %
9	70%	14%
10	100%	20%
11	70%	14%
13	55%	11%
16	65%	13%
19	75%	15%
20	65%	13%
21	90%	18%
25	105%	21%
26	105%	21%
29	75%	15%
30	100%	20%
33	95%	19%
1	80%	16%
2	50%	10%
3	55%	11%
8	85%	17%
6	55%	11%
4	55%	11%
39	100%	20%
38	105%	21%
36	105%	21%
40	90%	18%
42	75%	15%
43	95%	19%
Incoming WIS St. 116	35%	5%

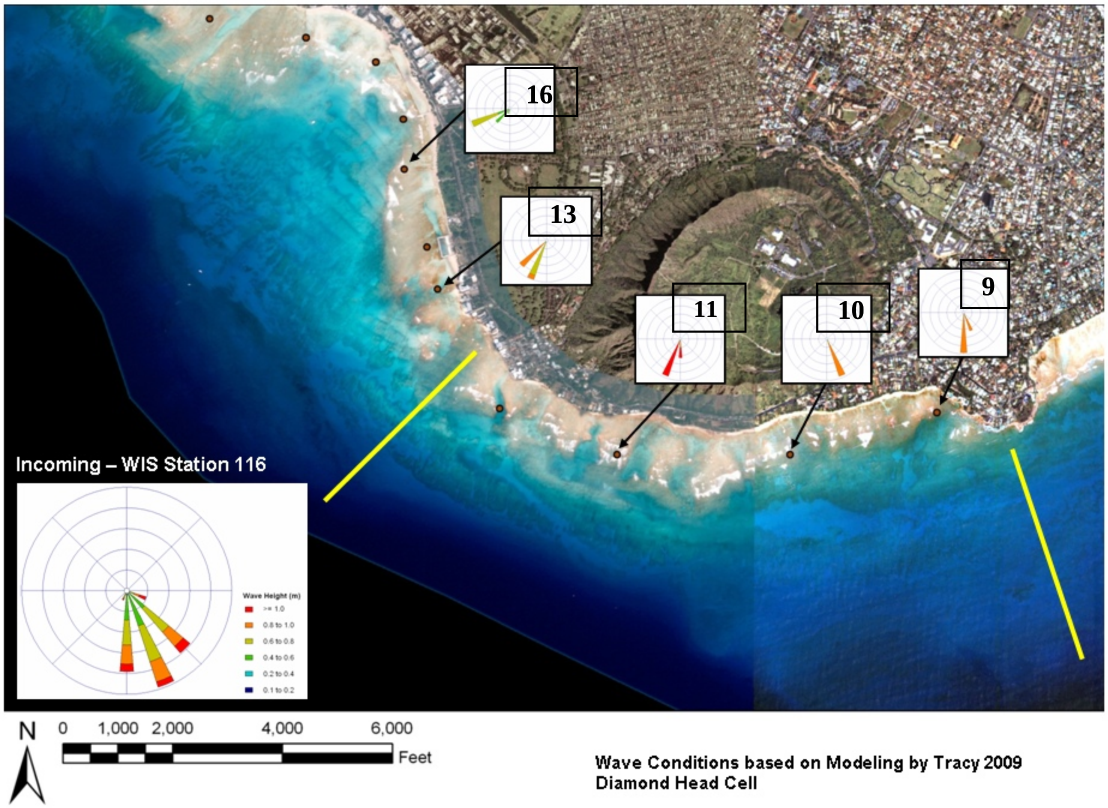


Figure 39. Modeling results for the three years of input waves at selected locations in the Diamond Head area. Station numbers are shown on the figure and information on wave rose ring values can be found in Table 6.

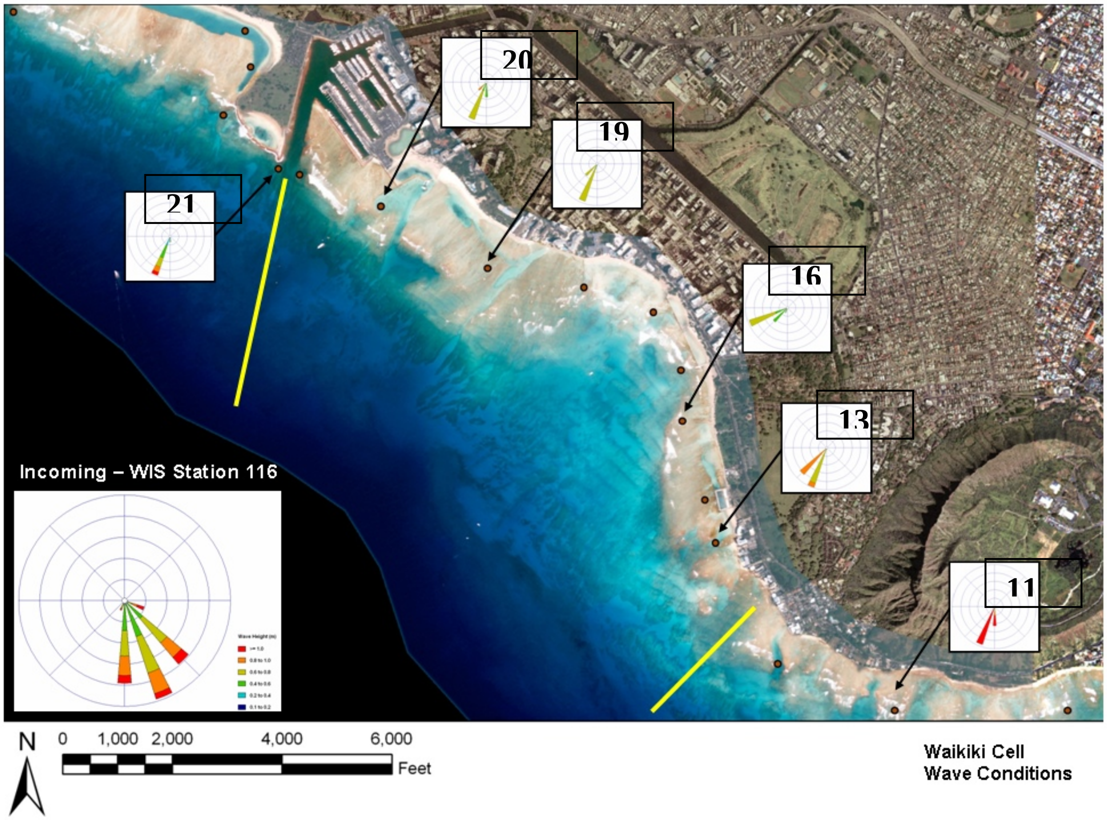


Figure 40. Modeling results for the three years of input waves at selected locations in the Waikiki area. Station numbers are shown on the figure and information on wave rose ring values can be found in Table 6.

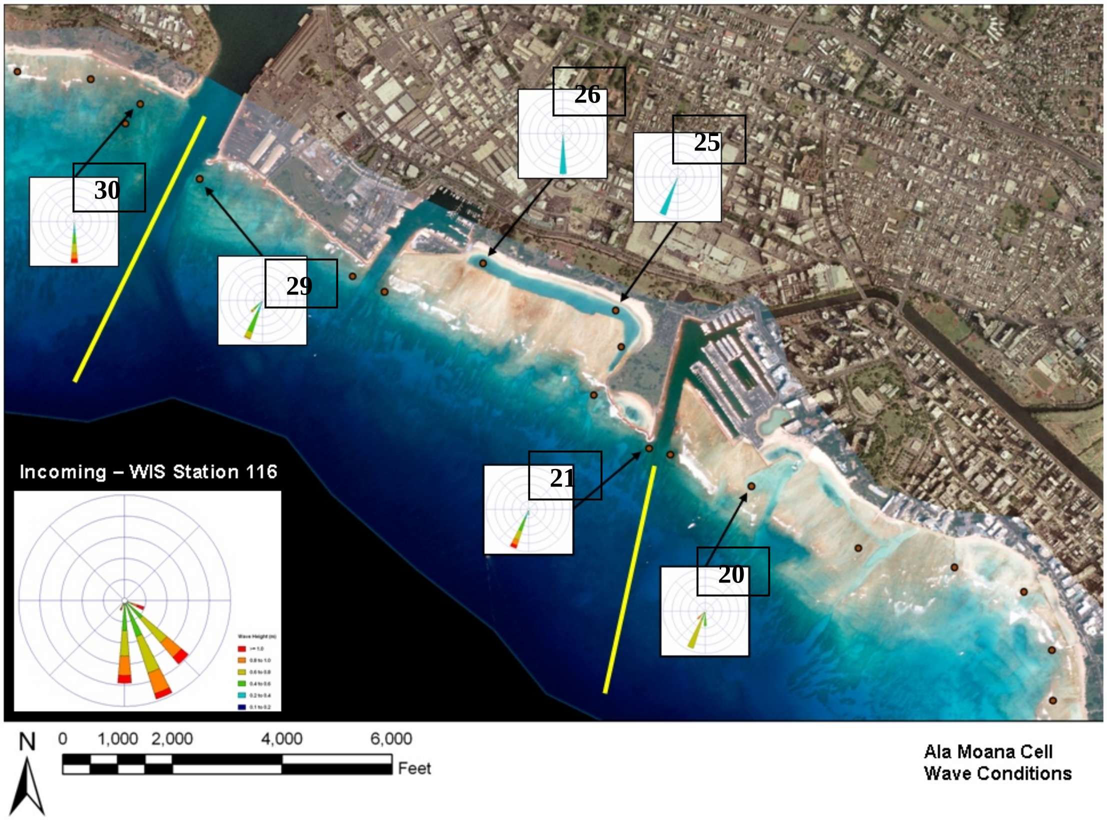


Figure 41. Modeling results for the three years of input waves at selected locations in the Ala Moana area. Wave rose ring values are shown in Table 6 and station numbers are on the figure.

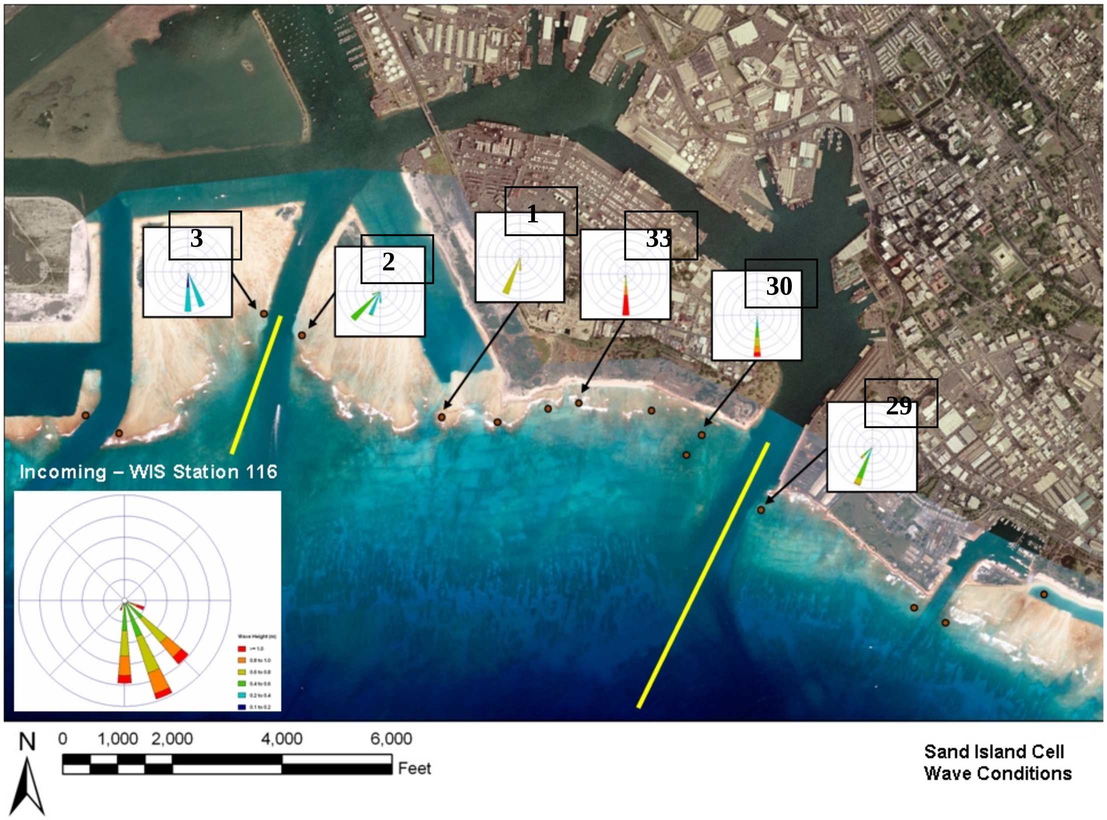


Figure 42. Modeling results for the three years of input waves at selected locations in the Sand Island area. Wave rose ring values are shown in Table 6 and station numbers are on the figure.

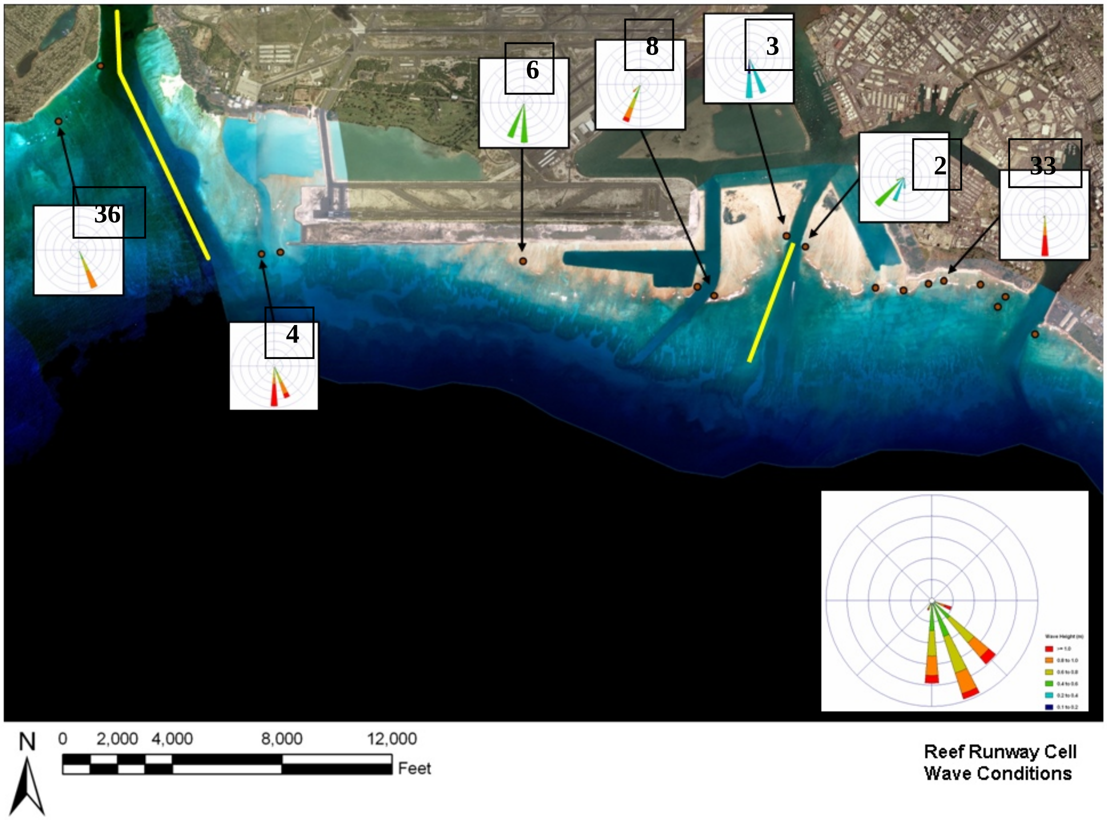


Figure 43. Modeling results for the three years of input waves at selected locations in the Reef Runway area. Wave rose ring values are shown in Table 6 and station numbers are on the figure.

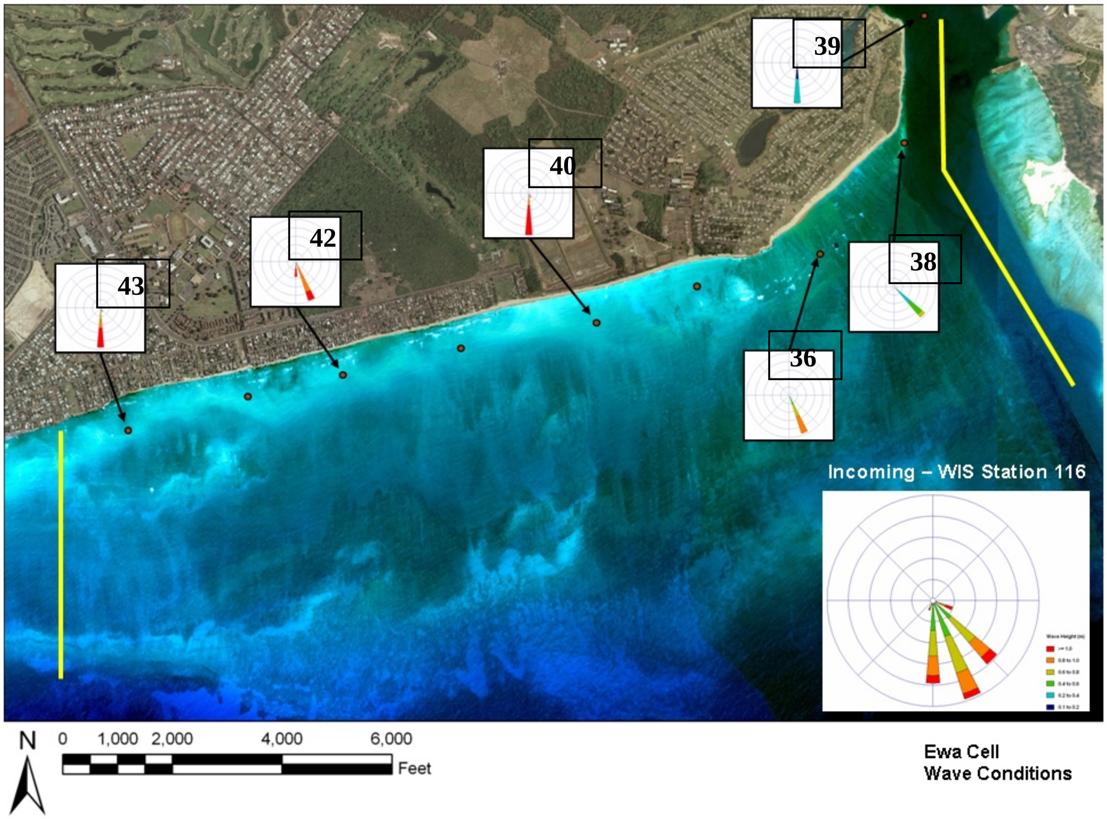


Figure 44. Modeling results for the three years of input waves at selected locations in the Ewa area. Wave rose ring values are shown in Table 6 and station numbers are on the figure.

Summary and Discussion

It appears that the use of the processed input spectra rather than the bulk spectral parameters from Station 116 produced a good STWAVE simulation. It was also interesting to note that the STWAVE simulation seemed to handle the reef situation without the need to use the option of differing bottom friction. Partitioning results for WIS Station 116 were invaluable to define the principal components of the input spectral situations from Station 116. The swell wave roses produced from these partitioned component results were also helpful in defining the input wave climate from the numerical wave model results. Additional validation results would be invaluable to verify the results from this study. If the WIS PACBAS information could be extended beyond 2004, there would be opportunities to verify results with the measurements that are now available close to Honolulu.

Acknowledgements

The available bathymetry from Mitch Brown's RSM study was very helpful to set up the STWAVE project files. Figures 39 through 44 were produced by Susan Tonkin at Moffat and Nichols. Advice from Dr. Jane Smith on output results and STWAVE details was invaluable. She also provided a 1-d wave transformation code that could be modified to

check if a wave transformation was needed between Station 116’s location and the edge of the STWAVE grid. Discussions with Ms. Mary Cialone on a previous Oahu nearshore transformation project (Cialone et al. 2008) were also helpful.

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APPENDIX I. Scope of Work for Project:

Scope of Work for Wave Transformation of Wave Information Studies Pacific Basin Information for the south shore of Oahu in the Hawaiian Islands (D2P Region from "Diamond Head" to "Pearl Harbor")

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Phone: 601 634-2400

Introduction and Background:

Wave Information Studies (WIS) has produced a 1981-2004 Pacific Basin (PACBAS) wave hindcast that includes output stations with hourly bulk wave parameter and spectral information around the Hawaiian Islands. These stations reside in very deep water about 1 degree offshore, and wave information is needed for coastal projects, coastal model applications and analysis closer to the shore. The Honolulu District (POH) is interested in transforming wave conditions from the PACBAS WIS wave information (Station 116) to save locations closer to the shore in increments along and within the 30-m contour and have asked ERDC/CHL to do this transformation project. Since nearshore bathymetry within the 30-m contour contains reef conditions, wave transformation will simulate these conditions. The transformation would include an application of the full-plane or half-plane STWAVE nearshore model using documentation and advice from Dr. Jane Smith.

The PACBAS wave hindcast is currently being reanalyzed because excess swell energy from winter storms in the north Pacific has caused WIS hindcast results to be higher than measured results, and WIS is currently in the process of finding out if a more viable PACBAS hindcast is possible. The south shore of Oahu is mainly influenced by swell from the south with the summer season swells making the biggest impact on the south Oahu shoreline. Swell from the north Pacific winter storms is blocked by the geographical location of the coastline. To make sure that the existing PACBAS WIS results would provide realistic input conditions for Oahu's south shore, WIS results for the summer of 2000 were compared with measurements at a directional buoy location south of Hawaii, NDBC 51028 at Christmas Island. Comparisons show that hindcast PACBAS WIS partitioned results at NDBC 51028 match very well with the measured results for the May through September season. Since WIS results compare well with measurements during the southern swell season, the existing WIS PACBAS results should provide realistic input for a nearshore evaluation of wave conditions on Oahu's south shore.

Ms. Mary Cialone recently completed a similar transformation project for POH under the Southeast Oahu Regional Sediment Management (SEO/RSM) project, and results are documented in ERDC/CHL TR-08-9. This application also included the transformation of waves over the nearshore reefs and used the bottom friction option available in STWAVE. Documentation and files from this project in addition to Ms. Cialone's expertise will be used in the planning and execution of the new Oahu south shore wave transformation project. In addition, grids are being developed for a concurrent SEO/RSM project in the D2P region this summer and information will be shared between the two projects.

Scope of Work:

All tasks will be planned and executed so the project comes to completion by 30 September 2009 (all funding will be expended by the end of FY09). The work will be divided into the following tasks:

> Task 1. To facilitate effective and efficient use of the 24-year WIS PACBAS hindcast, the relative severity of the annual wave conditions for Station 116 will be assessed. Three years of hindcast data will be chosen from the Station 116 hindcast representing mild, average and energetic years of wave activity. Bulk wave parameters or wave spectra for each time step in the WIS PACBAS hindcast for these three years at Station 116 will be transformed from deepwater to the 100-meter contour offshore of the mid-point of the D2P region. The wave transformation will include the requisite sheltering to ensure that waves from the northeast through the northwest are reasonably represented in the final wave transformation work.
>
> Task 2. Selection of all unique wave conditions from the bulk wave parameters or wave spectra transformed in Task 1 will be the next task. Wave rose and tabular information will be analyzed to identify all of the unique wave period, direction and height combinations for input into the STWAVE runs. Wave partitioning information indicates that this site receives consistent swell energy partitions from the south, southwest, and southeast. Additional input combinations containing swell parameter information may be added to the input data set if the bulk parameter input does include this contributions. The number of unique wave conditions will determine if the full-plane or half-plane STWAVE model will be used in the project.
>
> Task 3. Grid development and verification for the nearshore area is the next task. The grid will include the south shore of Oahu from the eastern side of Diamond Head to three miles west of Pearl Harbor. Existing grids from concurrent projects will be evaluated and used if they meet study needs. Existing available bathymetric data (LiDAR information) will be used to generate the grids. The gridded area will extend landward from the 100-m contour to include output locations along the 30-meter contour and within the nearshore reefs. A nested grid approach is planned so nearshore reef conditions can be modeled successfully, and tests will determine the resolution and boundaries of the STWAVE nested grid application. ERDC/CHL TR-08-9 results will be used to determine initial values for bottom friction coefficients in the interior STWAVE application.

Task 4. The next step involves the setup and testing of the STWAVE application. Sample conditions will be run to check if results are credible and changes will be made so runs can be submitted in a batch mode. Results will be validated by comparing with available measured information from POH.

Task 5. STWAVE can be run quickly using the parallel computing options of the ERDC HPC system and runs will be set up and computed using this system. Available batch files from previous applications will be used for this process.

Task 6. Output bulk parameter STWAVE transformation results will be saved at one-mile increments along the 30-m contour and at half-mile increments along the landward occurrence of the 4-meter contour. Based on the results of the STWAVE transformation, look-up tables will be utilized to transform bulk parameters for each time step in the original three years of WIS hindcast data to the 30-meter and 4-meter save points. Results will be analyzed, ported to Excel spreadsheets and documentation will be provided in the form of draft and final deliverables.

Cost Estimate

Staff: B. Tracy and A. Cialone with expertise from M. Cialone
Cost: $3K/week (some tasks will be overlapping)

Task 1: Determination of initial wave conditions and transformation to 100m contour	**2 weeks**	**$6K**
Task 2: Selection of wave conditions from Task 1 for input into STWAVE	**1 week**	**3K**
Task 3: STWAVE grid development for interior grid	**2 weeks**	**3.5K**
Task 4: STWAVE setup and validation	**2 weeks**	**5K**
Task 5: STWAVE computations for interior grid	**2 weeks**	**2K**
Task 6: Analysis of results/documentation	**1.5 weeks**	**3K**
Administrative and Branch overhead		**2.5K**
COST TOTAL:		**$25K**

Project will commence upon receipt of funding and will be completed by September 30, 2009.

APPENDIX C : NEARSHORE CURRENTS MODELING

CMS-FLOW and CMS-WAVE
Numerical Model Background and Development: D2P Region

Jessica Podoski, USACE-POH
December 2009

The suite of numerical models in the Coastal Modeling System (CMS) uses a combination of CMS-FLOW and CMS-WAVE to simultaneously model the tidal and wave generated currents between Diamond Head and Ewa Beach. The primary purpose of the numerical modeling was to qualitatively describe littoral transport pathways in the region.

Bathymetry

The bathymetry data set used for the CMS modeling was provided by the UH Department of Ocean and Resources Engineering. The data set include SHOALS LiDAR soundings, FEMA topographic information and UH derived data to fill existing gaps.

Coastal Modeling System

The USACE's Coastal Inlets Research Program has developed the Coastal Modeling System for simulating and predicting physical processes at and in the vicinity of coastal inlets and for coastal regions. The CMS consists of numerical models integrated to dynamically simulate waves, currents, water level, sediment transport, and morphology change in the coastal zone. The CMS contains coupled CMS-FLOW and CMS-WAVE models, which can also interact dynamically in driving sediment transport morphology change. The regional water circulation and wave transformation modeling used for this portion of the study was performed with CMS-FLOW and CMS-WAVE within CMS.

CMS-FLOW

CMS-FLOW is a two-dimensional hydrodynamic circulation model that uses a finite-difference numerical approximation of the depth-integrated continuity and momentum equations. CMS-FLOW includes robust flooding and drying, wave-stress forcing, wind-speed dependent (time-varying) wind-drag coefficient, variably-spaced bottom friction coefficient, efficient grid storage in memory, and the convenience, through control statements, of independently turning on or off the advective terms, mixing terms, nonlinear continuity terms, and flooding and drying calculations. Wave forcing was included through coupling with CMS-WAVE, which also provided wave radiation stresses to CMS-FLOW. Calculated currents and water level changes were input to the wave model to increase the accuracy of the wave transformation predictions. Physical processes calculated by CMS-FLOW are flow, water surface elevation, sediment transport, and morphology change forced by time- and space-varying water surface elevation (e.g., from tides or seiching), wind-speed dependent (time-varying) wind-drag, river discharge, and time- and space-varying wave-stress. Additional capabilities include flooding and drying, variably spaced bottom-friction coefficient, representation of non-erodible bottom (e.g., reef), efficient grid storage in memory, and hot-start options.

The CMS-FLOW hydrodynamic modeling required the following steps:

a) Develop model grid to include recent bathymetry and shoreline data.

b) Calibrate and verify the circulation model using measured water levels for the project domain for a 2- week simulation validation period. This was necessary to determine if the water levels and currents at nearshore locations on the reef can be accurately predicted using this forcing method.

c) Develop alternative forcing conditions.

d) Model multiple wave conditions for the existing conditions between Diamond Head and Pearl Harbor.

CMS-WAVE

CMS-WAVE is a two-dimensional model that approximates nearshore wave transformations and includes wave shoaling, refraction, diffraction, forward reflection, depth-limited wave breaking, dissipation, and wave-current interactions. It is a phase-averaged model, which means it averages changes in the wave phase in calculating wave and other nearshore processes. It employs a forward-marching, finite-difference, steady-state (time-independent) Eulerian method to solve the wave action conservation equation. The model operates on a coastal half-plane so primary waves can propagate only from the seaward boundary toward shore. If the seaward reflection option is activated, CMS-WAVE performs backward marching for seaward reflection after the forwarding-marching calculation is completed.

Application of CMS-WAVE required the following steps:

a) Development of computational grid to simulate wave propagation.

b) Verification of calculated waves by comparison to measurements.

The CMS modeling was conducted in two phases that encompassed six technical tasks: 1) compilation of existing data, 2) development of circulation and wave model grids, 3) development of forcing conditions for the models, 4) model validation, 5) model simulations, and 6) analysis and report preparation.

Wave Parameters

In the D2P study, CMS-FLOW and CMS-WAVE were used in tandem to simulate the wave and tidal driven currents generated along the southern shoreline of Oahu between Diamond Head and Pearl Harbor. Tidal forcing conditions were obtained from the National Oceanic and Atmosphere Administration (NOAA) Tides and Currents Historic Data Measurements Honolulu Harbor gauge and the offshore wave conditions were provided from the Scripps Institute of Oceanography Coastal Data Information Program (CDIP) Directional Waverider Buoy 146 located at Kaumalapau Harbor located at Lanai, Hawaii. The Kaumalapau wave buoy was chosen because there are no wave buoys located off of Oahu's south shore and the Kaumalapau buoy is the closest south shore wave buoy to the study area. A wave model comparison study of Kaumalapau and Waikiki (Sea Engineering, Inc. and Group 70 International 2008) showed that wave heights and wave periods from the Kaumalapau wave buoy provide a reasonable approximation for offshore wave conditions while wave direction may contain a sizeable amount of error. Previous studies have shown that south swell deepwater wave direction is not a significant parameter at locations along the region. This is due to the high degree of wave refraction exhibited over the wide shallow reef system in the region.

Field Data

The Honolulu District along with the ERDC's Coastal and Hydraulics Laboratory conducted field data collection in the study area from August 23-29, 2007, for the purpose of validating a numerical hydrodynamic model of the currents in the vicinity of the Natatorium.

Wave and current data were collected by a Nortek AWAC (1 MHz) deployed at 3 m depth, a RD Instruments ADCP (1.2 MHz) deployed at 6.6 m depth, and a Nortek Aquadopp current profiler (2 MHz) deployed at 2.5m. The instruments were deployed at various locations near the Waikiki Natatorium by the USACE from 23-29 August 2007. The instrument locations are shown in Figure 1, with their coordinates and depths shown in Table 1. CMS-FLOW and CMS-WAVE output data were compared to the recorded data at each of the sensors.

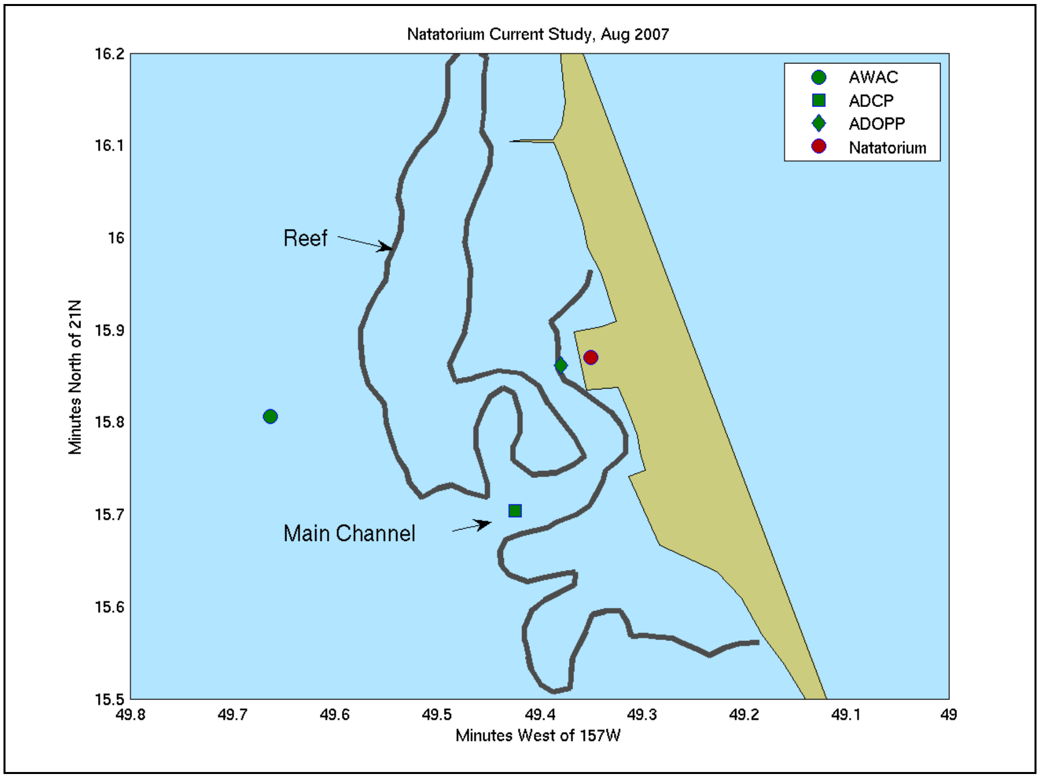


Figure 1. In Situ Instrument Locations

Table 1. In Situ Instrument Locations

Type	Latitude	Longitude	Waves	Currents	SN	Nominal Depth (m)
AWAC	21° 15.806' N	157° 49.663' W	Y	Y	5436	3.3
ADCP	21° 15.704' N	157° 49.424' W	Y	Y	2989	6.6
Aquadopp	21° 15.861' N	157° 49.379' W	N	Y	2603	2.5

The largest currents were observed at the AWAC location offshore of the reef (see Figure 2). AWAC currents ranged from near zero to about 0.4 meters per second (m/s). Currents in the channel (ADCP) were typically between 0.1 m/s and 0.25 m/s, and on the reef the Aquadopp gage currents were 0.05 m/s to 0.15 m/s. When currents recorded by the Aquadopp gage dropped below about 0.04 m/s the current direction was poorly resolved with large direction variations during slack current. This was likely caused by turbulent fluctuations of wave induced flow around and through the reef channels.

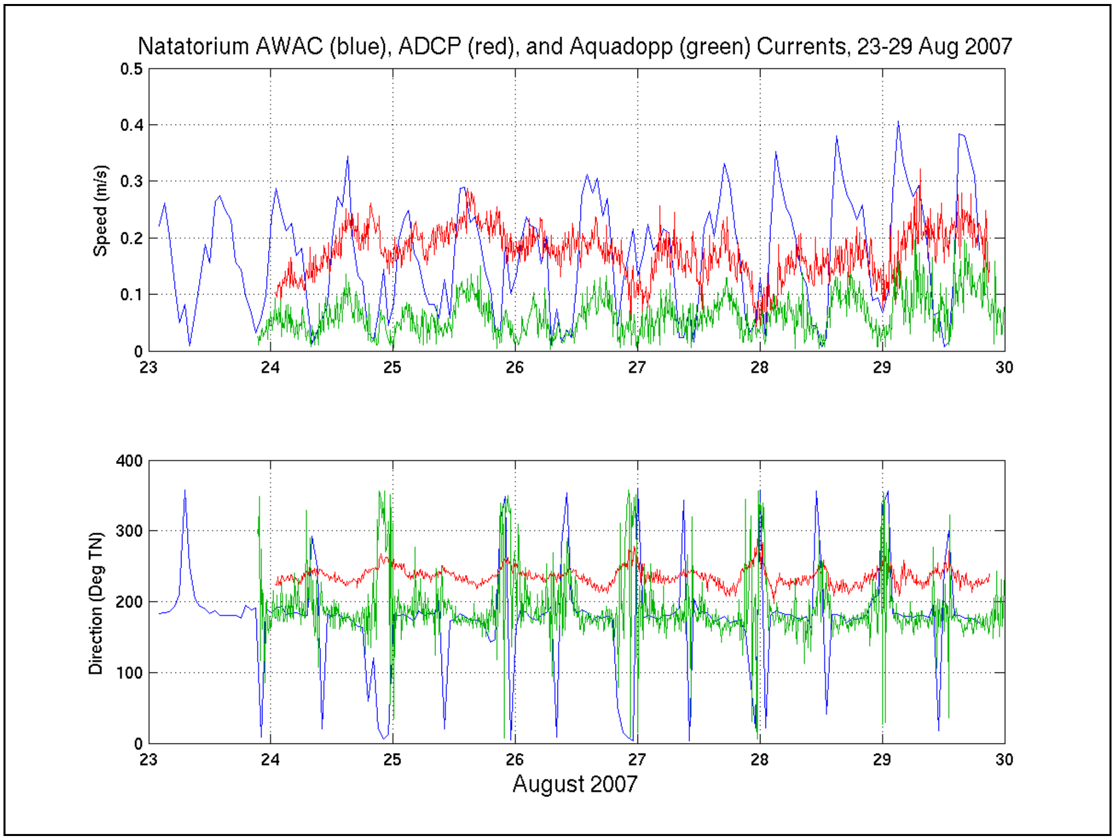


Figure 2. AWAC, ADCP, and Aquadopp Current Speed and Direction

Tidal variations of speed were most pronounced at the AWAC location, seaward of the reef. Short duration current reversals were observed in the AWAC and Aquadopp data, typically when speed dropped below 0.05 m/s. For current speeds above 0.05 m/s the Aquadopp current direction averaged about 180 degrees and 173 degrees for the AWAC.

Incident wave direction at the AWAC averaged 214 degrees for mean direction and 220 for the peak direction, with a range between 207 and 223 degrees for mean directions and between 209 and 234 degrees for peak direction. This was a small variability in direction. Mean wave period ranged between 5 and 8 seconds, whereas peak period was about 13-14 seconds between 23 and 26 August and 20 seconds on 27 August dropping to 16 seconds by the 29 August. A long period swell was observed in the spectra early on 26 August and became the dominant energy peak late on that day.

The AWAC appears to have performed well at picking the direction of these long period waves, despite the shallow deployment (~ 5m). At the 5m depth a 20s wave has a wavelength about 140m, and the lag spacing on an AWAC with 25 degree beam angle is less than 4m. This would be expected to poorly resolve the direction, as was seen in the large direction spread of the frequency-direction spectra near the 20 second period band (0.05 Hz).

CMS Runs

Table 3 indicates the wave and tidal conditions that were run using CMS-Wave and CMS-Flow in steering mode, including the validation run completed between August and September 2007 and compared with the Natatorium data set. Modeling results are provided in the associated Preliminary Sediment Budget Report.

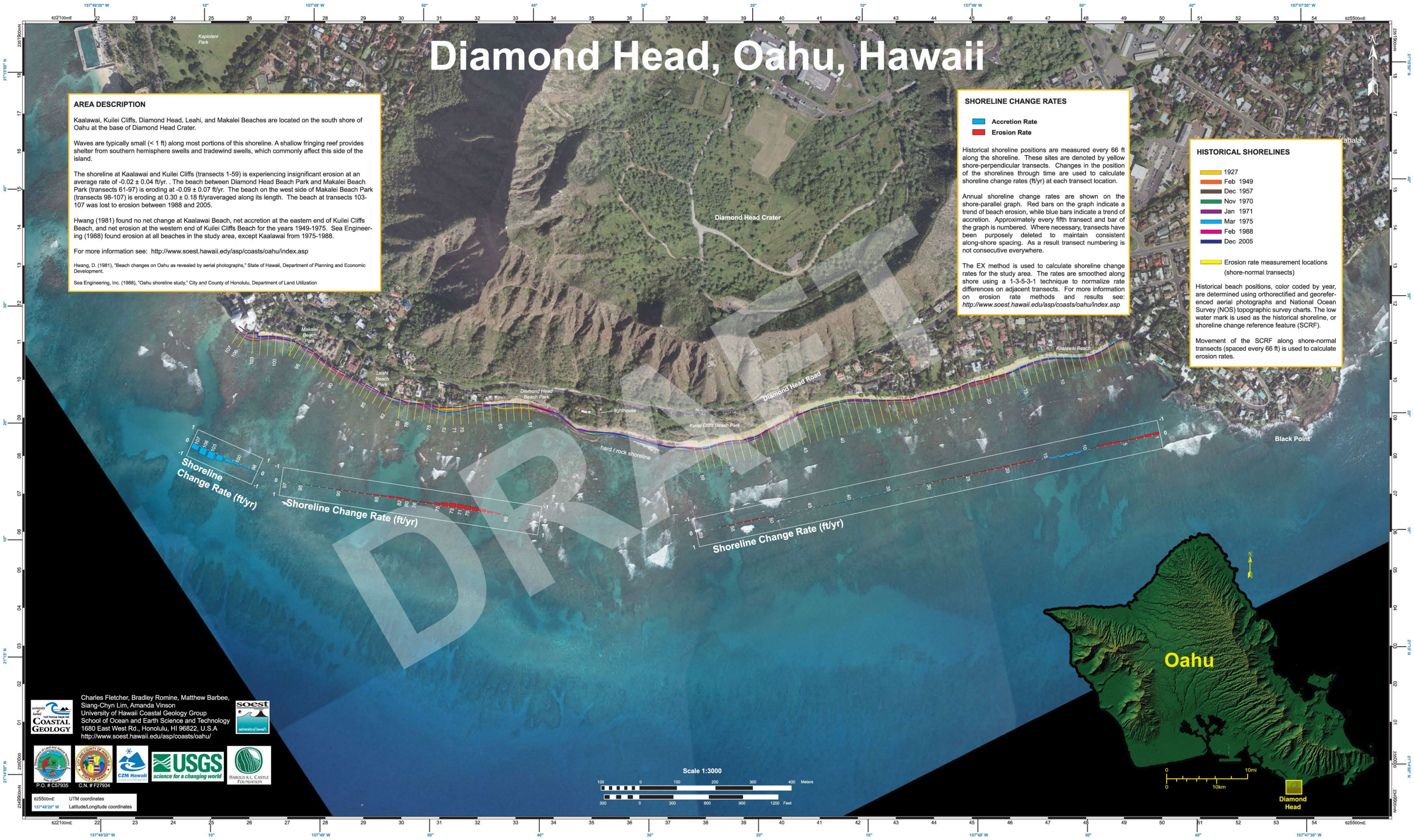
Table 3. Wave and Tide Parameters of CMS runs

Date	Duration	Peak Wave Height (m)	Typical Wave Period (s)	Typical Wave Direction	Tidal Range (m)
8/17/07 to 9/8/07	23 days	1.34	12 – 15	S (180)	0.8
12/10/08 to 12/17/08	8 days	2.59	12 - 17	SSE (160)	0.9
1/14/09 to 1/21/09	8 days	2.7	10 - 14	W (270)	0.6
8/23/07 to 8/30/07*	8 days	1.34	12 - 15	SSE (150)	0.8

* Wave Direction shifted 30 degrees east (CCW) to represent southeasterly swell

APPENDIX D : DRAFT EROSION HAZARD MAPS

Diamond Head, Oahu, Hawaii



AREA DESCRIPTION

Kaalawai, Kuilei Cliffs, Diamond Head, Leahi, and Makalei Beaches are located on the south shore of Oahu at the base of Diamond Head Crater.

Waves are typically small (< 1 ft) along most portions of this shoreline. A shallow fringing reef provides shelter from southern hemisphere swells and tradewind swells, which commonly affect this side of the island.

The shoreline at Kaalawai and Kuilei Cliffs (transects 1-59) is experiencing insignificant erosion at an average rate of -0.02 ± 0.04 ft/yr. . The beach between Diamond Head Beach Park and Makalei Beach Park (transects 61-97) is eroding at -0.09 ± 0.07 ft/yr. The beach on the west side of Makalei Beach Park (transects 98-107) is eroding at 0.30 ± 0.18 ft/yraveraged along its length. The beach at transects 103-107 was lost to erosion between 1988 and 2005.

Hwang (1981) found no net change at Kaalawai Beach, net accretion at the eastern end of Kuilei Cliffs Beach, and net erosion at the western end of Kuilei Cliffs Beach for the years 1949-1975. Sea Engineering (1988) found erosion at all beaches in the study area, except Kaalawai from 1975-1988.

For more information see: http://www.soest.hawaii.edy/asp/coasts/oahu/index.asp

Hwang, D. (1981), "Beach changes on Oahu as revealed by aerial photographs," State of Hawaii, Department of Planning and Economic Development.

Sea Engineering, Inc. (1988), "Oahu shoreline study," City and County of Honolulu, Department of Land Utilization

SHORELINE CHANGE RATES

🟦	**Accretion Rate**
🟥	**Erosion Rate**

Historical shoreline positions are measured every 66 ft along the shoreline. These sites are denoted by yellow shore-perpendicular transects. Changes in the position of the shorelines through time are used to calculate shoreline change rates (ft/yr) at each transect location.

Annual shoreline change rates are shown on the shore-parallel graph. Red bars on the graph indicate a trend of beach erosion, while blue bars indicate a trend of accretion. Approximately every fifth transect and bar of the graph is numbered. Where necessary, transects have been purposely deleted to maintain consistent along-shore spacing. As a result transect numbering is not consecutive everywhere.

The EX method is used to calculate shoreline change rates for the study area. The rates are smoothed along shore using a 1-3-5-3-1 technique to normalize rate differences on adjacent transects. For more information on erosion rate methods and results see: *http://www.soest.hawaii.edu/asp/coasts/oahu/index.asp*

HISTORICAL SHORELINES

▬	1927
▬	Feb 1949
▬	Dec 1957
▬	Nov 1970
▬	Jan 1971
▬	Mar 1975
▬	Feb 1988
▬	Dec 2005
▬	Erosion rate measurement locations (shore-normal transects)

Historical beach positions, color coded by year, are determined using orthorectified and georeferenced aerial photographs and National Ocean Survey (NOS) topographic survey charts. The low water mark is used as the historical shoreline, or shoreline change reference feature (SCRF).

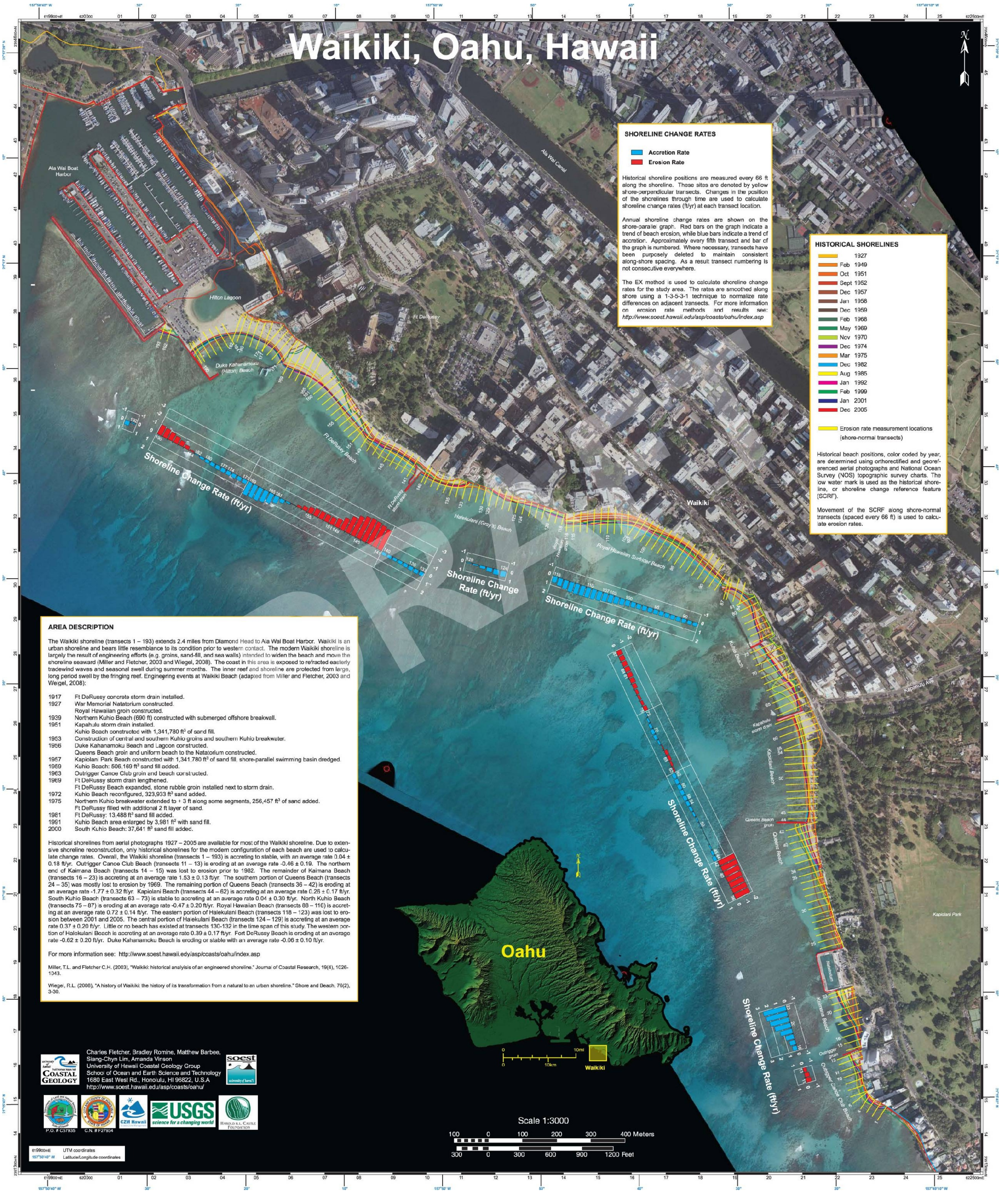
Movement of the SCRF along shore-normal transects (spaced every 66 ft) is used to calculate erosion rates.

Charles Fletcher, Bradley Romine, Matthew Barbee,
Siang-Chyn Lim, Amanda Vinson
University of Hawaii Coastal Geology Group
School of Ocean and Earth Science and Technology
1680 East West Rd., Honolulu, HI 96822, U.S.A
http://www.soest.hawaii.edu/asp/coasts/oahu/

P.O. # C57935
C.N. # F27934

625500mE	UTM coordinates
157°49'20" W	Latitude/Longitude coordinates

Waikiki, Oahu, Hawaii



SHORELINE CHANGE RATES

🟦 **Accretion Rate**
🟥 **Erosion Rate**

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HISTORICAL SHORELINES

▬		1927
▬	Feb	1949
▬	Oct	1951
▬	Sept	1952
▬	Dec	1957
▬	Jan	1958
▬	Dec	1959
▬	Feb	1968
▬	May	1969
▬	Nov	1970
▬	Dec	1974
▬	Mar	1975
▬	Dec	1982
▬	Aug	1985
▬	Jan	1992
▬	Feb	1999
▬	Jan	2001
▬	Dec	2005

▬ Erosion rate measurement locations (shore-normal transects)

Historical beach positions, color coded by year, are determined using orthorectified and georeferenced aerial photographs and National Ocean Survey (NOS) topographic survey charts. The low water mark is used as the historical shoreline, or shoreline change reference feature (SCRF).

Movement of the SCRF along shore-normal transects (spaced every 66 ft) is used to calculate erosion rates.

AREA DESCRIPTION

The Waikiki shoreline (transects 1 – 193) extends 2.4 miles from Diamond Head to Ala Wai Boat Harbor. Waikiki is an urban shoreline and bears little resemblance to its condition prior to western contact. The modern Waikiki shoreline is largely the result of engineering efforts (e.g. groins, sand-fill, and sea walls) intended to widen the beach and move the shoreline seaward (Miller and Fletcher, 2003 and Wiegel, 2008). The coast in this area is exposed to refracted easterly tradewind waves and seasonal swell during summer months. The inner reef and shoreline are protected from large, long period swell by the fringing reef. Engineering events at Waikiki Beach (adapted from Miller and Fletcher, 2003 and Weigel, 2008):

1917	Ft DeRussy concrete storm drain installed.
1927	War Memorial Natatorium constructed. Royal Hawaiian groin constructed.
1939	Northern Kuhio Beach (690 ft) constructed with submerged offshore breakwall.
1951	Kapahulu storm drain installed. Kuhio Beach constructed with 1,341,780 ft³ of sand fill.
1953	Construction of central and southern Kuhio groins and southern Kuhio breakwater.
1956	Duke Kahanamoku Beach and Lagoon constructed. Queens Beach groin and uniform beach to the Natatorium constructed.
1957	Kapiolani Park Beach constructed with 1,341,780 ft³ of sand fill, shore-parallel swimming basin dredged.
1959	Kuhio Beach: 506,169 ft³ sand fill added.
1963	Outrigger Canoe Club groin and beach constructed.
1969	Ft DeRussy storm drain lengthened. Ft DeRussy Beach expanded, stone rubble groin installed next to storm drain.
1972	Kuhio Beach reconfigured, 323,933 ft³ sand added.
1975	Northern Kuhio breakwater extended to + 3 ft along some segments, 256,457 ft³ of sand added. Ft DeRussy filled with additional 2 ft layer of sand.
1981	Ft DeRussy: 13,488 ft³ sand fill added.
1991	Kuhio Beach area enlarged by 3,981 ft² with sand fill.
2000	South Kuhio Beach: 37,641 ft³ sand fill added.

Historical shorelines from aerial photographs 1927 – 2005 are available for most of the Waikiki shoreline. Due to extensive shoreline reconstruction, only historical shorelines for the modern configuration of each beach are used to calculate change rates. Overall, the Waikiki shoreline (transects 1 – 193) is accreting to stable, with an average rate 0.04 ± 0.18 ft/yr. Outrigger Canoe Club Beach (transects 11 – 13) is eroding at an average rate -0.46 ± 0.19. The northern end of Kaimana Beach (transects 14 – 15) was lost to erosion prior to 1982. The remainder of Kaimana Beach (transects 16 – 23) is accreting at an average rate 1.53 ± 0.13 ft/yr. The southern portion of Queens Beach (transects 24 – 35) was mostly lost to erosion by 1969. The remaining portion of Queens Beach (transects 36 – 42) is eroding at an average rate -1.77 ± 0.32 ft/yr. Kapiolani Beach (transects 44 – 62) is accreting at an average rate 0.26 ± 0.17 ft/yr. South Kuhio Beach (transects 63 – 73) is stable to accreting at an average rate 0.04 ± 0.30 ft/yr. North Kuhio Beach (transects 75 – 87) is eroding at an average rate -0.47 ± 0.20 ft/yr. Royal Hawaiian Beach (transects 88 – 116) is accreting at an average rate 0.72 ± 0.14 ft/yr. The eastern portion of Halekulani Beach (transects 118 – 123) was lost to erosion between 2001 and 2005. The central portion of Halekulani Beach (transects 124 – 129) is accreting at an average rate 0.37 ± 0.20 ft/yr. Little or no beach has existed at transects 130-132 in the time span of this study. The western portion of Halekulani Beach is accreting at an average rate 0.39 ± 0.17 ft/yr. Fort DeRussy Beach is eroding at an average rate -0.62 ± 0.20 ft/yr. Duke Kahanamoku Beach is eroding or stable with an average rate -0.06 ± 0.10 ft/yr.

For more information see: http://www.soest.hawaii.edy/asp/coasts/oahu/index.asp

Miller, T.L. and Fletcher C.H. (2003), "Waikiki: historical analyisis of an engineered shoreline." Journal of Coastal Research, 19(4), 1026-1043.

Wiegel, R.L. (2008), "A history of Waikiki: the history of its transformation from a natural to an urban shoreline." Shore and Beach, 76(2), 3-30.

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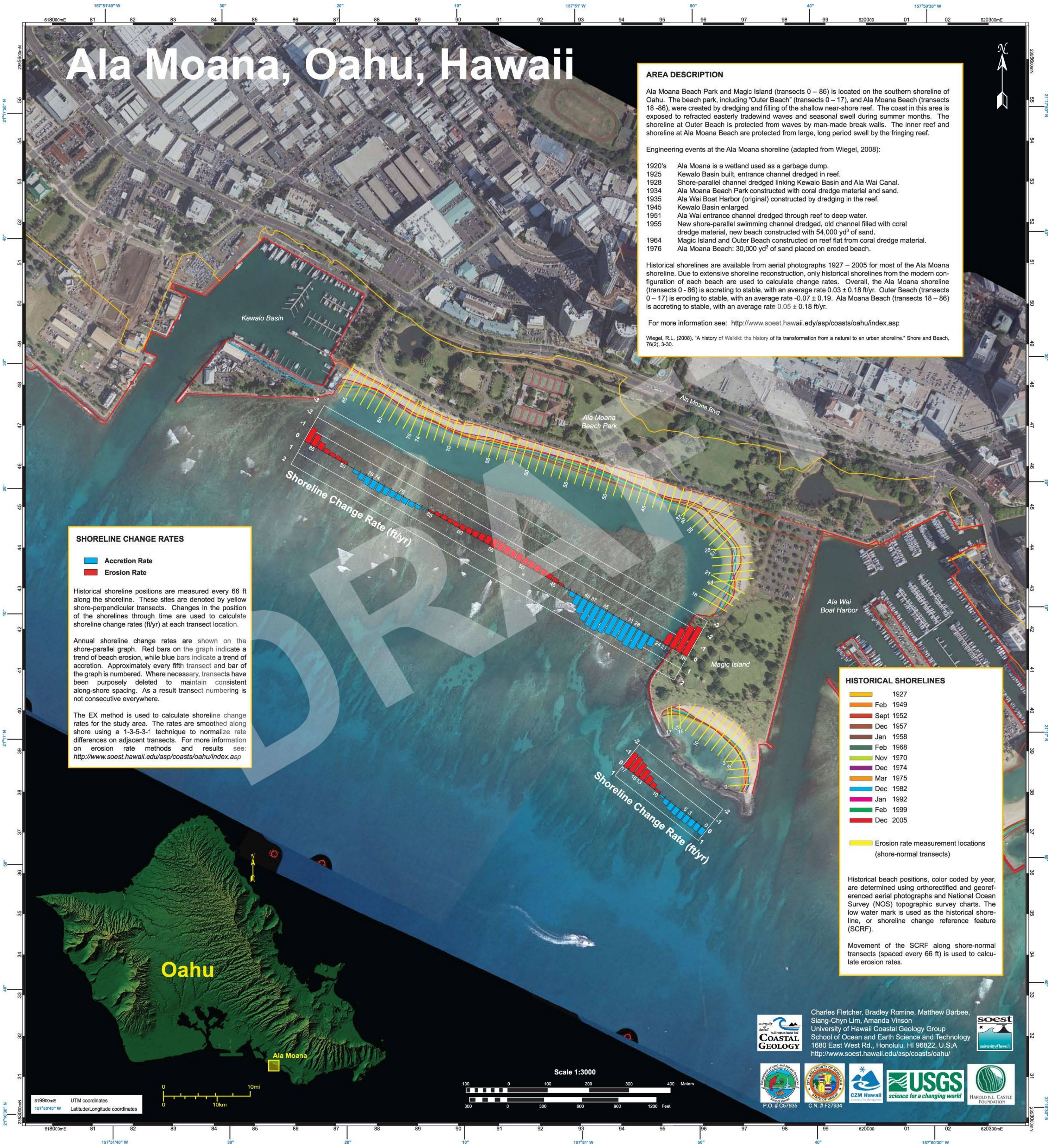
P.O. # C57935
C.N. # F27934

619900mE UTM coordinates
157°50'40" W Latitude/Longitude coordinates

Ala Moana, Oahu, Hawaii



AREA DESCRIPTION

Ala Moana Beach Park and Magic Island (transects 0 – 86) is located on the southern shoreline of Oahu. The beach park, including "Outer Beach" (transects 0 – 17), and Ala Moana Beach (transects 18 -86), were created by dredging and filling of the shallow near-shore reef. The coast in this area is exposed to refracted easterly tradewind waves and seasonal swell during summer months. The shoreline at Outer Beach is protected from waves by man-made break walls. The inner reef and shoreline at Ala Moana Beach are protected from large, long period swell by the fringing reef.

Engineering events at the Ala Moana shoreline (adapted from Wiegel, 2008):

1920's	Ala Moana is a wetland used as a garbage dump.
1925	Kewalo Basin built, entrance channel dredged in reef.
1928	Shore-parallel channel dredged linking Kewalo Basin and Ala Wai Canal.
1934	Ala Moana Beach Park constructed with coral dredge material and sand.
1935	Ala Wai Boat Harbor (original) constructed by dredging in the reef.
1945	Kewalo Basin enlarged.
1951	Ala Wai entrance channel dredged through reef to deep water.
1955	New shore-parallel swimming channel dredged, old channel filled with coral dredge material, new beach constructed with 54,000 yd^3 of sand.
1964	Magic Island and Outer Beach constructed on reef flat from coral dredge material.
1976	Ala Moana Beach: 30,000 yd^3 of sand placed on eroded beach.

Historical shorelines are available from aerial photographs 1927 – 2005 for most of the Ala Moana shoreline. Due to extensive shoreline reconstruction, only historical shorelines from the modern configuration of each beach are used to calculate change rates. Overall, the Ala Moana shoreline (transects 0 - 86) is accreting to stable, with an average rate 0.03 ± 0.18 ft/yr. Outer Beach (transects 0 – 17) is eroding to stable, with an average rate -0.07 ± 0.19. Ala Moana Beach (transects 18 – 86) is accreting to stable, with an average rate 0.05 ± 0.18 ft/yr.

For more information see: http://www.soest.hawaii.edy/asp/coasts/oahu/index.asp

Wiegel, R.L. (2008), "A history of Waikiki: the history of its transformation from a natural to an urban shoreline." Shore and Beach, 76(2), 3-30.

SHORELINE CHANGE RATES

🟦	Accretion Rate
🟥	Erosion Rate

Historical shoreline positions are measured every 66 ft along the shoreline. These sites are denoted by yellow shore-perpendicular transects. Changes in the position of the shorelines through time are used to calculate shoreline change rates (ft/yr) at each transect location.

Annual shoreline change rates are shown on the shore-parallel graph. Red bars on the graph indicate a trend of beach erosion, while blue bars indicate a trend of accretion. Approximately every fifth transect and bar of the graph is numbered. Where necessary, transects have been purposely deleted to maintain consistent along-shore spacing. As a result transect numbering is not consecutive everywhere.

The EX method is used to calculate shoreline change rates for the study area. The rates are smoothed along shore using a 1-3-5-3-1 technique to normalize rate differences on adjacent transects. For more information on erosion rate methods and results see: *http://www.soest.hawaii.edu/asp/coasts/oahu/index.asp*

HISTORICAL SHORELINES

🟨	1927
🟧	Feb 1949
🟥	Sept 1952
🟫	Dec 1957
🟫	Jan 1958
🟩	Feb 1968
🟩	Nov 1970
🟪	Dec 1974
🟧	Mar 1975
🟦	Dec 1982
🟪	Jan 1992
🟩	Feb 1999
🟥	Dec 2005
🟨	Erosion rate measurement locations (shore-normal transects)

Historical beach positions, color coded by year, are determined using orthorectified and georeferenced aerial photographs and National Ocean Survey (NOS) topographic survey charts. The low water mark is used as the historical shoreline, or shoreline change reference feature (SCRF).

Movement of the SCRF along shore-normal transects (spaced every 66 ft) is used to calculate erosion rates.

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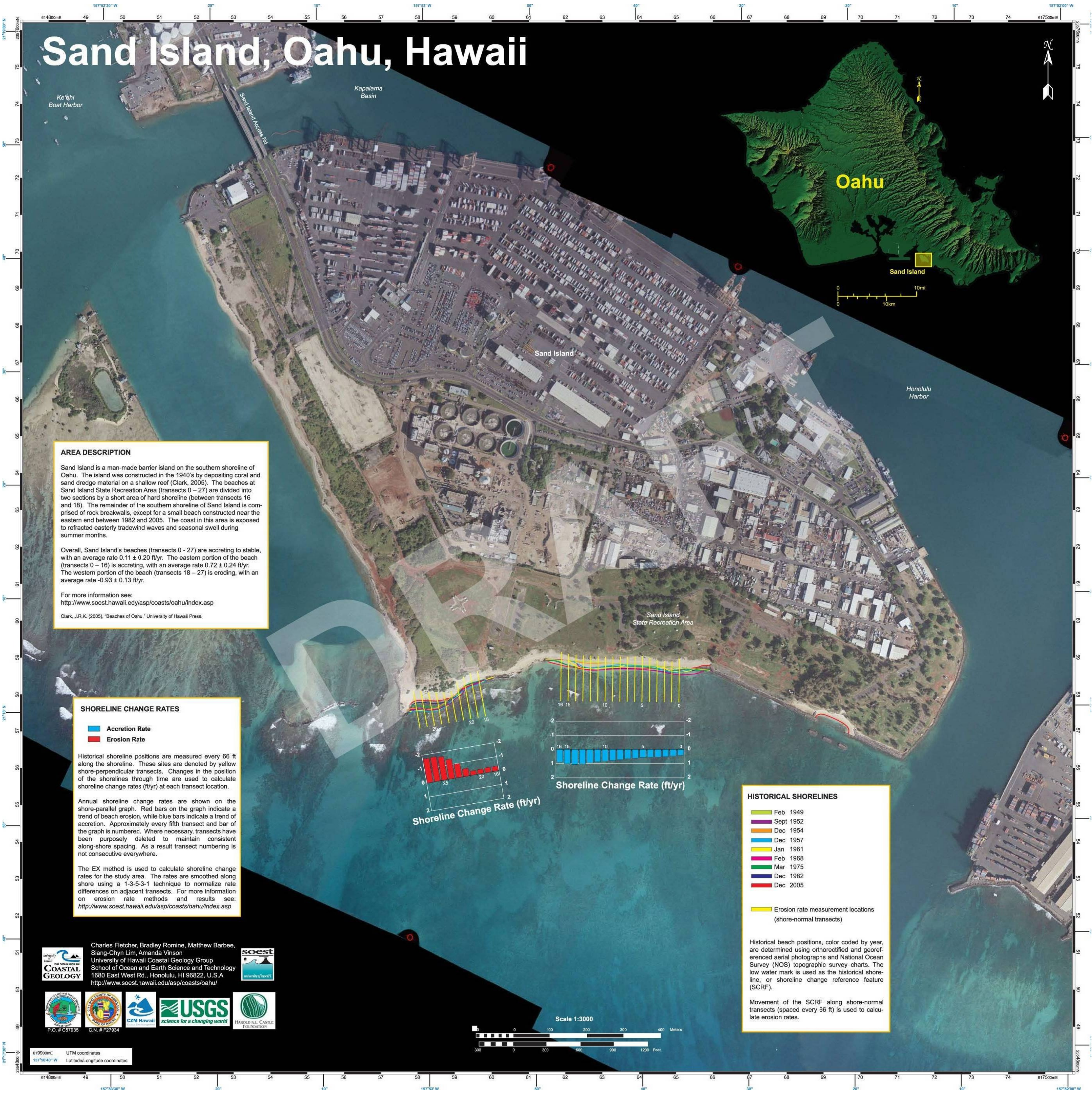
Sand Island, Oahu, Hawaii



AREA DESCRIPTION

Sand Island is a man-made barrier island on the southern shoreline of Oahu. The island was constructed in the 1940's by depositing coral and sand dredge material on a shallow reef (Clark, 2005). The beaches at Sand Island State Recreation Area (transects 0 – 27) are divided into two sections by a short area of hard shoreline (between transects 16 and 18). The remainder of the southern shoreline of Sand Island is comprised of rock breakwalls, except for a small beach constructed near the eastern end between 1982 and 2005. The coast in this area is exposed to refracted easterly tradewind waves and seasonal swell during summer months.

Overall, Sand Island's beaches (transects 0 - 27) are accreting to stable, with an average rate 0.11 ± 0.20 ft/yr. The eastern portion of the beach (transects 0 – 16) is accreting, with an average rate 0.72 ± 0.24 ft/yr. The western portion of the beach (transects 18 – 27) is eroding, with an average rate -0.93 ± 0.13 ft/yr.

For more information see:
http://www.soest.hawaii.edy/asp/coasts/oahu/index.asp

Clark, J.R.K. (2005), "Beaches of Oahu," University of Hawaii Press.

SHORELINE CHANGE RATES

🟦 **Accretion Rate**
🟥 **Erosion Rate**

Historical shoreline positions are measured every 66 ft along the shoreline. These sites are denoted by yellow shore-perpendicular transects. Changes in the position of the shorelines through time are used to calculate shoreline change rates (ft/yr) at each transect location.

Annual shoreline change rates are shown on the shore-parallel graph. Red bars on the graph indicate a trend of beach erosion, while blue bars indicate a trend of accretion. Approximately every fifth transect and bar of the graph is numbered. Where necessary, transects have been purposely deleted to maintain consistent along-shore spacing. As a result transect numbering is not consecutive everywhere.

The EX method is used to calculate shoreline change rates for the study area. The rates are smoothed along shore using a 1-3-5-3-1 technique to normalize rate differences on adjacent transects. For more information on erosion rate methods and results see: *http://www.soest.hawaii.edu/asp/coasts/oahu/index.asp*

HISTORICAL SHORELINES

🟩	Feb 1949
🟪	Sept 1952
🟧	Dec 1954
🟦	Dec 1957
🟨	Jan 1961
🟥	Feb 1968
🟩	Mar 1975
🟦	Dec 1982
🟥	Dec 2005
🟨	Erosion rate measurement locations (shore-normal transects)

Historical beach positions, color coded by year, are determined using orthorectified and georeferenced aerial photographs and National Ocean Survey (NOS) topographic survey charts. The low water mark is used as the historical shoreline, or shoreline change reference feature (SCRF).

Movement of the SCRF along shore-normal transects (spaced every 66 ft) is used to calculate erosion rates.

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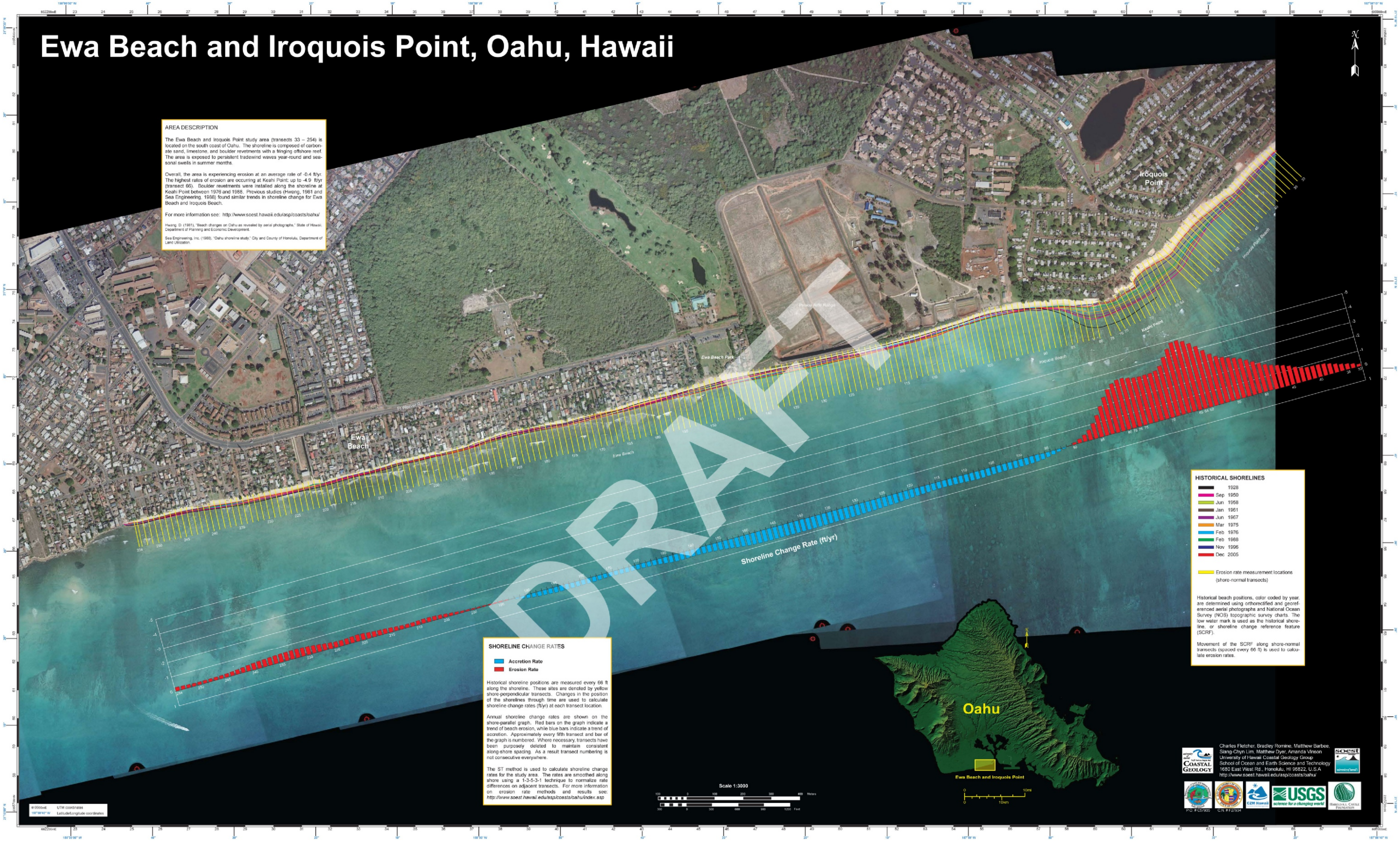
Ewa Beach and Iroquois Point, Oahu, Hawaii



AREA DESCRIPTION

The Ewa Beach and Iroquois Point study area (transects 33 – 254) is located on the south coast of Oahu. The shoreline is composed of carbonate sand, limestone, and boulder revetments with a fringing offshore reef. The area is exposed to persistent tradewind waves year-round and seasonal swells in summer months.

Overall, the area is experiencing erosion at an average rate of -0.4 ft/yr. The highest rates of erosion are occurring at Keahi Point: up to -4.9 ft/yr (transect 66). Boulder revetments were installed along the shoreline at Keahi Point between 1976 and 1988. Previous studies (Hwang, 1981 and Sea Engineering, 1988) found similar trends in shoreline change for Ewa Beach and Iroquois Beach.

For more information see: http://www.soest.hawaii.edu/asp/coasts/oahu/

Hwang, D. (1981), "Beach changes on Oahu as revealed by aerial photographs," State of Hawaii, Department of Planning and Economic Development.

Sea Engineering, Inc. (1988), "Oahu shoreline study," City and County of Honolulu, Department of Land Utilization.

SHORELINE CHANGE RATES

🟦 Accretion Rate
🟥 Erosion Rate

Historical shoreline positions are measured every 66 ft along the shoreline. These sites are denoted by yellow shore-perpendicular transects. Changes in the position of the shorelines through time are used to calculate shoreline change rates (ft/yr) at each transect location.

Annual shoreline change rates are shown on the shore-parallel graph. Red bars on the graph indicate a trend of beach erosion, while blue bars indicate a trend of accretion. Approximately every fifth transect and bar of the graph is numbered. Where necessary, transects have been purposely deleted to maintain consistent along-shore spacing. As a result transect numbering is not consecutive everywhere.

The ST method is used to calculate shoreline change rates for the study area. The rates are smoothed along shore using a 1-3-5-3-1 technique to normalize rate differences on adjacent transects. For more information on erosion rate methods and results see: *http://www.soest.hawaii.edu/asp/coasts/oahu/index.asp*

HISTORICAL SHORELINES

⬛ 1928
🟪 Sep 1950
🟩 Jun 1958
🟫 Jan 1961
🟪 Jun 1967
🟧 Mar 1975
🟦 Feb 1976
🟩 Feb 1988
🟦 Nov 1996
🟥 Dec 2005

🟨 Erosion rate measurement locations (shore-normal transects)

Historical beach positions, color coded by year, are determined using orthorectified and georeferenced aerial photographs and National Ocean Survey (NOS) topographic survey charts. The low water mark is used as the historical shoreline, or shoreline change reference feature (SCRF).

Movement of the SCRF along shore-normal transects (spaced every 66 ft) is used to calculate erosion rates.

Scale 1:3000

100 0 100 200 300 400 Meters
300 0 300 600 900 1200 Feet

619900mE	UTM coordinates
157°59'40" W	Latitude/Longitude coordinates

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